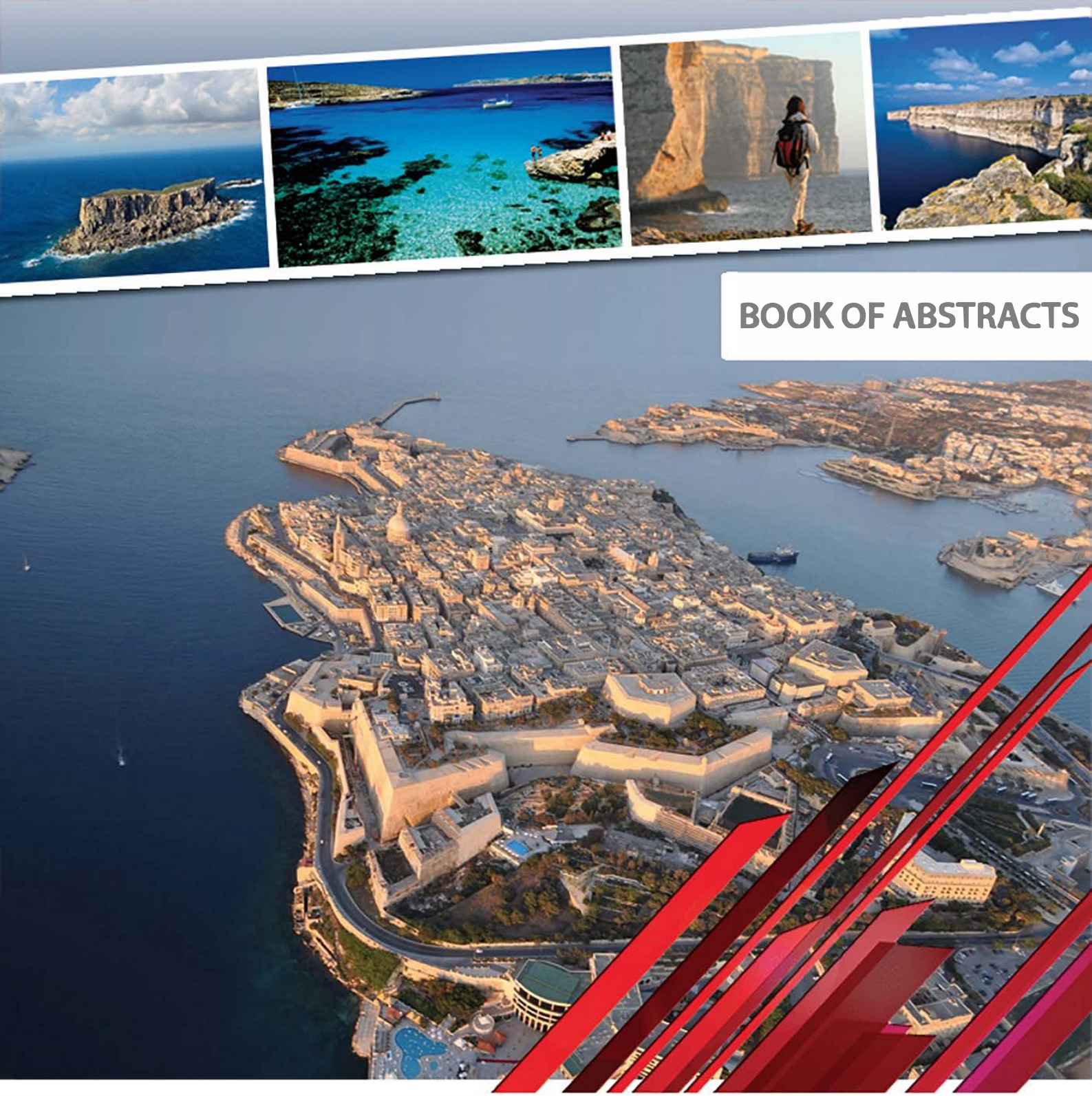

BOOK OF ABSTRACTS

36th General Assembly of the

European Seismological Commission

2-7 September 2018 | Valletta - Malta

www.escmalta2018.eu

Book of Abstracts of the
36th General Assembly of the
European Seismological Commission

Sebastiano D'Amico, Pauline Galea, George Bozionelos, Emanuele Colica, Daniela Farrugia and Matthew R. Agius (Eds.).

Published by Mistral Service Anna Lo Presti Via Romagnosi, 28 98100 - Messina (Italy).

Important Notice

First published: 2nd September 2018.
Assembled in Italy.

A free online copy of this book is available at www.mistralservice.it.

Book of Abstracts of the 36th General Assembly of the European Seismological Commission Sebastiano D'Amico, Pauline Galea, George Bozionelos, Emanuele Colica, Daniela Farrugia and Matthew R. Agius (Eds.).

ISBN: 978-88-98161-12-6

Welcome Messages

Dear Participants,

On behalf of the Local Organizing Committee I would like to welcome you to Valletta (Malta) and the 36th General Assembly of the European Seismological Commission. As in the previous successful conferences, we have committed ourselves to organizing and delivering a well-tailored and focused event, trying to keep the highest scientific and logistic standards.

Malta is an enchanting and beautiful archipelago in southern Europe with a warm hospitality and long history, and it has always been a crucible of culture and a strategic point in Mediterranean. We are proud to host you here, as well as holding for the first time the General Assembly in Malta because this represents a unique opportunity for discussing recent advances in earthquake seismology in a location that, despite being classified as having a low-moderate seismic hazard, can act as a scientific hub between Europe, Africa and the Middle East. This year about **700** young and experienced researchers from more than **60** countries across the world will meet in Malta to discuss different fields of seismology and related applications, including hazard evaluation, risk prevention as well as social aspects. We received more than **900** abstracts (494 oral presentation and 438 posters) spanning the broad fields of earthquake seismology, engineering, seismic monitoring, and their applications, making the General Assembly one of the largest meetings ever.

This welcome address should not miss expressing my warmest gratitude to all who contributed to the organization of this event: my colleagues of the LOC, the international scientific committee, ESC-ExeCom, and organisers of special sessions and other parallel events, without whose enthusiasm, support, and devotion it would not have been possible to make such an event happen. A special thanks goes also to the invited speakers, conveners, and authors for their excellent work and interest in the conference.

Finally, we are glad that the Young Seismologist Training Course this year was able to attract some **50** students from all over the world, providing a unique opportunity to learn and exchange ideas about “Array Seismology”. Our sincere thanks goes to all the lecturers, EGU and CTBTO for making this Training Course a big success.

We wish you a great stay in Malta.

Sebastiano D’Amico
Chairperson Local Organising Committee

Dear Participants of the 36th General Assembly of the European Seismological Commission,

I'm taking this opportunity to welcome you all to the 36th General Assembly of the European Seismological Commission hosted by the University of Malta. Thank you for joining the effort of the Local Organising Committee and making this conference an unforgettable experience. Malta has had its share of historical earthquakes, many of them being imported – another reminder that the forces of nature don't particularly care for political borders. In seismology, especially if we speak of Europe and the Mediterranean, there's no such thing as an isolated island. A strong earthquake, causing agitation and damage, can only be researched in depth using data, facilities and knowledge of the wider area – and that's one lecture our colleagues in Malta know very well. The opening of the conference is always a moment that we savour and enjoy; it is also a moment to think of all the people in history of ESC and the efforts being put into building a strong international community of scientists, who for more than six decades continuously produce important and inspiring results in seismology and related fields. Speaking about the people who left a strong imprint in ESC my thoughts go to the memory of our late Vice-President, Marco Mucciarelli, well-known around the world for his scientific talent and passion, and for his ability to bring people together. We will remember him and his diverse research interests, always presented in excitingly interesting way, in a special session. Another session, on earthquake forecasting, is dedicated to the memory of Hans Berckhemer, Victor Kuksenko and George Purcaru. Anyone familiar with Hitchhiker's guide knows that an Answer to the Ultimate Question of Life, The Universe, and Everything is 42. In tune with that, forty two different sessions in the conference week are going to give lots of answers to our questions, showing how richly diverse are our research interests. More than 700 participants, and many more who will follow our work from their offices are the proof that seismology is important and respected in today's society. More than a hundred candidates for this year's YSTC are probably the best evidence that this field is interesting and exciting also for young scientists, and I am especially happy that many of those young colleagues are joining the conference, to share their results and to learn more. The fascinating development of different technologies makes it possible to transfer huge quantities of data, analyse gigantic datasets in very short time, and to incorporate the knowledge in national and international networks and projects. ESC is proud to serve as a background to many such initiatives, bringing people together and producing a common place where the new ideas and the results can be discussed in a constructive way. I am pleased to notice that we're more and more extending the activities on interdisciplinary tasks, and reaching outside "pure" seismology to other fields that are interconnected in real life. It is especially important for the matters of education and outreach, as only the awareness of the hazards in our surroundings and the knowledge what to do about it can save lives in the long term.

Ina Cecić
President of ESC

Dear Participants,

It is my great pleasure to welcome you to Valletta, on behalf of the University of Malta, especially when Valletta is celebrating its special year as the European Capital of Culture 2018. The University of Malta has a long and prestigious history and several important connections with the imposing building in which you will be meeting. The University traces its origins to the founding in 1592 of the Collegium Melitense, run by the Jesuit order. The Sacra Infermeria, the great hall in which you will be spending much of your time, was the seat of the first "Faculty" of Anatomy and Surgery in 1676, considered as the foundation of today's medical school. A few tens of metres up the road from the Mediterranean Conference Centre is the old Valletta campus of the University, a historic place, now refurbished as a smaller conference centre and housing some University activities. Perhaps more relevant to this conference is the fact that in this Valletta campus was housed one of the earliest seismographs in Europe, a Milne instrument, which remained in operation for some 50 years, and contributed data consistently towards the development of global seismology.

Moving forward to the present day, the University has grown to a modern institution with 14 Faculties, and some 33 Institutes, Centres and Schools. It is home to almost 12,000 students, with a healthy component of international students and staff. The Faculty of Science, encompassing the newly-formed Department of Geosciences organising this meeting, celebrated its 100th anniversary 3 years ago. Within this Department, seismological operations and research activities have grown rapidly in recent years, with the establishment of a national seismic network and a number of international projects and collaborations, encouraging the growth of research.

I am very proud that our University, being part of one of the smallest countries represented in the European Seismological Commission, has taken on such a huge challenge in the organisation of this General Assembly, and I am certain that it will turn out to be a successful event. I augur that this large gathering of seismologists and other scientists and professionals will take the opportunity to push the boundaries of scientific and practical knowledge ever further, not only for the sake of science, but also for the benefit of society in the face of one of the most influential geohazards.

I wish you a wonderful time in Malta.

Alfred Vella
Rector, University of Malta

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KEYNOTE LECTURES

ESC2018-KN1

DOING SEISMOLOGY ON A SMALL ISLAND – HISTORY, PROBLEMS AND OPPORTUNITIES

Pauline Galea
UNIVERSITY OF MALTA, Malta

The history of seismology on Malta goes back to the first years of the 20th century, when a Milne seismograph was installed in Valletta, and operated almost continuously till the 1950's. Seismological recording resumed in the 1980's, converted to digital recording in 1995, always on a single instrument, and underwent a rapid upscaling in recent years with the installation of the Malta Seismic Network. The MSN now consists of 6 broadband stations, soon to be increased to 7 or 8, over an area of less than 300 km2 . Although such a network provides an added wealth of data, the problem of earthquake location on a small island when the seismicity is generally offshore still persists even if the number of stations on the island is increased. In this presentation we shall look at the development of seismology in Malta through the years, and the problems inherent in island observational seismology, together with some novel ways that we are using to better constrain epicenter location, and the implications of such earthquake location in the understanding of the plate margin processes affecting the Sicily Channel. This is a region affected by both compressive tectonics, due to the northward push of the African continent, as well as by extensional tectonics manifested in the Sicily Channel Rift Zone, whose mechanism is not yet fully explained, and which is seismically highly active. The expansion of the seismic network is also revealing a newly perceived level of seismicity, with a smaller detection threshold, and very close to the island's shores, that was previously unrecorded. This has important implications for the assessment of seismic hazard and the presence of active faults.

ESC2018-KN2

MODELLING FAULT SYSTEMS IN SEISMIC HAZARD ASSESSMENT: CHALLENGES AHEAD.

Oona Scotti
INSTITUT DE RADIOPROTECTION ET DE SURETE NUCLEAIRE, FONTANEAY AUX ROSES, France

Recent advancements in the understanding of complex fault systems at geological time scales (earthquake clustering) and recent evidences of dynamic fault rupture complexities involving numerous fault segments combined with increasing evidences for both seismic and aseismic behaviour of faults, are motivating earthquake geology and dynamic fault modelers researchers alike towards the development of increasingly more complex ("realistic") representations of fault system complexities. If earthquake clustering and episodic fault movements are ubiquitous features, then long-term displacement rates on single faults are not expected to be representative of longer-term displacement rates.The main theme of my presentation tackles the following issue: to what extent can and should such advancements be incorporated in fault-based PSHA models? In the talk I will illustrate some of the tools that have been developed within the Fault2sha ESC working group as a first step towards adressing this fundamental issue.

ESC2018-KN3

USING CTBTO INTERNATIONAL MONITORING SYSTEM SEISMIC ARRAYS FOR BASIC SCIENCE

Keith Koper
UNIVERSITY OF UTAH, USA

The seismic network operated by the International Monitoring System (IMS) is one of four technologies used to monitor the Comprehensive Nuclear Test Ban Treaty. It differs from other global seismic networks in that a large number of IMS stations consist of arrays of short-period, vertical component sensors installed in low-noise environments. The enhanced sensitivity of IMS stations makes it possible to detect and locate small-magnitude seismic events around the world with relatively few stations. This enhanced sensitivity also makes the IMS arrays useful for many other problems in seismology. Here I review some of the recent work accomplished in basic (non-monitoring) science with IMS seismic arrays. Topics include high-resolution earthquake location, microseism analysis, and imaging deep Earth structure.

ESC2018-KN4

UPPER MANTLE DISCONTINUITIES – ANISOTROPIC VIEW ON THE LITHOSPHERE-ASTHENOSPHERE SYSTEM

Jaroslava Plomerova
Czech Academy of Sciences, Czech Republic

S tructure of the upper mantle and processes ongoing inside, at present as well as in the past, are decisive for our understanding of the Earth development. Moreover, these processes affect the surface topography and govern most of geologic features within the crust. Different geophysical techniques map several more or less distinct discontinuities down to the transition zone between the upper and lower mantle at 410-660 km depth. The discontinuities, (e.g., Hale, Gutenberg, Lehmann, MLD, LAB, 410km, 660km) are identified by detecting changes of various physical parameters – e.g., seismic velocity, anisotropy, strain, resistivity, reflectivity, phase transitions. The plate tectonic regime of the Earth, broadly adopted in the 70th of last century, emphasizes the role of a discontinuity linked with the lower boundary of the rigid plates called the lithosphere-asthenosphere boundary (LAB). Regardless of whatever physical parameter we are looking at, the LAB, either a boundary or transition, delimits the bottom of lithospheric plates moving coherently above the sub-lithospheric part of the convecting upper mantle. Evaluation of seismic anisotropy within the upper mantle, particularly imaging fabrics of the mantle lithosphere in 3D, results in advanced models of the upper mantle structure and broadens family of plausible Earth models. Though driving mechanisms of plate tectonics throughout the planet history are disputable, delineation of the architecture of continental plates can help to answer questions how the plates were assembled, and to what extent they could later be deformed. Interdisciplinary approaches, particularly joint inversions/interpretations move us ahead, towards a more realistic model of the Earth and its evolution

ESC2018-KN5

UNCERTAINTIES IN SITE SPECIFIC RESPONSE ANALYSIS.

Atilla Ansal (1), Gökçe Tönük (2), Aslı Kurtuluş (3)
(1) Özyeğin University, Istanbul, Turkey (2) MEF University, Istanbul, Turkey (3) Özyeğin University, Istanbul, Turkey

Definition of the uniform hazard acceleration response spectrum on the ground surface has primary importance for performance-based design of structures and assessment of seismic vulnerabilities in urban environments. The approach requires a probabilistic local seismic hazard assessment, probabilistic definition of representative site profiles down to the engineering bedrock, and probabilistic 1D or 2D equivalent or nonlinear, total or effective stress site response analyses depending on the complexity and importance of the structures to be built. Thus, a site-specific response analysis starts with the probabilistic estimation of local seismicity and earthquake source and path characteristics that would yield probabilistic uniform hazard acceleration response spectrum on the engineering bedrock outcrop. Thus, site specific response analyses need to produce a probabilistic uniform hazard acceleration response spectrum on the ground surface. The major uncertainties in site-specific response analysis arises from the variability of (a) local seismic hazard assessment, (b) selection and scaling of the hazard compatible input earthquake acceleration time histories, (c) soil stratification and corresponding engineering properties of encountered soil and rock layers, and (d) method of site response analysis. The uncertainties related to local seismic hazard assessment, even though it has significant effect on the outcome of the site-specific response analyses, will not be considered in this study. The second source of uncertainties are related to selection and scaling of the hazard compatible input earthquake acceleration time histories. One option is to select large number of acceleration records compatible with the local earthquake hazard in terms of fault mechanism, magnitude and distance range recorded on stiff site conditions to account for the variability in earthquake source and path effects. It was observed that if the number of selected acceleration records are in the range of 20-25, the calculated mean response spectrum is consistent with only minor changes with additional input records. However, hazard compatibility with respect to magnitude and source to site distance ranges may also be considered as one source of variability. Bazzuro and Cornell (2004) observed

that the match with engineering bedrock uniform hazard spectrum is more important than the hazard compatibility with respect to magnitude and source to site distance compatibility. It was observed that the importance of source to site distance compatibility varies with the adopted scaling procedure based on a parametric study conducted to observe the effects of source to site distance compatibility. The other source of variability is the scaling procedure adopted to modify the selected earthquake acceleration records to match with the uniform hazard acceleration response spectrum calculated on the engineering bedrock outcrop. The scaling procedure may have three goals, (a) to obtain the best match with respect to rock outcrop target uniform hazard acceleration spectrum, (b) to match the target acceleration spectrum within the considered period range (c) to decrease the scatter in the acceleration spectra after scaling. Parametric studies were conducted to observe the effects of different scaling parameters and procedures. The third source of uncertainty are site conditions with respect to soil stratification and engineering properties of soil layers. Site conditions may play an important role in modelling site response (Li and Assimaki, 2010). Thus, one option may be conducting site response analyses for large number of soil profiles for the investigated site to assess design acceleration spectra with respect to different performance levels. One may also consider using Monte Carlo Simulations to increase the number of soil profiles to account for the possible variability of site conditions. The fourth source of uncertainty stems from the adopted method of site response analysis. There has been significant amount of work done related to the sources of variability and bias in site response analysis. Kaklamanos et al. (2013) conducted a detailed study based on the data obtained in the Kiban- Kyoshin network (KIK-net) to determine the critical parameters that contribute to the uncertainty in site response analysis. They observed that 1D equivalent-linear site-response method generally yields underprediction of ground motions, except in the range of 0.5–2s, where the bias is slightly negative. Relative to empirical site amplification factors, site specific ground response analyses offer a reduction in the total standard deviation at short spectral periods. In general, site-specific response analyses are deterministic computations of site response given certain input parameters. The results of these calculations need to be merged with the probabilistically derived ground motion hazard for rock outcrop site conditions. Bazzurro and Cornell (2004) recommended a convolution method for combining a nonlinear site amplification function with a rock hazard curve to estimate a soil hazard curve. The principal advantage of this approach is that uncertainties in the site amplification function are directly incorporated into the analysis. Another more simplified approach may be to evaluate site response analyses results adopting a probabilistic interpretation. Site-specific probabilistic ground-motion estimates should be based on the full site-amplification distribution instead of a single deterministic median value. A probabilistic methodology using siteamplification distributions to modify rock ground-motion attenuation relations into site specific relations prior to calculating seismic hazard need to be considered. The use of a completely probabilistic approach can make about a 10% difference in ground motion estimates over simply multiplying a bedrock probabilistic ground motion by a median site-amplification factor even larger differences at smaller probabilities of exceedance. However, site response is considerably more complex including surface waves, basin effects (including focusing and basin edge-generated surface waves), and topographic effects. Thus, 1D site-specific response analyses may not always be effective for accurately modelling and/or predicting site effects, however, in comparison to alternatives of GMPEs and empirical amplification factors, site response analysis would model the probable surface uniform hazard spectrum more adequately.

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ESC2018-KN6

EARLY WARNING SYSTEMS FOR EARTHQUAKES AND TSUNAMIS. SOME REFLECTIONS ON THEIR PHYSICAL, SOCIAL AND LEGAL IMPACT.

Alessandro Amato
Istituto Nazionale di geofisica e Vulcanologia, Italy

Early Warning systems for tsunamis (TEWS) date back to the mid 20th century, after a large earthquake that occurred in 1946 in the Aleutians Islands. The earthquake triggered a powerful tsunami that killed more than 100 people in the Hawaii, several hours later. A local TEWS was established in the Hawaiian Islands, whereas the Pacific Tsunami Warning System (ICG/PTWS) was established in 1968 under the coordination of UNESCO-IOC, after the 1960 M9.5 Chilean earthquake. Several warnings were released in the following decades for large earthquakes along the Pacific ring of fire, contributing to save lives and reduce damage. However, more than half a century later in the Indian Ocean, the 2004 M9.3 earthquake in Sumatra triggered a powerful tsunami that caused thousands of victims without any warning, including hundreds as far as Somalia, several hours later. Today, several tsunami warning centers are operating in all the hazardous areas of the world, including the Mediterranean, in the framewok of the ICG-NEAMTWS (Intergovernmental Coordination Group for the North-East Atlantic, Mediterranean and connected seas Tsunami Warning System), one of the four ICGs of UNESCO. These TEWS are able to provide alerts within few minutes after the occurrence of large marine and coastal earthquakes. More recently and with higher technological challenge, Earthquake Early Warning systems (EEWS) have started to become operational in some regions. The first positive experience dates back to the 90's, after the devastating 1985 earthquake in Mexico. Since 1991, the Mexican EEWS (SASMex) has issued 158 alerts in the capital for distant earthquakes. Other EEWS are operational in Japan, China, Taiwan, Turkey, Romania and few other countries. Experimental EEWS are under test in California, Italy and some other regions. Along with the increasing power of seismic and sea level monitoring, and the consequent improved performance of Early Warning systems, also the expectations from authorities, media and citizens have grown and will continue to grow. More rapidity and accuracy are continuously searched and reached by the scientists. At the same time, any technological achievement in EWSs, although at an experimental stage, might become a requirement by the authorities, and even by prosecutors and judges in the event of a deadly tsunami or earthquake. The risk for scientists and emergency managers of being prosecuted for a "late" or underestimated alert, or even for a false alarm, must be seriously taken into account. In the long and complex chain of responsibilities, scientists operating in real time risk reduction and communication are the first (and possibly the weakest) ring. For this reason, it is important for scientists and Institutions to be able to assess and communicate limits and uncertainties inherent in any real-time estimate. Particular attention must be given to the roles and responsibilities of scientists (as well as of the other experts – civil protection officers, authorities, etc.) involved in the decision chain during an alert. In order to avoid to put EW science in the dock, it is important to establish clear, transparent, effective standard operational procedures which delineate the roles and the duties of all the operators. Moreover, since EWSs' goals include both automatic actions (mainly for EEWS) and self protective behaviors (for both E- and T-EWSs), it is important that citizens are correctly informed and prepared to an alert. Assessing and improving risk perception is a crucial step towards risk mitigation and require social science studies. In this talk I will summarize the main issues related to Early Warning Systems, with particular emphasis to the work we are carrying out at the INGV Tsunami Alert Center (CAT) for the Mediterranean.

ESC2018-KN7

TEN YEARS' EXPERIENCE OF NATIONWIDE EARTHQUAKE EARLY WARNING IN JAPAN

Mitsuyuki Hoshiba
METEOROLOGICAL RESEARCH INSTITUTE, JMA, Japan

As a new tool for earthquake disaster prevention/mitigation, Japan Meteorological Agency (JMA) has been operating nationwide Earthquake Early Warning (EEW) in Japan since 2007. During the ten years, we have experienced many M6- and M7-class earthquakes, and the Mw9.0 Tohoku earthquake. I will explain the ten years' experience, lessons learned, feedback from

general public (results of questionnaire survey), and future prospects

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SCIENTIFIC SESSIONS

S01 MARCO MUCCIARELLI MEMORIAL SESSION: BRINGING SCIENTISTS AND ENGINEERS FROM AROUND THE WORLD TOGETHER TO REDUCE THE IMPACT OF FUTURE EARTHQUAKES

Conveners

John Cassidy, Geological Survey of Canada, john.cassidy@canada.ca

Maria Rosaria Gallipoli, Institute of Methodologies for Environmental Analysis, Italy, mariarosaria.gallipoli@imaa.cnr.it; Dario Albarello, University of Siena, Italy, dario.albarello@unisi.it; Sebastiano D'Amico, University of Malta, Malta, sebastiano.damico@um.edu.mt; Atilla Ansal, Ozyegin University , İstanbul · Department of Civil Engineering, ansal@boun.edu.tr; Sebastiano Foti, Politecnico di Torino, sebastiano.foti@polito.it; Angelo Masi, University of Basilicata and ReLUIS Network, angelo.masi@unibas.it; Francesca Pacor, INGV, francesca.pacor@ingv.it Stefano Parolai, Seismological Research Centre – OGS, sparolai@inogs.it; Dario Slejko, Seismological Research Centre – OGS, dslejko@inogs.it; Alan Yong, U.S. Geological Survey, yong@usgs.gov

The goal of this Session is to reflect on the many scientific contributions, and to honour the memory of our dear colleague, Dr. Marco Mucciarelli. We do this by following in his footsteps and bringing together earthquake scientists and earthquake engineers from around the world to reflect on what we have accomplished, and where we are going. Marco's scientific interests and important contributions were numerous, and diverse. We seek contributions to this session that reflect his legacy, including: all aspects of earthquake seismology and earthquake hazards; earthquake site response; seismotectonics; induced seismicity; science communication, and much more. If you would like additional information, or have questions, please feel free to contact any of the co-convenors of this session. Marco Mucciarelli was well-known across Europe and around the world for his scientific talent and passion, for his ability to bring people together, his strong desire to reduce the impact of future earthquakes, and his laughter and his smile. We look forward to a lively scientific session that provides a fitting honour to a great scientist who travelled the world doing cutting-edge science, and who brought so many people together, with the unwavering goal of reducing the impact of future earthquakes, helping to protect people, protect communities, and protect our environment.

S02 -SEISMOLOGICAL E-INFRASTRUCTURES AND THEIR DATA AND PRODUCTS SERVICES

Conveners

Florian Haslinger, ETH Zürich, haslinger@sed.ethz.ch; Alberto Michelini, INGV Rome & ORFEUS, alberto.michelini@ingv.it; Rémy Bossu, EMSC-CSEM, Remy.BOSSU@cea.fr Stefan Wiemer, ETH, stefan.wiemer@sed.ethz.ch; Andreas Rietbrock, Karlsruhe Institute of Technology, andreas.rietbrock@kit.edu

e-infrastructure is a fashionable term used in various contexts, mainly describing the combination of advanced ICT tools and resources with scientific data and products in an effort to enable and support multi- and cross-disciplinary investigation and collaboration. In that sense, the term accurately describes what seismologists globally are doing since decades: openly sharing data and results, and utilizing the best available computer technology to provide access to that data and to perform advanced calculations to better understand the phenomena related to the physics of the planet. Within the European Plate Observing System EPOS, a coordinated e-infrastructure is being implemented to support European solid Earth science research, and EPOS Seismology constitutes its seismological part (www.epos-ip.org/tcs/seismology). Building upon ORFEUS, EMSC, and EFEHR to cover seismic waveforms, seismological products, and seismic hazard and risk, and integrating results of recent projects e.g. in computational seismology, EPOS Seismology is putting together a broad portfolio of data and product services within a coordinated framework, fully integrated with the EPOS ICS infrastructure and with the other domains in EPOS. EPOS Seismology will also foster the testing, implementation and integration of new services and data products as they emerge from the scientific community. In this session, we welcome contributions on all issues related to building and operating e-infrastructures for seismology, with or without connection to EPOS, and on any scale (institutional, national, international), as well as presentations on specific new data or products services made available to the community. Contributions may cover scientific background,

operational implementation, data and metadata management, or governance issues.

S03 FROM SITE SELECTION TO DATA PUBLICATION THROUGH THE DATA LIFE CYCLE IN SEISMOLOGY

Conveners
Damiano Pesaresi, OGS Trieste, Italy, dpesaresi@inogs.it; Javier Quinteros, GEOFON / Deutsches GFZ Potsdam, Germany, javier@gfz-potsdam.de; Helle Pedersen, University of Grenoble, France, helle.pedersen@univ-grenoble-alpes.fr; Luca Trani, KNMI, Netherlands, luca.trani@knmi.nl; Maggie Hellström, ICOS Lund University, Sweden

Developments in seismological instrumentation, telecommunications and power systems has allowed seismologist to exponentially increase the number of seismic stations for high quality as well as cost effective seismological observations. The innovation alongside with the very well established standard data formats and real-time data exchange protocols enabled the scientific community to explore new field of research and have an ever growing treasure of digital seismological data. Thus, operations of seismic networks and data centers, have shifted their focus from the main challenge of acquiring high quality seismic data in standard formats towards enhancing internal data management policies and standard services on the downstream part to enable themselves and users in dealing with the big data challenges. In this session, we expect contributions related, but not limited to:

- All aspects of seismic station/network installation, operation. This includes site selection; equipment testing and installation; planning and implementing communication paths; development of efficient power systems, etc.
- Integration of new instruments/observables in the seismological community as well as new applications (e.g. Infrastructural monitoring, Large-N, Deployments in extreme environmental conditions, etc.)
- Best practices for network operators and data centres producing data.
- Different approaches towards FAIR principles, including citation and referencing.
- Data Policies and Curation activities related to data/metadata, including provenance information, data models and metadata standards. Usage of persistent identifiers for datasets, instruments, and other entities. Activities within European initiatives related to Data Management and links to other disciplines

S04 OBSERVATIONS FROM THE SEA FLOOR: INSTRUMENTATION, NETWORKS, PROCESSING AND ANALYSIS

Conveners
Matthew R. Agius, University of Southampton, UK, matthew.agius@soton.ac.uk; Catherine A. Rychert, University of Southampton, UK, C.Rychert@soton.ac.uk; Nicholas Harmon, University of Southampton, UK, N.Harmon@noc.soton.ac.uk; Christopher J. Bean, Dublin Institute for Advanced Studies, Ireland, chris.bean@dias.ie; Martin Möllhoff, Dublin Institute for Advanced Studies, Ireland, martin@dias.ie; Francesco Italiano, INGV Palermo, Italy, francesco.italiano@ingv.it;

Ocean bottom experiments are on the increase with a growing number of experiments across the planet. In recent years, there have been significant advancements on both the technical and the scientific side, which have increased the overall success of such deployments. On the scientific side, these experiments are giving seismologists, geophysicists, geologists, geochemists and also oceanographers the opportunity to explore new, previously-unreached regions to answer important questions about plate tectonics, offshore seismicity and ocean-seafloor interactions. On the technical side, seafloor stations are becoming more reliable, and record better quality data. In this session, we welcome contribution for oral and poster presentation about all aspects of Ocean Bottom Seismometers (OBS) and multidisciplinary seafloor observatories, including instrument design, site selection, deployment, quality control, data archiving, processing and results. Contributions about stand-alone, permanent online and real-time underwater stations and early warning systems are also welcome.

S05 SEISMOTECTONICS AND SEISMIC HAZARD IN NORTH-AFRICA AND THE MEDITERRANEAN REGIONS

Conveners
Assia Harbi, Center of Research in Astronomy, Astrophysics, and Geophysics*, Bouzareah, Algiers, Algeria, harbi.assia@gmail.com; Mustapha Meghraoui, Institut de Physique du Globe, France ; Said Maouche,* Center of Research in Astronomy, Astrophysics, and Geophysics*, Bouzareah, Algiers, Algeria; Abdelhakim Ayadi* Center of Research in Astronomy, Astrophysics, and Geophysics*, Bouzareah, Algeria*

Earthquake hazard in Northern Africa and the Mediterranean constitutes a constant threat to human life and property, causing major economic losses and disruption. These regions experienced several devastating earthquakes, some of them even causing tsunami (e.g. in AD, Pompeii 62, Cyrene 262, Alexandria 320, Marmara 358, Crete 365, Sitifis 419, Beirut 551, Tunis 856, Rhodos 1303, Algiers 1365, Fez 1624, Sicily 1693, 1908, Oran 1790, Djidjelli 1856; Liguria 1887, etc.). Generally, most of the western Mediterranean regions including North-Africa were affected by moderate earthquakes (with Mw < 6.5). However, the region remains vulnerable due to the old building stock combined with the shallow character of its seismicity, poor mechanical properties of its soil and local site conditions, and the consequent strength of the ground shaking. Recently, the 1997, 2009 and 2016 earthquake sequences in central Italy (Apennines) were responsible of extensive damage. The destructive earthquakes of Agadir in 1960 (Morocco, Mw 5.9, 15000 people killed), El Asnam in 1980 (Algeria, Mw 7.3, 3000 people killed), Cairo in 1992 (Egypt, Mw 5.8, 541 people killed), Zemmouri in 2003 (Algeria, Mw 6.8, 2278 people killed) and Al Hoceima in 2004 (Morocco, Mw 6.4, 600 people killed) resulted in damage worth 11.5 Billion US$ losses.

In this session, we seek presentations on case studies of significant earthquakes of the North African and Mediterranean regions, revised historical and instrumental seismicity, new seismotectonic analysis including fault kinematics, stress distribution and paleoseismic input data. Contributions on seismic hazard models, scenarios, exposure database, vulnerability and risk assessment at regional scale or at specific sites across North Africa and the Mediterranean regions are also welcome.

S06 RECENT STRONG EARTHQUAKES IN THE AEGEAN SEA AND IMPLICATIONS FOR REGIONAL TECTONICS

Conveners
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The Aegean Sea is a natural laboratory for studying active tectonics and earthquakes due to the interaction of Eurasia with Nubia plate and the westward motion of Anatolia. All types of faulting are present and deformation of the crust is influenced by deep geodynamic processes. The East and Southeast Aegean Sea is of particular interest as the dominant mode of regional deformation is extension, however active fault kinematics are both normal and strike-slip. This session seeks insights into the source mechanism, aftershock sequence, tectonic setting and geodynamic implications of the recent series of earthquakes in the Aegean: onshore Biga peninsula (Turkey; February 2017; mainshock M5.2) offshore Lesvos (June 2017, Aegean Sea, Greece; M6.3) and offshore Bodrum Kos (July 2017; M6.6). All three mainshocks were well recorded by modern seismic and GNSS networks while the generated surface deformation was imaged by satellite radar missions. In this session we invite papers covering all aspects of these earthquake sequences and their seismotectonic context. Foreseen contributions may include (but not limited to) analyses of seismological data to identify the seismic faults and to refine their geometry and kinematics using inversion techniques, analyses of rupture patterns and source properties of the mainshocks, statistical properties of the aftershock sequences, processing of geodetic data (GNSS, InSAR) to locate the seismic faults and subsequently used in combined inversion studies, offshore campaigns exploring sea-bottom geomorphology and shallow faulting patterns, local tsunami studies, soil-structure interaction studies, studies to retrieve

co-seismic vertical land movements from coastal observations etc. We aim for a multi-disciplinary session that will attract workers in all aspects of the seismology and geophysics of the Aegean Anatolia area including users of active fault databases such as the SHARE ESHM13 fault sources database, NOAFaults etc. We also solicit posters from a very broad base such as tectonophysics, geodynamics and marine geology, and especially encourage interdisciplinary contributions.

S07 SEISMICITY, CRUSTAL AND UPPER MANTLE STRUCTURE OF THE AFRICAN CONTINENT

Conveners

Dr. Ezekiel Jonathan, CTBTO, Austria, Ezekiel.JONATHAN@ctbto.org; Dr Rapelang Edward Simon, University of Botswana, Botswana, SIMONRE@mopipi.ub.bw; Dr Vunganai Midzi, Council for Geoscience, Republic of South Africa, vmidzi@geoscience.org.za; Dr. Stephen Myers, Lawrence Livermore National Laboratory, USA Istvan Bondar, Research Centre for Astronomy and Earth Sciences of the Hungarian Academy of Sciences, ibondar2014@gmail.com

The CTBTO-PTS is organizing a series of workshop/training sessions in Africa with the goal of improving seismological analysis practices, including the use of CTBTO-provided tools, the iLoc seismic location method, and the Regional Seismic Travel Time (RSTT) earth model for improved hypocentre accuracy. These sessions emphasize the importance of data sharing, and they have resulted in the determination of event hypocentres and associated arrival-time data that can significantly advance the quality of regional seismic bulletins and improve the accuracy of earth models that are based on regional bulletins. The CTBTO-PTS effort complements other efforts throughout the African continent, which have the goal of gathering continent-wide seismological information, and to refine the seismo-tectonic map of Africa. This session features efforts to improve assessments of African seismicity and develop models of crustal and upper-mantle structure throughout the African continent. We welcome submissions on seismicity studies with particular emphasis on newly instrumented areas where previous knowledge is sparse. Detailed studies of seismic events of special interest, including aftershock studies are sought. Studies of crustal and upper mantle structure in Africa in the context of improved prediction of seismic travel time, amplitudes, and waveforms are also encouraged.

S08 SEISMIC TOMOGRAPHY: METHODOLOGICAL ADVANCES AND APPLICATIONS AT DIFFERENT SCALES

Conveners

Cristina Totaro Messina University, Italy – ctotaro@unime.it; Claudia Piromallo – INGV, Italy, claudia.piromallo@ingv.it; Sergei Lebedev Dublin Institute for Advanced Studies – Dublin – Ireland sergei@cp.dias.ie

Seismic tomography is one of the most effective tools for Earth structure investigation. Several techniques and algorithms have been developed in the last few years with the aim to better characterize the Earth's interior through higher-resolution imaging, from global to local scale. This session will focus on advances in seismic tomography general theory, applications, and outstanding, debated methodological problems, including proper starting model definition, robustness tests, result representation, and the effects of uncertainty in earthquake locations. Contributions on methodology and applications of tomographic inversion at different scales and with different types of data (local earthquake, teleseisms, ambient noise, surface waves, etc.) are welcome. The session will also provide the stage to present and discuss recent results on the crustal and mantle structure in the Euro-Mediterranean region, as well as other areas worldwide

S09 SEISMIC STUDIES AND MULTI-DISCIPLINARY VIEWS ON OCEAN ISLANDS, HOTSPOTS AND MANTLE PLUMES

Conveners

Graça Silveira, Instituto Superior de Engenharia de Lisboa; mdsilveira@fc.ul.pt; Sergey Lebedev, Dublin Institute for Advanced Studies, Ireland, sergei@cp.dias.ie; Matthew R. Agius, University of Southampton, UK, matthew.agius@soton.ac.uk; Joana Carvalho, Instituto Dom Luiz, jfcarvalho@fc.ul.pt

Ocean Island volcanoes result from magmatism traditionally attributed to mantle plumes, responsible for heat and mass transfer from the

deep mantle to the Earth's surface. Yet, plumes remain elusive features, fostering a controversy on whether or not they are the mechanism behind hotspot volcanism. Seismic images of the subsurface structure, when integrated with other geophysical data and models, provide valuable information on the underlying structure of those geological features as well as on the tectonic processes that shape them. This session invites oral and poster contributions in which seismic studies, but also multi-disciplinary approaches, are conducted to image the subsurface structure of ocean islands from the crust to the deep mantle. This session is a contribution to the TIDES COST Action ES1401

S10 ADVANCES IN SEISMIC ANISOTROPY: STUDIES FROM CRUST TO CORE

Conveners
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Studies focused on seismic anisotropy at various depths represent an effective approach to improve our understanding processes that govern the inaccessible Earth' s interior and drive its long-term geological and geodynamic evolution. Moreover, the anisotropy studies provide additional information on both past and present-day deformation of the coupled lithosphere-asthenosphere system and on the state of crustal stress. The availability of a large amount of seismic data recorded recently worldwide, in combination with advanced methods of measuring seismic anisotropy, has lead the scientists to new promising results.
They encompass the deformation of the lithosphere associated with active subductions and related volcanism, mantle flow dynamics and plate kinematics, as well as the lithosphere interactions and coupling with the convecting mantle below. In addition, observations of seismic anisotropy in the crust can be used to characterize better the deformation associated with a wide range of tectonic processes.Moreover, further studies are necessary to harmonize different results at variety of scales. The aim of this session is to share recent results on seismic anisotropy to increase our knowledge of the deformation and structures of the solid Earth at a wide range of scales. Therefore, we invite submission of contributions dealing with seismic anisotropy studies focused on the analysis of deformation and structure from the crust down to the inner core by integrating different geological and seismological observations, laboratory experiments, and analog and numerical modelling results.

S11 ADVANCES IN VOLCANO SEISMOLOGY

Conveners
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Volcanic processes such as magma intrusions and dike propagation, faulting, landslides, explosive eruptive activity and hydrothermal fluid circulation produce a diverse range of geophysical signatures, including caldera deformation, variations in tilt of the volcanic edifice and changes in gravity and electric conductivity. Seismic data, however, are the primary source of information on volcano dynamics and provide a direct link to assess volcanic activity levels. In combination with interdisciplinary observations, the deployment of extensive seismic networks has significantly improved our ability to forecast and assess volcanic hazards, from the first signs of unrest to long-lived eruptions. The aim of this session is to explore the role of seismology in a wider volcanological context, and

- to discuss major advances in instrument and network design leading to improvements in both spatial coverage and temporal resolution of seismic observations;
- to explore the seismological insight in the internal structure and physical processes of volcanic systems through new processing tools, physical models and interpretations of volcanic seismic data;
- to exhibit the variety of seismic sources a volcano can have, revealing differences and similarities to tectonic seismic sources.

S12 SEISMOLOGICAL AND STRUCTURAL STUDIES IN POLAR REGIONS AND THE CRYOSPHERE

Conveners
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Sergei Lebedev, Dublin Institute for Advanced Studies, Ireland, sergei@cp.dias.ie
Peter Voss, Geological Survey of Denmark and Greenland – GEUS, Denmark, pv@geus.dk
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The Polar Regions attract increased attention and have special significance as regions strained the most by the consequences of climate change. The unanswered questions over the regions' tectonic evolution, the implications of their natural resources and the UN Law of the Sea Treaty stimulate further interest in them. Some of the seismological challenges in the Polar Regions are the origin and properties of intraplate seismicity, the mechanisms of ultra-slow sea-floor spreading, the role of glacial rebound in seismicity triggering and the exploration for oil and gas. As an exploration tool for the Earth's structure, both in depth and on the surface, seismology nowadays contributes to studies of paleoclimate and ice structure. Seismology has also proven itself as an effective tool to study glacier and ice-sheet dynamics, and to monitor glacier-related natural hazards, the rich cryo-seismological wavefield providing unrivalled insights into crevassing, subglacial water flow, basal motion, iceberg drift and iceberg calving. We invite submissions on seismology and Earth structure in the Polar regions and in glaciated environments with temperate climates. All seismological topics are welcome, including monitoring and analysis of seismicity (tectonic and cryogenic) and related hazardous, near-surface processes, studies of recent larger seismic events, seismotectonics and seismic imaging of crustal and mantle structure. We welcome contributions both on recent research results and their interpretation, and on experiments under the special conditions of the polar environment and mountain glaciers.

S13 GEOPHYSICAL IMAGING OF FAULT ZONES AT DIFFERENT SCALES: CHALLENGES AND PERSPECTIVES.

Conveners
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The geophysical investigation of fault zones is of primary importance for extending at depth the knowledge provided by surface structural studies aimed at characterizing their internal architecture and understanding the processes that drive fault growth and interaction. In particular, brittle fault zones in active tectonic settings play a major role in the evolution of the lithosphere, since they accommodate a large proportion of deformation, even far form plate boundaries. Earthquake faulting is a compound structural process, so that gaining sights into the properties of fault zones is crucial to understand their control on earthquake nucleation and on the complexity of coseismic rupture propagation and arrest. Moreover, fault zones represent preferential pathways for fluid flow at different scales, and display dynamic spatio-temporal behaviour, particularly in the different phases of the seismic cycle. From a near-surface geophysical perspective, in urbanized settings the characterization of shallow fault zones is crucial for a better assessment of surface faulting hazard and site effects due to ground motion amplification. In offshore settings, deep geophysical prospecting is the key for the exploration of inaccessible fault zones, such as in the case of mega-thrust along subduction margins, or tectonically active submarine escarpments on spreading centres and back-arc basins. The aim of this session is to collect the most recent results of geophysical imaging of fault zones supporting geological characterization of tectonically active areas, including also discussions on challenges and perspectives. In particular, we encourage to submit works dealing with multi-disciplinary high-resolution methods (among the others, seismic and electrical tomography, reflection profiling, full-waveform inversion, electromagnetic and gravimetric methods) together with new developments in data processing, imaging techniques and field acquisition layouts. Case studies from active tectonic settings and areas recently hit by earthquakes are welcome.

S14 FAULT2SHA: SO WHAT?

Conveners
Laura Peruzza – OGS Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste

(Italy); Oona Scotti – IRSN, Institut de Radioprotection et de Sûreté Nucléaire, Paris (France); Bruno Pace – DiSPUTer, Università "G. d'Annunzio" Chieti-Pescara, Chieti (Italy) Francesco Visini – INGV Istituto Nazionale di Geofisica e Vulcanologia, L'Aquila (Italy) Thomas Chartier – IRSN & Ecole Normale Supérieure de Paris, Paris (France)

Accounting for faults in PSHA studies is a crucial challenge as it involves a wide spectrum of subjects of a varied community that goes from earthquake field geologists to seismic hazard and risk practitioners, earthquake source dynamic rupture modelers, statistical seismologists and geodynamic experts. The Fault2SHA Working Group has been formally approved by ESC at the 35th General Assembly, Sept 2016, and it acts to provide a discussion forum on how to transform basic geological information into parameters for seismogenic sources useful for seismic hazard assessments. The first annual report of 2016-17 activities is available on the new WG website at http://fault2sha.net/what/. In Malta, at the 2018 ESC General Assembly, the aim is to bring together researchers and PSHA practitioners to discuss field data collection issues and challenges for their integration into PSHA. The Fault2SHA WG solicits contributions such as: 1) field data issues – methodological approaches to identify, model and quantify the seismic potential of faults to be used in seismic hazard analysis, geological/geodetical constraints to estimate present-day slip rates, paleoseismological constraints to estimate the degree of periodicity of major events; 2) data vs hypotheses issues concerning possible fault-to-fault rupture scenarios based on geometrical complexities or on physics-based approaches: case-studies illustrating the evolution of knowledge of a faults system, and the role played by the latest earthquakes in confirming/changing the previous hypotheses; 3) data vs hypotheses issues concerning the earthquake recurrence based on time-dependent processes, hazard assessments that illustrate the capabilities and critical aspects of faults models in representing real, observed shakings. We encourage, in particular, presentations focused on specific field laboratories: the Betics (E) and Central Apennines (I) are already onboard with invited/solicited talks. During the session an overview of the past/ongoing initiatives will be presented as well. Finally, we are planning a special hands-on presentation of some tools used for parameterizing fault activity rates. Fill in the form at http://fault2sha.net/form-esc-2018/ and follow the most recent POST if you are interested in such initiative

S15 CURRENT PRACTICE, CRITICAL ASPECTS AND NEW CHALLENGES IN PSHA AT LOCAL, NATIONAL AND REGIONAL SCALE

Conveners
Aybige Akinci, INGV Rome, aybige.akinci@ingv.it Dario Albarello, University of Siena, dario.albarello@unisi.it; Fabrice Cotton, GFZ Potsdam, fcotton@gfz-potsdam.de; Stefan Wiemer, ETH Zurich, wiemer@sed.ethz.ch

In recent years, great efforts have been devoted to improve PSHA standards and understanding their implications for seismic hazard and risk assessments. Increasing number of world-wide damaging earthquakes, exponential growth of data and knowledge, together with new engineering demands and needs for the operational safety for society motivated the research of alternative and more effective approaches incorporating new concepts and tools. We welcome presentations that explore and introduce new criterions, aspects and approaches advancing standards in the traditional PSHA, and/or contributions that help reducing aleatory/epistemic uncertainties in the seismic hazard and allow testing effectiveness of available estimates. Topics of main interest will be:

- Definition and determination of earthquake sources and activity rates, including the assessment of earthquake datasets, calibration of magnitude scales, identification of faults and seismogenic sources, implementation of strain and simulation-based earthquake rupture forecasts;
- estimation of strong ground motion and its uncertainty; Ground Motion Predictive Equations and alternative approaches based on based deterministic and stochastic simulations. The assessment of site effects, the consideration of new parameters to characterise the intensity of ground shaking;
- validation of seismic hazard models, statistical tests of activity rates, calibration of ground motion models;

Model building process and related uncertainties, formal elicitation of expert opinion, comprehensive treatment of aleatory/epistemic uncertainties, development of innovative testing procedures.

- Case studies of SHA from Europe and around the globe (contributions related to the ongoing update of the Harmonised European Seismic Hazard model and the emerging EPOS infrastructure on hazard and risk).

S16 ADVANCES IN MODELS, OBSERVATIONS AND VERIFICATION TOWARDS OPERATIONAL EARTHQUAKE FORECASTING

Conveners
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The observed seismic dynamics before and after many major earthquakes demonstrated common features of predictability and diverse behavior. Significant steps have been made towards assessing earthquake space-time correlations, clustering, and the emergence of seismicity patterns, showing the potential for reproducible and testable earthquake forecasting. But seismicity is only one manifestation of Earth's complex dynamics in advance of catastrophic earthquakes. Besides identified patterns and probabilistic models of earthquake occurrence, many newly available data collected on a global scale provide new opportunities for systematic analysis and model testing. A variety of physical observables, ranging from ground-related deformation patterns (GPS, SAR, etc.) to pre-earthquake changes (be they geochemical, electromagnetic, or thermodynamic), may be related to stress variations in the lithosphere prior to a large earthquake. With this session, we intend to better understand the feasibility and practical relevance of earthquake forecast/prediction methods. The following theoretical and practical issues will be addressed:

- Systematic analysis, physical interpretation and modeling of pre-earthquake processes;
- Model validation and statistical assessment of the proposed physical-based precursors;
- Statistical methods and problems in earthquake forecast validation;
- Input data analysis and requirements for real-time model testing;
- Dissemination and use of earthquake forecasting information;
- Approaches for the evaluation of earthquake forecasting methods and case studies;
- Possible extension to seismic risk and loss forecasting.

Presentations addressing the issue of time-dependent seismic hazard assessment, based on the space-time characterization of impending earthquakes, are also welcomed. We emphasize that we are interested in both probabilistic and deterministic approaches to these problems.

S17 INTERNET MACROSEISMOLOGY

Conveners
Valerio de Rubeis, INGV, Rome, Italy, valerio.derubeis@ingv.it; Thomas Lecocq, ROB, Bruxelles, Belgium, thomas.lecocq@oma.be Ina Cecić, ARSO, Ljubljana, Slovenia, Ina.Cecic@gov.si

With several years of experience of collecting internet macroseismic data behind us, we can more easily identify existing problems, present already solved ones and explore the possibilities to solve the open questions. This applies to the whole range of topics, starting from database issues, data formats, questionnaires and thumbnails, all the way to multi-hazard approach. The aim of this session is to explore ways in which the macroseismic datasets from different countries and institutions could possibly be merged, and to what extent these data should be harmonized, especially for earthquakes affecting different countries, but also with respect to

building comprehensive European macroseismic catalogues, e.g. for use in seismic hazard assessment. Presentations of national or institutional methodologies, objectives, collecting systems, studies of merging different datasets etc. are welcome.

S18 TOWARDS A FASTER AND MORE ACCURATE ASSESSMENT OF THE IMPACT OF AN EARTHQUAKE.

Conveners

Matteo Picozzi, University of Naples Federico II, matteo.picozzi@unina.it; John F. Clinton, SED, ETH Zürich, jclinton@sed.ethz.ch; Stefano Parolai, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, sparolai@inogs.it; Aldo Zollo, University of Naples Federico II, aldo.zollo@unina.it

Over the last few years, scientific and technological advances in real-time seismology and earthquake early warning mean we are approaching an era when assessments of the impact of an earthquake can be available as an earthquake is progressing and grow increasingly reliable with increasing time as predictive estimates become constrained by observed data. Recent efforts that can critically improve real-time assessment of the impact include advanced signal processing that discriminates pick types; tracking evolving finite ruptures using peak amplitude patterns or waveform simulation techniques; the selection of appropriate GMPEs and fragility curves for rapid damage assessment; and the integration of non-traditional monitoring datasets (cheap acceleration sensors, GPS) and felt reports as they become available. With this session, we aim to provide a state-of-the-art overview of the field of earthquake early warning and rapid response systems. In particular, we intend to create a forum to share experiences, techniques, perspectives, to identify areas for improvements, and to move towards an international agreement on standards, instrumentation, and methods for new real-time seismic risk mitigation systems. We welcome contributions on early warning and rapid response development, both in methodological as well as application level, and particularly encourage submissions dealing with real-time seismic risk mitigation applications and loss-based early warning.

S19 PHYSICS OF EARTHQUAKES AND SEISMIC SOURCES

Conveners

Efthimios Sokos, University of Patras, Greece, esokos@upatras.gr; Christos Evangelidis, National Observatory of Athens, Greece, cevan@noa.gr Václav Vavryčuk, Institute of Geophysics, Czech Republic, vv@ig.cas.cz; Jiří Zahradník, Charles University, Czech Republic, jz@karel.troja.mff.cuni.cz

Earthquake physics attempts to answer fundamental questions in seismology as how do earthquakes prepare, how does seismic rupture start, propagate and stop, what is the role of the long-term and short-term processes in the Earth, what is the role of fluids in earthquake triggering, and what is the link between fault dynamics, energy, friction and other physical parameters of the focal zone. Recent advances in seismological, geodetic and satellite observations provide a vast amount of data, which, linked with advances in computational methods, have significantly expanded our ability to study earthquake related phenomena on various scales. Nevertheless, despite the achieved progress, earthquake source processes are not often sufficiently understood and in some cases the results are controversial, calling for increased efforts towards source studies. The goal of this session is to attract scientific contributions related to broad aspects of methodological as well as data-oriented earthquake source studies. Submissions focusing on earthquake source parameters, focal mechanisms and their inversion for stress, non-double-couple components of moment tensors, source slip inversions, finite fault inversions, back-projection techniques and their applications, resolution limits and related uncertainties are particularly welcome as well as physics-based simulations. In addition, the session is suitable for studies of source imaging as well as frequency-dependent source parameters, imaging of dynamic rupture, characterization of source complexity, statistical properties of earthquake source parameters as scaling laws etc.

S20 EARTHQUAKE SOURCE MECHANISMS AND TRIGGERING PROCESSES

Conveners

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Earthquakes are triggered by various natural and artificial processes. Especially, human-induced earthquakes are brought into the focus of public attention, the most prominent example is the dramatic increase of the number of earthquakes in the central and eastern US. However, the topic gains attention also in Europe, e.g. seismicity induced during geothermal exploration, gas field depletion or reservoir impoundment. Similar swarm activity has been reported for natural earthquakes and is often considered to be related to underground fluid movement and slow deformation in tectonic fault systems, some of which supposedly reflect preparation stages before very large earthquakes. Microseismic monitoring emerged as important tool for the general understanding of hidden background conditions, such as location of fractured reservoirs, faults and fluid flow paths. It is not yet clear if induced earthquakes should be treated the same or differently than natural events. Also, the relationship between fluid injection or extraction and resulting seismicity is still poorly understood. Although the discrimination between natural, triggered and induced earthquakes might be required for legal purposes in the future, it is still challenging and no clear rules or scientific methods are established. The aim of this session is to advance the understanding of the relationship between characteristics of earthquake sources and background triggering processes, including industrial operations, fluid flow and volcanic or tectonic movements. We welcome presentations on the development and application of analysis methods to investigate the differences between ordinary, naturally triggered and artificially induced seismicity as well as insightful theoretical and experimental works.

S21 PHYSICS OF EARTHQUAKE PREPARATION PROCESS: FROM LABORATORY EXPERIMENTS TO EARTHQUAKE FORECAST (DEDICATED TO THE MEMORY OF PROF. HANS BERCKHEMER, PROF. VICTOR KUKSENKO AND DR. GEORGE PURCARU)

Conveners

Alexey Zavyalov, Institute of Physics of the Earth RAS, Moscow, Russia, zavyalov@ifz.ru
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The skepticism connected with earthquake forecasting, both deterministic and probabilistic, is related with the complexity of earthquake generation process that put limitations in scientific knowledge and incomplete insights. These latter prevent a reliable estimation of the occurrence place, time and magnitude of an ensuing earthquake. Meanwhile, it is known that the earthquake process is not momentary, but on the contrary there are several gradually evolving stages that take place in time and space. Before the main rupture occurs, the destruction process is going through a number of levels (stages), starting with the micro–scale and ending on macro–scale, including earthquake focal area. In this session, we invite researchers to discuss the results and directions for further studies on the physics of the seismic process – from experiments in laboratory conditions, to rock bursts in mines and seismically active regions during the preparation phase of strong earthquakes. Special emphasis will be given to quantitative physical models of the seismic process at different scales, observations on earthquake triggering by other earthquakes or nearby faults, and synchronization between nearby faults with positive stress coupling, fault system interactions controlling earthquake occurrence, the connection of smaller magnitude seismicity with stress changes as expressed through the Rate/State model, calculation of stress changes from changes in earthquake occurrence. Modeling and simulations across a wide range of spatial and temporal scales provide a better understanding of the source processes and interactions, and advance predictive capabilities. This session will be devoted to the memory of outstanding scientists in the field of rock physics and physics of seismic process – Prof. Hans Berkhemer (Germany), Prof. Victor Kuksenko (Russia), Dr. George Purcaru (Romania/Germany).

S22 ADVANCES IN UNDERSTANDING EARTHQUAKES IN REGIONS OF DISTRIBUTED DEFORMATION: FROM FIELD STUDIES TO SEISMIC HAZARD ASSESSMENT

Conveners

Susana Custódio, IDL, Univ. of Lisbon, Portugal,sicustodio@fc.ul.pt; Michele Carafa,

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The theory of plate tectonics explains the occurrence and recurrence time of strong earthquakes along discrete boundaries. However, large regions of spread deformation are observed in nature, both around plate boundaries and in orogens. Furthermore, seismicity in regions with very low strain rates show that the interiors of plates also deform. Earthquakes in regions of distributed and low deformation can also reach high magnitudes, but in contrast to plate boundaries it is not clear if cyclic behavior applies and if yes how recurrence times can be estimated with the classical approaches and concepts. The significant increase of high-density data collected in past years resulted in high-quality data sets of hypocentral distribution, focal mechanisms, crustal stress pattern and GPS surface deformation. These can be used for an integrated approach to understand the earthquake occurrence away from the well-known plate boundaries. Fundamental questions that have to be addressed concerning the recognition of seismogenic faults and the occurrence of earthquakes in these regions include: Can we identify faults that take up deformation in regions of distributed deformation? Can the tectonic and possibly seismogenic signal be singled out for each fault? Can we relate the characteristics of fault networks to earthquake potential, and subsequently to seismic hazard assessment? What is the role of fault interaction in long-term seismicity forecasts? How can the time-space variability of earthquakes in these regions be modeled? How can we integrate GPS data and physics-based models in the future seismic hazard assessment? In this session we welcome contributions that improve our understanding of seismogenesis and seismic hazard in regions of distributed and low deformation. We welcome theoretical, observational, and numerical contributions from a broad range of disciplines, including field geology, structural geology, seismology, geodesy, rheology, crustal stress, geodynamics and seismic hazard assessment.

S23 EXPERIMENTAL MARKERS AND PHYSICAL MODELLING OF GEODYNAMIC PROCESSES

Conveners
Barbara Orecchio, Università degli Studi di Messina, orecchio@unime.it; Anna Maria Marotta, Università degli Studi di Milano, anna.maria.marotta@unimi.it

Experimental data and observations such as GPS measurements of crustal motions, earthquake locations and focal mechanisms, fault activity and local geology, are commonly used to infer space-time distributions of tectonic stress and strain in the Earth's lithosphere. These distributions lead to identify geodynamic processes acting as sources of the observed deformation patterns. Different methods and procedures are adopted for solving this inverse problem, such as the Finite Element Modelling of the dynamics of the crust-mantle system under assigned tectonic boundary conditions. This Session aims at opening a wide discussion on the most recent developments of this geodynamic theme, stimulating the presentation of contributions concerning the different aspects of the problem, from collection of geophysical and geological experimental data to physical modelling of lithospheric deformation processes. Analyses of data and processes carried out in the Euro-Mediterranean region are primarily expected (given also the context of the Assembly) but contributions focusing on different regions are also strongly welcome.

S24 PHYSICAL AND STATISTICAL MODELS FOR FORESHOCKS, AFTERSHOCKS AND MULTIPLETS AT DIFFERENT SCALES, FROM LABORATORY EXPERIMENTS TO REAL-SCALE OBSERVATIONS.

Conveners
Stefania Gentili, INOGS, Centro Ricerche Sismologiche, Italy, sgentili@inogs.it; Rita DiGiovambattista, Istituto Nazionale di geofisica e Vulcanologia, Italy, rita.digiovambattista@ingv.it; Filippos Vallianatos, Technological Educational Institute of Crete, fvallian@chania.teicrete.gr

Seismicity can occur with great spatio-temporal variability, dominated by background activity or several kinds of earthquake clusters, from swarm-like to burst-like types. In many regions where complex fault systems exist, clusters are characterized by multiple mainshock sequences, with the mainshock followed by large aftershocks.

Foreshock occurrence is still poorly understood: some events are preceded by significant foreshock activity, others occur suddenly. In this session, we invite researchers to present the latest results on physical and statistical models for foreshocks, aftershocks and multiplets, including experimental results based on laboratory experiments on rock fracture and friction, along with theoretical and numerical models, methods for seismic hazard analysis related to the complex patterns of seismicity and their statistical properties. A persistent behaviour of the seismicity and cluster properties has been observed in some seismotectonic areas. Topics to assess the variation of seismicity style with a characterization of geological/tectonic conditions are strongly encouraged.

S25 ADVANCES IN ARRAY BASED STUDIES OF SEISMIC SOURCES

Conveners

Keith D. Koper, University of Utah, Utah 84016, USA,koper@seis.utah.edu; Johannes Schweitzer, NORSAR, Norway, johannes@norsar.no

Compared to a single seismometer, a seismic array provides enhanced signal-to-noise ratio and strong constraints on the direction of incoming seismic energy. Historically, these properties have made arrays useful for detecting and locating small seismic events, and seismic arrays are a critical component of the International Monitoring System that operates in support of the Comprehensive Nuclear Test-Ban Treaty. In recent years, the number and density of seismic stations have increased and new applications of array seismology have emerged such as imaging the rupture properties of large earthquakes with back-projection. In this session, we invite presentations on new advances in array processing and the use of arrays to better understand all types of seismic sources, including tectonic earthquakes, induced earthquakes, landslides, explosions, and microseisms.

S26 COMPUTATIONAL SEISMOLOGY. TECHNICAL IMPLEMENTATIONS, ETHICAL CONSIDERATIONS

Conveners

Christopher Dimech, SMRG, University of Malta, dimech.christopher@gmail.com; Cristiana Sebu, Department of Mathematics, University of Malta
Sinan Mehmet Ozeren, Eurasia Institute of Earth Sciences, ITU

Several aspects of seismology, as well as our knowledge of the Earth, have advanced rapidly in recent years in parallel with advances in computational facilities and resources. This session aims to explore recent innovative developments in computational techniques, numerical solution of classical and new seismology problems, and the use of High Performance Computing. We invite submissions related, but not limited to numerical inversion problems in seismology big data and HPC full waveform inversion and its computational implications advances in wave propagation computations. In this session we would also like to promote the use of Free Software. Most scientific endeavours operate as independent state, industrial or university units with little or no coordination between them. Seismology at all levels should use and teach the principles of Free Software (i.e., the values of freedom and cooperation and the principle of sharing) because it is the only way that fosters a community of goodwill, cooperation, and collaboration, not only for those actively working, but also for attracting new people. This session strongly encourages the free software philosophy and the following types of presentation:

- Projects that integrate the distribution of datasets, software and documentation in their release;
- Advances in the distribution of computational techniques beneficial to seismologists wishing to use, distribute, study, extend to do more jobs or adapt to new needs;
- Discourses that detail functional computations of value to seismologists; Research investigating the effectiveness of computational resources.

S27 10 YEARS OF SEISCOMP3

Conveners

Joachim Saul and Winfried Hanka, GFZ Potsdam,saul@gfz-potsdam.de; Bernd Weber and Dirk Rössler, gempa GmbH
John Clinton, SED, ETH Zuerich
Jean-Marie Saurel, IPGP

SeisComP3 is an open-source, end-to-end, seismological software package. It consists of modules that span data acquisition, re-distribution and archival, automatic event detection, characterization, and notification, as well as interactive analysis. Most functionality is available as C++ libraries together with Python wrappers. SeisComP3 supports FDSN standards like MiniSEED, StationXML, QuakeML and webservices and the transmission standard SeedLink. SeisComP3 was originally developed by GFZ Potsdam for the German-Indonesian Tsunami Warning System (GITEWS). It is now maintained and developed by GFZ Potsdam and gempa GmbH. Over the years, a vigorous user community has formed, who also contribute modules to SeisComP3 that compliment the existing framework, like tools for ShakeMaps or Earthquake Early Warning. Comprehensive documentation is provided online. User support is available via a web forum with currently more than 250 users from all over the world. SeisComP3 is used as the primary earthquake monitoring software by several dozens of networks monitoring local, regional and global seismicity across the globe. Primarily a solution for real-time monitoring and data distribution, it is increasingly being used to generate earthquake catalogues for off-line analysis, e.g. from temporary experiments. 10 years ago SeisComP3 was released as a public package. The anniversary is an opportunity to bring together users, developers and interested parties. In this session we invite contributions from all fields related to SeisComP3, including scientists using the software for data analysis and data centers using it for data handling and distribution. We also welcome contributions about possible challenges facing the SeisComP3 community, and discussion on further improvements.

S28 APPLICATIONS AND DEVELOPMENTS IN AMBIENT NOISE SEISMOLOGY

Conveners
Andrea Cannata, Dipartimento di Fisica e Geologia, Università di Perugia, andrea.cannata@unipg.it; Flavio Cannavò, INGV, flavio.cannavo@ingv.it; Raphaël De Plaen, Faculté des Sciences, Université du Luxembourg, raphael.deplaen@uni.lu; Anne Obermann, ETH, anne.obermann@sed.ethz.ch

In the absence of earthquakes and other strong seismic signals, the Earth surface is not static but constantly vibrating due to many continuous noise sources such as ocean waves, storms and anthropic activities, generating the so-called ambient seismic noise. Ambient seismic noise has proven to be a valuable tool for imaging the earth at different scales via surface and body wave tomographies. The continuity and reproducibility of ambient noise correlations, make them an excellent candidate for the monitoring of crustal properties, which has found applications ranging from volcano monitoring, dynamic recovery processes of earthquakes to civil engineering. The energy source for most applications is the microseism. The microseism sources are closely related to ocean wave energy coupling with the Earth's motion and have today broad applications, among which the investigation on atmosphere-hydrosphere-cryosphere-solid earth interactions, to make also inferences on climate changes. In this session, we welcome contributions focused on ambient noise seismology. We invite contributions concerning multi-scale applications of seismic noise interferometry, such as imaging structure and monitoring subsurface changes. We are also enthusiastic to receive studies on the sources of ambient seismic noise (i.e. microseisms, hum, microbaroms), their generation processes, and their applications on the investigation of atmosphere-hydrosphere-cryosphere-solid earth interactions. This extends also to methodological and more theoretical approaches (i.e. role of scattering, alternative processing techniques).

S29 Advances in seismic site response and microzonation for improving the resilience of urban centers

Conveners
Giovanna Laurenzano, INOGS, Italy, glaurenzano@inogs.it; Alessandro Pagliaroli, University of Chieti-Pescara, Italy, alessandro.pagliaroli@unich.it; Marco Pilz, Helmholtz Center Potsdam, Germany, pilz@gfz-potsdam.de; Giovanna Vessia, University of Chieti-Pescara, Italy, g.vessia@unich.it; Rajib Biswas, Tezpur University, India, rajivb27@gmail.com Nilutpal Bora, Tezpur University, India

Realistic and robust ground motion estimation for future earthquakes is one of the most challenging

problems in seismology and earthquake engineering. In particular, the influence of the local site conditions has been shown to be particularly important for quantifying the level of ground motion. The differences, commonly up to 3 degrees of seismic intensity, that are detected at nearby sites (a few hundred of meters) are today recognized as the resultant of the seismic impedance contrasts among soil strata and the bedrock, buried basin or articulated geometries of the underground formations and the topographic effects combined with the seismic behavior of out-of-ground structures. These effects can strongly affect ground motion amplitude, duration and frequency content, producing highly-variable ground motion levels. The quantitative and reliable assessment of those phenomena is required for potential future events in a specific zone, for seismic hazard and seismic risk mitigation. Although site effects have been deeply studied over past decades, several scientific and engineering issues remain unsatisfactorily answered. An open issue is still debated that is how to represent the local seismic response by means of homogeneous areas for planning purposes named microzoning studies. This session aims collecting contributions of recent advances regarding local site effects (basin resonance, topographic effects, nonlinearity, soil liquefaction, slope instability, scattering effects) and corresponding microzonation activities. Multi-disciplinary investigations, including a range of multi-hazard estimation of local amplification, slope instability or liquefaction phenomena and laboratory testing, are further encouraged. We also welcome contributions with a special focus of site effect studies for long-term urban planning, land planning and also for emergency management.

S30 From source to site: understanding and modelling high-frequency attenuation of earthquake ground motion.

Conveners
Olga-Joan Ktenidou, Department of Engineering Science, University of Greenwich, UK, olga.ktenidou@gmail.com; Chris Van Houtte, GNS Science, New Zealand, skykkur@hi.is Benedikt Halldorsson, University of Iceland & Geoscience Research Group, c.vanhoutte@gns.cri.nz

In this session, we would like to bring together the seismological and engineering communities to discuss high-frequency ground motion and its attenuation, as it may have significant impact on engineering design. Understanding and modelling ground motion at high frequencies is becoming an important issue in seismic hazard assessment and site-specific hazard, especially for critical facilities, where seismic response at 5-20 Hz may be crucial. Physics-based broadband simulations have been attempting to reach higher frequencies than ever before, while the empirical high-frequency attenuation factor kappa is gaining visibility. We welcome contributions related to modelling, be it physics-based or empirical, as well as spectral analysis studies and simulations that may shed light on the nature of high-frequency attenuation of earthquake ground motion, in particular parameter trade-offs and the relative contributions of source/path/site on high-frequency motions. Topics of interest include fmax, kappa, crustal attenuation, Q, site effects and the rock site characterisation. The origin and physical components of kappa and fmax are still objects of debate, as are the relative effects of damping and scattering. Finally, the effect of high-frequency attenuation and its uncertainty on ground motion models and their adjustment is a very pertinent and timely question, particularly for moderate-to-low seismicity regions. This session therefore also welcomes results and experiences from recent projects that dealt with such issues.

S31 New Techniques and Technologies in Earthquake Engineering

Conveners
Aleksandra Bogdanovic, Institute of Earthquake Engineering and Seismology, Skopje; Marta Stojmanovska,Institute of Earthquake Engineering and Seismology, Skopje, saska@pluto.iziis.ukim.edu.mk

Recent seismic events emphasize the importance of introducing new technologies and techniques as a best solution for achieving substantially earthquake resistant structures. The experience has shown that high seismic performance cannot be expected from the conventionally designed and constructed buildings. Therefore, new technologies and techniques that provide dissipation of energy without structural damages

are required in seismic prone regions.The main purpose of the session is to bring together researchers with diverse backgrounds, academic staff, post-graduate students, professional engineers, who are interested in the behavior of objects and structures during earthquakes. The session will cover all aspects of up-to-date earthquake engineering such as new materials, structural control and health monitoring, experimental studies, soil structure interaction, laboratory and field testing

S32 Induced and triggered seismicity: observations, modelling, monitoring, discrimination and risk management strategies (Joint ESC / SSA)

Conveners
Enrico Priolo, OGS, Italy, epriolo@inogs.it Tony Alfredo Stabile, IMAA-CNR, Italy, tony.stabile@imaa.cnr.it; Simone Cesca, GFZ, Germany, cesca@gfz-potsdam.de Leo Eisner, Seismik s.r.o., Czech Republic), leo@irsm.cas.cz; William Ellsworth, Stanford Univ., USA, wellsworth@stanford.edu Kristine Pankow, University of Utah, USA, pankow@seis.utah.edu; Manfred Joswig, Stuttgart Univ., Germany, manfred@m-joswig.de Antonio Pio Rinaldi, ETH, Switzerland, antoniopio.rinaldi@sed.ethz.ch

It is well known that industrial activities related to development and production of energy have the potential to induce minor seismicity or trigger larger earthquakes. This is a global phenomenon with implications for seismic hazard and risk, and real concern exists about larger earthquakes that might be triggered by industrial activities especially in densely populated areas. In addition to human-induced seismicity, there are also natural induced earthquakes that occur in response to naturally driven stress perturbations such as seismic waves, tidal stressing, and volcanic processes. Public and regulatory concerns about the potential hazard from induced earthquakes continues to evolve in response to a deepening scientific understanding of the underlying mechanisms and improvements to probabilistic seismic hazard models. There is a growing understanding that taking steps to reduce the hazard can mitigate the risk. Consequently, guidelines for monitoring are being revised and improved. This session focuses on theoretical, experimental and observational advances in understanding, detecting, discriminating the seismicity induced or triggered by hydrocarbon exploitation, mining, geothermal development and other industrial operations, as well as hazard management strategies for reducing the risk. Topics related to fluid induced and triggered seismicity in other research areas are also of interest. We welcome contributions on advances in seismic and deformation monitoring; analysis and modelling of induced and triggered seismicity at different spatial and temporal scales; laboratory experiments; discrimination between natural, triggered and induced seismicity; multidisciplinary studies combining different data types and observations; assessment of seismic hazard and mitigation of the seismic risk in areas where such activities are carried out; existing regulations and new policy directions; and public perception and concern. The session will be organized into two main subtopics: 1) observations, physical mechanisms and modelling; 2) monitoring, discrimination, and risk management strategies. Furthermore, the session will include some selected/invited presentations of 20 minutes net length, one of them assigned to a young researcher. Therefore, we particularly appreciate contributions from early career scientists.

S33 Advances in single station and array methods for subsurface characterization

Convenors
Agostiny Marrios Lontsi, ETH Zurich, alontsi@ethz.ch; Manuel Thomas Hobiger, ETH Zurich, manuel.hobiger@sed.ethz.ch; Cecile Cornou, ISTerre, France, cecile.cornou@univ-grenoble-alpes.fr

The use of ambient seismic noise has significantly increased over the last decades. Controlled source signals are also widely used and can complement ambient noise measurements. Taking advantage of the large wavelength range of these signals, the subsurface structure can be investigated in a broad depth range from few meters to several hundreds of meters. The analysis of the subsurface structure of the Earth is a necessary step towards mitigating natural hazards such as earthquake, landslide, instable rock slopes, or non-linear site behavior such as liquefaction. However, the approach is not limited to the

Earth's solid surface, but can also be applied in marine or lake environments, on the Lunar surface or, in the context of the forthcoming InSight mission, on Mars. We invite contributions that address single-station and/or array data modeling, processing and applications. Methods may range from:

1. Single-station methods, e.g. microtremor horizontal-to-vertical (H/V) spectral ratio, ellipticity estimation, receiver functions, transfer functions;
2. Array methods using single- or multi-component data processing (passive or active sources), e.g. frequency-wavenumber, spatial autocorelation, Multichannel Analysis of Surface Waves (MASW), Interferometric-MASW;

Any combination of (1) and (2) and innovative techniques. Methods based on the Diffuse Wakefield approach or using cross-correlation techniques are also welcome, as well as any contribution concentrating on the inversion of any of the aforementioned methods on any depth-scale range.

S34 Developments in Strong Motion Seismology, a COSMOS Session

Conveners
Robert Nigbor, COSMOS, nigbor@ucla.edu Jamison Steidl, COSMOS and University of California at Santa Barbara, jamie.steidl@ucsb.edu; Alan Yong, U.S. Geological Survey, yong@usgs.gov

The strong motion end of the seismological data spectrum continues to be primary for earthquake engineering and applied seismology. Availability and reliability of strong ground motion recordings continue to be important for mitigating seismic hazards. COSMOS, the Consortium of Organizations for Strong Motion Observation Systems, serves as a consortium through which international programs and institutions can address mutual problems with strong-motion measurements, data, and data dissemination. This COSMOS-organized session brings together a wide variety of topics on the advances and limitations of current state-of-art and -practice on monitoring and disseminating earthquake-induced ground motion data. Our purpose is to promote discussions that bridge the gap between operators of seismic networks and the researchers and applied practitioners of seismic hazards analyses. We encourage presentations on the state-of-the-practice and new developments in strong motion network operations and data utilization. Specific topics of interest include, but are not limited to: instrumentation, station site characterization and metadata, data archiving, and data mining. After the selected presentations we will have an open discussion regarding the overall state of knowledge and priorities for advancing the state-of-art in strong motion seismology.

S35 Tsunamis in Europe and Worldwide: Observations, Theory and Numerical Analyses for Hazard and Risk Assessment and Risk Reduction

Conveners
Andrey Babeyko GFZ babeyko@gfz-potsdam.de Stefano Lorito INGV stefano.lorito@ingv.it Öcal Necmioğlu KOERI ocal.necmioglu@boun.edu.tr; Gerassimos Papadopoulos NOA papadop@noa.gr; Fabrizio Romano INGV fabrizio.romano@ingv.it; Alexander Rudloff GFZ rudloff@gfz-potsdam.de

A surge of great earthquakes worldwide in the last fifteen years has caused a significant number of damaging tsunamis, some of which will be remembered among the worst natural disasters ever occurred. This has been a grave natural warning that tsunami risk should not be underestimated but, at the same time, these events offered a number of clues for a deeper understanding of tsunami generation, propagation and impact mechanisms. In response, the continuously growing interdisciplinary tsunami science community has put an unprecedented effort in: understanding tsunami physics, addressing tsunami hazard and risk, and contributing to tsunami risk reduction primarily through the development of regional and national tsunami warning systems, input to long-term coastal planning and public awareness raising. This session aims to gather tsunami scientists in the broad sense, and we encourage contributions on all the themes ranging from fundamental tsunami science, through case-studies worldwide, towards hazard- risk- and early warning methodologies. Contributions concerning tsunamis in Europe will be particularly welcome. Reports on the 2017 moderate tsunamis in Greece and Turkey as well as progress reports on NEAMTWS are also especially encouraged.

S36 Cultural Heritage and Earthquakes: case studies, issues and new challenges

Conveners
Laura Pecchioli, Technical University of Berlin, l.pecchioli@campus.tu-berlin.de; Valerio Poggi, GEM) Foundation, Pavia, Italy, valerio.poggi@globalquakemodel.org; Francesco Panzera, University of Catania, Italy, panzerafrancesco@hotmail.it; Giovanni Cangi, ITABC-CNR, Rome, Italy, ingcangi@tiscali.it

Historical sites, monuments and constructions of architectural importance are part of the world's cultural heritage and are of unquestionable value for our society. As with every element in the built environment, these are particularly vulnerable to extreme natural events such as earthquakes and their associated secondary effects (landslides, ground fractures, tsunamis). Recent earthquakes in Italy, Turkey and Greece (e.g. Umbria-Marche 1997, Izmit and Duzce 1999, Central Italy 2016, Kos 2017) have emphasized the increased need for mitigation actions to preserve the vast cultural and historic heritage from natural disasters. However, targeted measures are not sufficient, as it has been demonstrated, unless they are coordinated into common Disaster Risk Reduction (DRR) policies. Moreover, to fully address the modality of the damaging process, a multidisciplinary approach involving complementary research fields is essential. For this session, we encourage original contributions from a wide range of topics that are common grounds of interest between engineering seismologists, earthquake engineers, architects, geologists and historians. In particular, we invite professional and early career scientists (students and Post Docs), who are engaged in the preservation of sites, buildings and monuments of cultural and historical heritage, to contribute with novel ideas and recent case studies. This might include, but is not limited to, the following areas:
Protection and conservation of monuments and archaeological sites; Integration of archaeoseismology in Site Management (preservation in-situ, display of excavated sites), as a mean for establishing a local earthquake culture; Advances in site-specific seismic hazard, including local response analysis and new geophysical techniques for site characterization;
Analysis of historical, pre-instrumental and archaeological records, by investigation of existing historical buildings and archaeological sites, to extend the seismic history of critical regions; Methods, principles, norms and technologies for the seismic retrofit of ancient structures to mitigate the effect of future earthquakes; Numerical modeling and simulation of ground motion and the damaging process; Possible actions to be taken by architects and engineers prior to the occurrence of an earthquake as well as procedures post-earthquake (reconnaissance reports and damage assessment); modalities of intervention; Case studies on urban hazard and risk studies for sites of scientific relevance. In light of the value to our modern societies, it is our responsibility to preserve the existing cultural and built heritage using state-of-the art science, knowledge and information, and to limit the extent and severity of acceptable interventions.

S37 Open questions in (European) Historical earthquake research

Conveners
Andrea Rovida, INGV, Milano, andrea.rovida@ingv.it; Christa Hammerl, ZAMG – Austria; christa.hammerl@zamg.ac.at

In the last decades the quality of historical earthquake research has improved dramatically. Nevertheless, there are still numerous aspects that should be worked out and faced. As such aspects have been of course frequently discussed, the session focusses on how do historical seismologists deal with any of the problems they encounter in their researches. In practice, intensity assessment for historical earthquakes sometimes still poses questions, such as how to deal with single intensity points, or with the intensity estimation of single earthquakes in a sequence. The conversion of the different macroseismic scales to the EMS-98 is another point of discussion and whether it has any impact on catalogues. An old question – but still a question – deals with the homogeneity of European earthquake catalogues. The interest of end-users in natural phenomena induced by past earthquakes (liquefaction, landslides, tsunamis) is increasing and, through the calibration of paleo- and historical earthquakes, it might represent the point of contact between Paleoseismology and Historical Seismology, which is another open question. Finally, a further calibrating approach for paelo- and/or historical earthquakes would be the use of ShakeMaps. Moreover, ShakeMaps may

help in dealing with problems such as single intensity point events, outlier identification, etc. Contributions referring to all these topics, as well as to any related one, are welcome in accordance with the scope of the ESC Working Group 01-12 "Archive of historical earthquake data for the European-Mediterranean area".

S38 Complexity measures of seismic catalogs and recordings

Conveners

Conviners: Filippos Vallianatos: Technological Educational Institute of Crete, fvallian@chania.teicrete.gr; Luciano Telesca: Institute of Methodologies for Environmental Analysis, National Research Council, Italy, luciano.telesca@imaa.cnr.it; Tamaz Chelidze:, M.Nodia Institute of Geophysics, , Georgia, tamaz.chelidze@gmail.com

Both major experimental seismic data bases– seismic catalogs and seismic recordings of Earth vibrations contain a plethora of important information that cannot be obtained by traditional statistical methods. Seismic catalogs contain both correlated and non-correlated component: only the former one is used in probabilistic seismic hazard assessment (PSHA). The correlated component is practically excluded from analysis, though it contains information on the time-dependence of seismic process, which is important for earthquake forecast. New tools of nonlinear dynamics reveal in both seismic catalogs and recordings many hidden time structures with different levels of ordering – from colored noise to chaos. It seems important to apply these tools to earthquake catalogs and recordings to reveal hidden nonlinear structures in seismic data bases, which can lead to significant progress in understanding complex seismic process.

S39 Knowledge Bases About Past Earthquakes Consequences

Conveners

Nina Frolova, Seismological Center of IGE, RAS, Moscow, Russia, frolova@esrc.ru; Li Guoqing, Institute of Remote Sensing and Digital Earth, CAS, Beijing, China Robin Spence, Cambridge Architectural Research Ltd, London, UK Virginia Murray, Public Health England, London, UK

The efforts to collect data on past earthquakes and other natural hazards consequences was primarily made by insurance and reinsurance companies, as well as some universities and individual scientists. Since 2000 Center for Research of Epidemiology of Disasters in Brussels maintain the international disaster database, including earthquakes. Still these data can't be directly used for calibration of analytical loss models' of the systems assigned for near real time loss computation. At present GEM and some other data bases which are under development may be used for these purposes. Such efforts are aimed at increasing the reliability of social and economic loss estimations just after the strong earthquake. The goal of inter-disciplinary session is to summarise different factors affecting on the reliability of near real time loss estimations and identify the way to minimize their ifluence. We are interested in contributions devoted to macroseismic datasets and information on engineering analysis of strong earthquake cosequences occured in diffrent countries. This applies to the whole range of topics, starting from database issues and set of guidelines for data collection, data base contents and formats, questionnaires and thumbnails, all the way to multi-hazard approach. The important aim of this session is to explore ways in which the datasets on earthquake consequences from different countries and institutions could possibly be merged, and to what extent these data should be harmonized, as well as to discuss different issues dealt with creation of distributed data base.

S40 Seismology and Society

Conveners

Nicos Melis, NOA, Greece, nmelis@noa.gr; Remy Bossu, EMSC, France, remy.bossu@cea.fr; Silvia Peppoloni, INGV, silvia.peppoloni@ingv.it; Giuseppe di Capua, INGV, , giuseppe.dicapua@ingv.it; Iain Stewart, Plymouth, UK, iain.stewart@plymouth.ac.uk; Graça Silveira, Lisbon, Portugal, mdsilveira@fc.ul.pt; Susana Custódio, Lisbon Portugal, susanacustodio@campus.ul.pt; Tataru Dragos ,INFP, Romania, dragos@infp.ro; Paul Denton, BGS, UK, pdenton@bgs.ac.uk

This session aims to bring together seismologists working in the fields of educational seismology, citizen seismology and geoethics. The common

theme being the process of communicating the science of seismology to non-specialists. Seismology has an important role to play in modern society and seismologists should be having two-way communications with a wide variety of stakeholders across all levels of society, encompassing schools, engineers, general public, other scientists, politicians and civil protection professionals. In educational seismology projects across the world practical studies of seismology can be used to enhance the scientific literacy not just within the school but also within the wider community through family interactions. Nowadays non-specialist citizens are becoming increasingly involved with the collection and dissemination of seismological information through a growing number of citizen seismology networks, maybe by reporting directly or indirectly felt effects or by instrument based programmes. This session aims to promote the discussion on social aspects involved in seismic risk communication and (geo)ethical implications. Improving the relationships between scientists, decision makers, and general public means to increase the resilience of the human communities, and to make seismologists more aware of the responsibility in conducting their activity.

S41 Earthquake risk perception, communication and mitigation strategies

Conveners
Elena Dell'Agnese, University of Milano-Bicocca, Italy, elena.dellagnese@gmail.com; Francesco De Pascale, University of Calabria, Italy, fr.depascale@gmail.com; Piero Farabollini, University of Camerino, piero.farabollini@unicam.it; Francesca Romana Lugeri, ISPRA/University of Camerino, francesca.lugeri@unicam.it; Fausto Marincioni, Marche Polytechnic University, Italy; Long Island University, U.S.A., fausto.marincioni@gmail.com Francesco Muto, University of Calabria, Italy;francesco.muto@unical.it

Risk and disasters are social constructs deriving from an unsustainable human-environment interaction. Earthquake hazard do not created damages and destruction; it is our vulnerability and exposure to such processes that creates the conditions of risk. There is nothing natural about an earthquake disaster, yet the common perception is that humans are victims of nature's extreme events. Moreover, the ability of a society to respond to earthquakes does not depend primarily on the emergency conditions created by the impact, but rather on the pre-disaster settings and circumstances. From the agricultural revolution onwards, humans have tried to free themselves from the control of nature by modeling the territory for his own benefit. This, on the one hand, has enabled the social development we enjoy today, yet, on the other, the interaction with natural processes we do not fully understand has created problems of exposure and vulnerability. The consequences went beyond the creation of risk conditions and caused profound changes in environmental cycles contributing to the current geographies of the Anthropocene. Recent earthquakes, including those in Italy and Iran, have unequivocally shown the dominant role of societal vulnerability in creating those disasters. The Mediterranean region, unceasingly affected by strong earthquakes and almost all type of known natural hazards, is very representative of these complex and multi-scale dynamics. From an examination of the dramatic events that have recently occurred in the central region of Italy, there emerges the need to provide the general public with correct and clear information on the complex scenario characterising this as well as another- country. Experience teaches us that tackling the subject of the prevention of risk and protection from danger (the avoidance of exposure) is very difficult. What is needed is a communicative strategy that informs the public of the characteristics of a territory (understood as a natural and cultural environment) and the relative operative dynamics, just as one should understand the anatomy and physiology of one's own body in order to manage and protect it in the best possible way. The proposers encourage abstracts discussing the multiple dimensions of earthquake risk reduction, including, but not limiting to, the following research lines:

- Risk communication and social perception;
- Prevention and population preparedness;
- Community based approach;
- Adaptive capacity;
- Representation of earthquakes in popular culture;
- New technologies for investigations of hazards and risk;
- Vulnerability reduction;

- Disaster governance.

The conveners are considering the publication of a special volume in the book series “Geographies of the Anthropocene” (Il Sileno).

S42 General Seismology

Conveners

Pauline Galea pauline.galea@um.edu.mt; Paivi Mantyniemi paivi.mantyniemi@helsinki.fi

This session is intended to cover any topic in seismology which may not be directly relevant to any of the other sessions. We welcome contributions dealing with seismicity and seismotectonics of regions in or outside the Euro-Mediterranean area, global and planetary seismology, novel ideas or improvements to conventional methodologies, theoretical or applied aspects of seismology, etc.

36thGA
ESC
MALTA
2018

SESSION 01

ESC2018-S1-38

MARCO'S CONTRIBUTION TO THE STUDY OF THE DYNAMIC PROPERTIES OF BUILDINGS IN MALTA

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Marco Mucciarelli was always a promoter of rapid, low-cost methods of measuring the dynamic properties of buildings, such as their fundamental frequencies, modal deformation and damping, with a view to assessing their seismic vulnerability. His scientific contributions at the interface of seismology and earthquake engineering have been very important in equipping several localities with efficient and reliable methodologies to integrate site response, soil-structure interaction and urban vulnerability into seismic risk assessments and microzonation, as well as to account for certain aspects of earthquake damage. In September 2013, Marco kindly accepted to lecture in a short course on "Seismic Hazard Analysis and Site Effects" organised at the University of Malta. With his usual enthusiasm, Marco insisted that we carry out a hands-on ambient noise survey of a building in Malta. We chose the highest apartment/office tower in Malta at the time – the Portomaso Tower in St. Julian's. The Portomaso tower is 23 storeys high (97.54 m), free-standing from the 8th floor upwards, built on bedrock and encompassing a three-level underground garage. Armed with three Tromino velocimeters, the participants recorded 20 minutes of ambient noise at each of the floors. The data was downloaded, and processed on the spot, in the foyer of the building, giving participants an excellent opportunity to understand the whole process. Here we present the results and further analysis of those measurements, including an insight into different vibrational modes of the tower, and implications about seismic vulnerability. This course led to a wider study of the dynamic properties of building typologies covering the Maltese archipelago, in particular the issue of buildings constructed on bedrock, typical of most of the eastern half of the archipelago, as opposed to buildings constructed on a clay layer geology, typical of the western half and of the island of Gozo. Height-period relationships prove to be very similar to ones in Eastern Sicily, Italy and the Balkans, obtained through similar methods, but highly different from relationships in other parts of the world and derived through different methodologies.

ESC2018-S1-51

THE IMPORTANCE OF BEING MARCO

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I want to talk about Marco's activities on science and risk communication and outreach, and how they impacted on me and on the group he directed during his last 4 years at OGS-Centro di Ricerche Sismologiche. Marco was able to transform pieces of life into topics for scientific journals. This was the case, for example, of the fun-quake, or a quake of the fans, one of his SRL papers, telling about the soccer world cup final in Berlin, in 2006. Italy and France were tied 1-1 after 120 minutes of regular and extra time of play, and he analysed the jumping Joy quake, recorded by the seismic station at the Basilicata University Campus, in Potenza at the final penalty shoot-out of the Italian team. He was capable in disseminating its results to a wide audience, putting experience and surprise in his job, such as when he went to Turkey just after the 1999 devastating Ismit earthquake, for recording and documenting the facts, with just a fancy car, cameras and some survival items. He was able to reduce the gap between science and ordinary people, such as when he used the digital signal of a seismographic station for recovering the truth about the facts for the Costa Concordia crash. Marco's skills in science communication emerged with age, like the qualities of exceptional wine. The TERSISCIO website he opened when he became a blogger in 2010 has more than 200 posts, more than 6 hundred thousand visualizations: some posts have lots of comments, and are constantly read and shared, for their clarity and simplicity. The IONONRISCHIO campaignshe co-promoted nowadays involve hundreds of teams of volunteers, and reach increasing amount of citizen and schools. He dedicated an incredible amount of time to science communication, not rewarded by career or financial reasons, because of his character; this is message I want to share with the colleagues who knew him, and not.

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ESC2018-S1-84

STUDY ON THE APPLICABILITY OF THE MICROTREMOR HVSR METHOD TO SUPPORT SEISMIC MICROZONATION IN THE TOWN OF IDRIJA (W SLOVENIA)

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The town of Idrija is located in an area with an increased seismic hazard in W Slovenia and is partly built on alluvial sediments or artificial mining and smelting deposits which can amplify seismic ground motion. There is a need to prepare a comprehensive seismic microzonation in the near future to support seismic hazard and risk assessment. To study the applicability of the microtremor Horizontal-to-Vertical Spectral Ratio (HVSR) method for this purpose, 70 free-field microtremor measurements were performed in a town area of 0.8 km2 with 50–200 m spacing between the points. The HVSR analysis has shown that it is possible to derive the sediments' resonance frequency at 48 points. With the remaining one third of the measurements, nearly flat HVSR curves were obtained, indicating a small or negligible impedance contrast with the seismological bedrock. The iso-frequency (a range of 2.5–19.5 Hz) and the HVSR peak amplitude (a range of 3–6, with a few larger values) maps were prepared using the natural neighbor interpolation algorithm and compared with the geological map and the map of artificial deposits. Surprisingly no clear correlation was found between the distribution of resonance frequencies or peak amplitudes and the known extent of the supposed "soft" sediments or deposits. This can be explained by relatively well-compacted and rather stiff deposits and the complex geometry of sedimentary bodies. However, at several individual locations it was possible to correlate the shape and amplitude of the HVSR curve with the known geological structure and prominent site effects were established in different places. In given conditions (very limited free space and a high level of noise) it would be difficult to perform an active seismic refraction or MASW measurements to investigate the S-waves velocity profiles and the thickness of sediments in detail, which would be representative enough for microzonation purposes. The importance of the microtremor method is therefore even greater, because it enables a direct estimation of the resonance frequency without knowing the internal structure and physical properties of the shallow subsurface. The results of this study can be directly used in analyses of the possible occurrence of soil-structure resonance of individual buildings, including important cultural heritage mining and other structures protected by UNESCO. Another application of the derived free-field iso-frequency map is to support soil classification according to the recent trends in building codes and to calibrate Vs profiles obtained from the microtremor array or geophysical measurements. This study strongly benefited from my long lasting and very fruitful cooperation with Marco Mucciarelli. He was the person who introduced me to the microtremor HVSR method and soil-structure resonance studies already 20 years ago in 1998 after the strong (M=5.6, Imax=VII-VIII EMS) earthquake in W Slovenia. Our cooperation was most intensive in years 2006-2010 through realisation of a very successful NATO Science for Pace and Security project 980857: Assessment of seismic site amplification and seismic building vulnerability in FYR of Macedonia, Croatia and Slovenia. It was further enhanced when Marco become a director of OGS Seismological Department in Trieste in 2012 through close cooperation of Slovenian and Friulian seismological networks and within Central and Eastern European Earthquake Research Network (CE3RN). With Marco's departure we lost a great colleague, a scientist, a teacher and a friend.

ESC2018-S1-91

THE IMPORTANCE OF BRINGING ENGINEERS AND SEISMOLOGISTS TOGETHER: MEMORIES OF DUBROVNIK

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Professor Marco Mucciarelli has always recognised the importance of, and has been a strong advocate for, close linkages between

earthquake engineers and seismologists. In September of 2007, an Advanced Research Workshop was organized on Marco's suggestion, as a follow-up to a NATO Science for Peace Project. It brought together 30 earthquake seismologists and engineers from 14 countries around the world, with the goal of helping to improve seismic safety. The workshop took place in Dubrovnik and was organised by Marco and Croatian project partners. It resulted in the Springer book "Increasing Seismic Safety by Combining Engineering Technologies and Seismological Data". This presentation will summarise the key questions addressed at the Dubrovnik meeting, a summary of progress made, and some of the outstanding questions that remain today. Important topics that were addressed included: 1) how can ambient noise data be used to characterise both soil and building response; 2) how to separate frequency decrease due to distributed or concentrated damage, time-varying building and soil behaviour; 3) what is the role of transients in ambient noise analysis; 4) what is the role of building-soil resonance in damage patterns; 5) how to understand soil and building non-linear behaviour? A few of the key, practical results from this meeting include: 1) suggested modifications to existing building codes for soil classification, and 2) simplified approaches to estimating building vulnerability and soil-building resonance for use in practise in cities. Results from this meeting have advanced both earthquake science and earthquake engineering. The science that resulted from this meeting was important – but just as important were the new linkages and partnerships that developed between seismologists and engineers from all corners of the world. Those partnerships continue to this day, thanks to Marco.

ESC2018-S1-105

PUBLIC RELEASE OF THE EXTENDED ISC-GEM GLOBAL INSTRUMENTAL EARTHQUAKE CATALOGUE 1904-2014 (VER. 5) AND PLANS FOR FURTHER ADVANCEMENT

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The first version of the ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009) (www.isc.ac.uk/iscgem/index.php) was released in January 2013 (Storchak et., 2013) after a 27-month project co-funded by the GEM Foundation. The catalogue was required to improve the homogeneity (to the largest extent possible, in time and space) of the earthquake parameters (especially location and magnitude) and list them along with formal uncertainties to facilitate seismic hazard and Earth's seismicity studies. The first release included earthquakes selected according to the following time-variable cut-off magnitudes: Ms=7.5 before 1918; Ms=6.25 during 1918-1963; and Ms=5.5 from 1964 onwards. Because of the importance of having a reliable seismic input for seismic hazard studies, funding from USGS, NSF, BGR, GEM and several commercial companies in the US, UK, Japan and Switzerland allowed us to start working on the extension of the ISC-GEM catalogue both for earthquakes that occurred after 2009 and historical earthquakes listed in the International Seismological Summary (ISS), which fell below the original ISC-GEM cut-off magnitude of 6.25 before 1964. At the end of a four-year project we present the updated ISC-GEM catalogue (Version 5) which includes over 2,500 more earthquakes during 2010-2014 and several thousands more between 1904 and 1959 as compared to the first version. We also discuss further plans to advance the catalogue's quality and completeness over different time periods. The ISC-GEM catalogue is useful to research of the patterns of global seismicity and for regional seismic hazard studies. The ISC-GEM catalogue also serves as a reference and calibration dataset for more homogeneous earthquake catalogues.

ESC2018-S1-141

ATTENUATION AND SITE EFFECTS IN DIFFERENT REGIONS OF ITALY

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We present a summary of attenuation and site effects studies made in different regions of Italy (Lombardia-Piemonte, Eastern Sicily, Friuli, Marche and Central Apennines) during the years 1992-2008. These investigations were conceived by Marco Mucciarelli and involved different seismological engineering and geological aspects. In particular, we will show results obtained using nonparametric attenuation functions (NAF) that describe how the spectral amplitudes of S waves decay with distance. We find that in the Central Apennines region the spectral amplitudes decay faster than in the other regions for all the frequencies analyzed, between 1 and 20 Hz. In the Lombardia and Eastern Sicily regions the amplitudes decay slower with distance indicating less seismic attenuation. We show estimates of Q calculated using these NAF for the region of Marche, Central Italy, and we compare the attenuation between P and S waves. We found that Qp = 108 f**0.7 for P waves and QSH = 86 f 0.7 for S waves. We also estimated S-wave Q in Southern Italy using data from the Basilicata network and found that QS = 32 f**1.7. In addition, we used a generalized spectral inversion technique (GIT) to analyze whether the vertical component of ground motion is amplification free, a common assumption used to estimate site effects (e.g. Nakamura Method). We determined site functions using the vertical component of the ground motion using records at sites with different geologic conditions. The site functions obtained show small vertical amplifications, mostly below a factor of 2. We also found that when the S wave window used to calculate the spectral amplitudes contain surface waves, the vertical amplification is significant and the spectral ratio technique will sub-estimate the site amplification. We also used the GIT to determine the characteristic frequency of vibration of two dams, one located in Arvo Lake, and the other in the lake Ampollino, both in the region of Calabria, Italy. These estimates were compared with the expected one-dimensional response of the dams and concluded that the GIT gives consistent results of the natural frequency of the structures analyzed.

ESC2018-S1-151

EARTHQUAKE RISK MITIGATION: LESSONS FROM THE FIELD

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The contribution of post-earthquake field missions in the mitigation of seismic risk is the main topic of the present contribution. As a real “open air” laboratory, the place of a damaging earthquake certainly provides important lessons. But, are the lessons suitably identified? And, consequently, learned ? Further, are the lessons put in practice? These are crucial questions, especially if we look at the dramatic consequences that earthquakes still cause around the world, frequently despite their low intensity. To this regard, lessons provided and, in some cases learned, from recent Italian earthquakes are shortly reported. Specifically, some examples relevant to the 1997 Umbria-Marche earthquake, the 2002 San Giuliano (Molise) earthquake, the 2009 L’Aquila earthquake, the 2012 Emilia earthquake and, finally, the recent seismic sequence that hit large areas of Central Italy in 2016 and 2017, are discussed. Further, lessons learned need to be disseminated and, above all, applied. To this end, crucial is the role of citizens. About that, the role of communication activities to inform common people turns out to be quite important. A prominent example of such activities is the Italian Communication Campaign on natural risks “I do not take risks” (http://iononrischio.protezionecivile.it/). The campaign was purposely designed to transfer information on risk mitigation to civil protection volunteers and common people, with the main objective of enhancing the self-protection capability: what everyone can do and what not to do to reduce the consequences of earthquakes. The contribution of Marco Mucciarelli to the activities above described, as a researcher, as a volunteer, and, finally, as a man of the Civil Protection System, has been great and unforgettable. Besides, the interaction between the communities of seismologists and engineers got a big boost from his work.

ESC2018-S1-158

IN MEMORY OF MARCOS MUCCIARELLI AND HIS CONTRIBUTIONS TO THE DEVELOPMENT OF THE COSMOS INTERNATIONAL GUIDELINES FOR APPLYING NONINVASIVE GEOPHYSICAL TECHNIQUES TO CHARACTERIZE SEISMIC SITE CONDITIONS (INVITED)

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In his career, Dr. Marcos Mucciarelli (1960 – 2016) actively conducted seismic site effects studies, as well energetically supported similar efforts, to assess near-surface geological conditions that are an important part of any seismic hazard assessment. Traditional invasive downhole methods directly measure shear-wave velocity (VS), a primary indicator of seismic site amplification. Those methods, however, are often costly and/or environmentally prohibitive. Moreover, their results do not always reflect the lateral variability of seismic conditions beyond the immediate vicinity of the test site. In comparison, noninvasive methods record active- or passive-source data consisting of surface- or body-waves and are less prohibitive to employ. Further, these methods use multiple horizontally-spaced surface receivers, thus lateral variability beneath the array is accounted for in their results. Most noninvasive methods, however, indirectly measure VS, and thus have inherent uncertainties. Despite this issue, the use of noninvasive methods continues to gain popularity. As the research community works to improve and understand uncertainties in noninvasive methods, a select group of developers and practitioners came together to develop guidelines for best-practices when applying noninvasive techniques to characterize seismic site conditions. To support this effort, the Consortium of Organizations for Strong Motion Observation Systems (COSMOS) established the COSMOS Guidelines Development Facilitation Committee, which included Dr. Mucciarelli as a key founding member. With help from Dr. Mucciarelli (2015 – 2016), COSMOS hosted multiple workshops to facilitate progress in the development of the guidelines; the most notable workshop being the 2016 35th European Seismological Commission General Assembly in Trieste, Italy, where Dr. Mucciarelli was Chair of the Local Organizational Committee. Other workshops have followed, including the 2017 16th World Conference on Earthquake Engineering in Santiago, Chile. The project, thus far, has established topical subcommittees, drafted several papers, and developed studies to assess the uncertainties associated with noninvasive methods. This COSMOS effort owes a debt of gratitude to Dr. Mucciarelli for his energetic support during the initial formative period of the ambitious project.

ESC2018-S1-305

K0: ORIGIN AND USABILITY

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In 2006, together with Marco, we started the analysis of borehole data collected at the Tito test site for estimating the quality factor in the very shallow geological layers. Since then, I focused part of my research activity on this subject and in particular on the estimation (and its reliability) of k. Recent studies have focused on the analysis of the nature of k0, the term that is generally considered to be representative of the attenuation below a site, and its application for improving seismic hazard assessment. It follows that a better understanding of the nature of k0 (what does it exactly represent) and therefore of its correct application for improving the estimation of local shaking is mandatory. In this study, by means of the numerical simulation of vertically incident SH waves, I set out to clarify the contribution of the intrinsic attenuation and the transmission of the media within different portions of the seismic signal and, in particular, within time windows similar to what generally used for real data analysis. Numerical simulations were carried out using models with constant or increasing with depth velocities, that are perturbed with increasing random vertical impedance contrasts. The analysis allows us to quantify, for the analyzed situation, the apparent attenuation related to the transmission part and to outline the variability of the results depending on the chosen window of signal. Finally, an example of this method's application to real data collected from an array of borehole sensors is used to show some possible limits arising when k0 is adopted for correcting ground motion estimation from bedrock to the surface.

ESC2018-S1-437

CORRELATIONS BETWEEN MACROSEISMIC AND INSTRUMENTAL MEASURES OF SEISMIC INTENSITY

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In this paper correlations between macroseismic and instrumental measures of seismic intensity have been developed. Starting from past studies (Margottini et al., 1992; Faccioli and Cauzzi, 2006; Chiauzzi et al., 2012) and adopting more detailed database, the relationships between Housner Intensity and both EMS-98 and MCS macroseismic scales have been carried out. The database consisted of 192 records (574 time histories related to NS, EW and Z components) derived from 31 earthquakes occurred mainly in Italy in the last 40 years (from 1980 to 2017). The strong motion recordings have been selected from the Italian Accelerometric Archive (ITACA) and the European Strong-Motion Database (ESD). Instead, macroseismic intensity values have been selected from past studies and historical catalogues and QUEST. The database mostly contained Italian earthquakes with a known macroseismic local intensity estimated in areas close to the accelerometric station. In order to define the relationships between Housner intensity and macroseismic scales, two different databases have been achieved considering seismograms recorded in the same local areas where EMS-98 or MCS macroseismic intensity values are available, respectively. Then, for each available seismogram, the ground motion parameters have been computed through accurate procedures. Housner intensity (IH) has been selected because is more suitable parameter to correlate the severity of seismic events with building damage (Masi et al., 2011; Masi, 2003). Moreover, an accurate statistical analysis based on "Bootstrap Method" (Efron, 1979) has been carried out considering database in terms of Housner and macroseismic intensity. The main goal of these relationships is to take information about historical earthquakes and/or to define the relevant values of ground motion parameters starting from the knowledge of local macroseismic intensity in a damaged area and viceversa. Furthermore it is possible define shake maps in terms of expected macroseismic intensity or convert macroseismic catalogs, in MCS scale, in terms of instrumental values to achieve hazard maps. The correlations can be also applied to define the seismic severity of earthquake shaking scenarios in terms of EMS-98 macroseismic intensity which is suitable as seismic input in the empirical building damage estimation models. Finally, the relationships between macroseismic intensity scales and instrumental parameters represent useful tools in risk analysis and scenario studies in order to reduce the impact of future earthquakes.

ESC2018-S1-484

HOW INTERNATIONAL COOPERATION CHANGED ENGINEERING SEISMOLOGY IN CROATIA

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In December 2003 I received an e-mail from Prof. Marco Mucciarelli introducing himself, and offering a cooperation on preparation of proposal for the NATO SfP grant to perform seismic microzonation studies or geophysical surveys using microtremors, which I gladly accepted. Although we used ambient noise for site investigation for decades, our techniques and instruments were quite outdated. Eventually, the project 'Assessment of Seismic Site Amplification and Seismic Building Vulnerability in the former Yugoslav Republic of Macedonia, Croatia and Slovenia' was awarded in 2004, in largest part thanks to Marco's initiative and efforts. The benefits were numerous: each project partner obtained state-of-the art portable pool of instruments for ambient noise recording, new techniques and software were introduced, and lasting cooperations were established. Within the project, each partner performed and analysed hundreds of measurements both in free-field and in buildings. Upon successful completion of the project, Marco suggested that we apply for funds for a NATO Advanced Research Workshop (ARW). This application was also successful and 30 world renown experts met in Dubrovnik (Croatia) in September 2007. Their contributions were subsequently published (again on Marco's initiative!) in a Springer book, well received by the research community. The know-how and experience acquired over the period 2004-2007 was subsequently built upon, and resulted in a number of ambient noise related studies in Croatia. Only a few will be mentioned – the microzonations of Zagreb and Ston, field-campaigns in Dubrovnik, and a large set of measurements in buildings all over Croatia. The

microzonation studies provided important data characterizing seismic response of shallow structures to earthquake excitation. The measurements in buildings resulted in a large database of building free-frequencies and damping, also suggesting which buildings are potentially prone to soil-structure resonance. Some of the results were also incorporated into the Croatian National Annex to Eurocode 8. In retrospective, it is clear that Marco's inexhaustible energy, enthusiasm, love for science and open-hearted cooperation were among the key ingredients that opened new perspectives for Croatian engineering seismology.

ESC2018-S1-546

ARMONIA: TOWARDS HARMONIZATION OF STRONG MOTION NETWORKS BETWEEN NORTHEASTERN ITALY AND AUSTRIA

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The Southeastern Alps corresponds to the northernmost part of the Adriatic microplate which in this sector collides and rotates anticlockwise with respect to the Eurasian plate. As a consequence, the area, a seismically active region in particular the pre-Alpine belt, has a high seismic hazard, with an expected maximum acceleration for an exceedance probability of 10% in 50 years between 0.250 and 0.275 g. In the area several seismological networks, from different countries, operate. In Austria and in Italy, the main ones are the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) seismological network, the Friuli Venezia Giulia Accelerometric network, managed by University of Trieste, which is integrated to the National Accelerometric Network managed by Dipartimento della Protezione Civile Nazionale, and the Austrian seismological Network managed by the ZAMG of Vienna. In addition the real-time data are exchanged in the Southern Alps area with the seismic network managed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and by the Autonomous Provinces of Trento and Bolzano; further the networks are integrated with the networks operating in Slovenia, Croatia and Switzerland. The seismic signals are acquired and processed in real-time by the Antelope® software. The sharing of cross-border waveforms improves the network geometries and, as a consequence the earthquake detection threshold near the borders. This is very important because natural disasters, as strong earthquakes, can cause damages and loss of life on the cross border area and in different countries; thus, the development of a trans-frontier strategies in the management of natural disasters is an important issue in order to harmonize trans-frontier actions to accelerate and facilitate the rescue operations. In this context we develop the interregional ARMONIA project between Austria and Italy aiming to tighten collaboration between the civil protection institutions for the risk prevention. Through the use of innovative methodologies, it develops a trans-frontier strategy in the management of natural disasters. The development of common protocols allows joint planning and implementation of harmonize actions to accelerate and facilitate the rescue operations. Partners develop an innovative seismic monitoring system extended also to the specific buildings (called 'sentinella' buildings) that will provide critical information, in the cross-border area, crucial for a rapid and focused interventions at the occurrence of earthquake. Tools for data analysis, as real time cross-border thematic maps, are developed, for operative rooms to have an immediate evaluation of the damages distribution. The realization of a homogeneous trans-frontier management model of risk prevention will help the civil defence institutions and regional government prepare plans to protect the population, mitigate the earthquake damages. The realization of common protocols for the training and joint exercises of civil protection volunteers and citizen will help to improved coordination of cross border interventions and a fast emergency actions.

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ESC2018-S1-622

A STRONG MOTION NETWORK FOR SENTINEL BUILDINGS IN NORTHEASTERN ITALY

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The Friuli Venezia Giulia (FVG) region is characterized by medium seismic hazard in the pre-Alpine belt, with an expected maximum acceleration between 0.250 and 0.275 g for an exceedance probability of 10% in 50 years. The state of stress is remarkable due to the northernmost part of the Adriatic microplate which collides and rotates anticlockwise with respect to the Eurasian plate. The seismicity of this region can be considered moderate, with occasional destructive seismic events exceeding magnitude 6; the most recent strong earthquake (ML 6.4) occurred on May 6, 1976 and caused about 1000 deaths and a widespread damage. Exactly one year after this earthquake, the seismometric network of the National Institute of Oceanography and Experimental Geophysics (OGS) was put into operation. The network was initially composed of 7 stations located in the epicentral area. In the beginning, the aim of the installation was to document the seismic sequence. In the following years, the network has been extended to the entire Friuli Venezia Giulia and Veneto regions in order to collect data of the regional seismicity. The seismic network consists presently of 35 stations extending from Garda Lake to the Italian–Slovenian border and from the Po River to the Italian–Austrian border. The OGS network has been integrated into the national seismic monitoring system, ensuring a real-time data exchange with the National Institute of Geophysics and Vulcanology (INGV). Starting from 1992, in the framework of several European projects, the University of Trieste installed the Accelerometric Network of Friuli Venezia Giulia (RAF) for research and civil protection purposes. Nowadays, thanks to a research agreement, the network is fully integrated into the National Accelerometric Network (RAN), managed by National Civil Protection of Rome. The integrated network provides in nearly real time the ground motion parameters, on national territory, for the alert system. The integrated network counts more than 55 accelerometric stations in the Veneto and Friuli Venezia Giulia regions. Both OGS and RAF networks are integrated in the international seismic network CE3RN for the international data exchange with Austria, Slovenia, Croatia, and other Balkan countries. These seismic networks offer a significant potential for both research and civil protection purposes, for example for the rapid and automatic determination of the hypocentral parameters, the estimation of the magnitude of earthquakes or the relative estimates of ground shaking. Within the "Edifici Sentinella" (in English: sentinel buildings) project a widespread monitoring of buildings identified as significant for civil protection purposes, is planned on the regional territory in order to support the prevention and management of seismic emergencies in FVG. The project is an evolution of an initial application introduced by University of Udine during the North-Est2013 full scale post-earthquake exercise of civil protection. It involves the University of Trieste, the University of Udine and the OGS and is supported by the Civil Protection of FVG. The realization of a seismic monitoring network for the development of shaking and damage scenarios immediately after an event is the main objective of the project. Based on the requirements of the sensors (Threeaxial accelerometers, sampling rate at least 100 Hz, possibility to connect to the internet and to transmit the data in real time, power and battery supply for the case of power breakdown, etc.) and the decision to use cost-effective sensors to make a widespread building monitoring possible, the accelerograph "Suricat" produced by MoHo s.r.l. has been selected for the installation in, or near to, pre-selected buildings (sentinel buildings). City halls, communal buildings, police stations, forest supervisors etc., have been selected as sentinel buildings. The municipalities were identified in order to improve the instrumental coverage of the strong motion network especially in regions of high seismic hazard. The selected sentinel buildings are representative for the localities. An overview of the ongoing installations in the sentinel buildings as well as the first results obtained from the recorded data set will be presented herein.

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ESC2018-S1-651

UNDERSTANDING BUILDING BEHAVIOR DURING EARTHQUAKE SEQUENCES: FIFTEEN YEARS OF WORK WITH MARCO ON ONE OF HIS FAVOURITE RESEARCH TOPICS

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It all began in 2002, after the Molise earthquake, Marco was intrigued by the peculiar damage on Bonefro's building and climbed to the top floor to make ambient noise measurements, the building had suffered level 4 damage and Marco soon returned due to risk to safety. Despite this big scare, Marco's scientific curiosity pushed him, involving me and all his co-authors to study the building's behavior during earthquakes and its interaction with the ground and adjacent buildings. Marco considered the occurrence of seismic events as the best opportunity to understand more, and so we rushed to install sensors on the Town Hall in Navelli (Abruzzo earthquake2009) damaged even at a considerable distance from the epicenter, on a building in San Gregorio, an example of nano-zonation, on the Mirandola hospital, Emilia earthquake 2012, where continuous recordings provided an opportunity to follow the main period and relative damping variation during the aftershocks, and on the Rotonda school, Pollino seismic swarm 2011, and the Ferrara University building, Emilia earthquake 2012, Marco threw himself head first into testing the low-cost accelerometer prototypes. Hundreds of ambient noise measurements were carried out on reinforced concrete and masonry buildings around the world, from Italy to New Zealand, giving rise to discussions about experimental building behavior with engineering scientific community. During his scientific adventures Marco involved many co-authors with whom he had scientific debates, shared experiences, worked on projects and measurement campaigns and above all showed always great enthusiasm and passion and so much good humor.

ESC2018-S1-653

DEVELOPMENTS ON SEISMIC HAZARD MODELLING IN NORTHERN ALGERIA

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Regions with a significant percentage of non-seismically designed buildings and limited urban planning are particularly vulnerable to seismic hazard. Recent seismic activity in Algeria, particularly during the last 50 years, has been characterized by several damaging earthquakes. In particular, the El Asnam region (now Cheliff) suffered the most destructive and damaging earthquakes recorded in northern Algeria. These were the earthquakes of 9 September 1954 (MW 6.8) and 10 October 1980 (MS 7.3). The most significant recent event was the 21 May 2003 (MW 6.9) earthquake, in Zemmouri, located approximately 50 km to the northeast of Algiers, the capital of Algeria. It is generally accepted that seismic hazard values, by analyzing the most energetic seismicity and its spatial distribution, are an important tool to provide design engineers and planners with critical information on earthquake-prone areas and their seismic potential. Therefore, the interest of the scientific community in Seismology and seismotectonics of Algeria is steadily increasing, especially with regard to the mitigation of the impact of destructive events and the seismic risk assessment of urban areas. In this context, the EU-funded project "Improved Tools for Disaster Risk Mitigation in Algeria" (ITERATE) aims at seismic risk mitigation in Algeria, leading to updates in the seismic design regulations. This work, as a stage of the whole project, will address a number of proposed developments and considerations made towards a further improvement of the component of seismic risk related to the probabilistic quantification of earthquake hazard. In specific, an updated earthquake catalogue (until

December 2017) homogenized to moment magnitude is used. A declustering procedure is employed, and its final Poissonian character is analysed. Furthermore, and for some specific sites, Oran and Blida cities, a detailed probabilistic seismic hazard analysis is carried out. The obtained results are presented in terms of different ground motion parameters, i.e., PGA, spectral acceleration for different oscillation periods and uniform hazard spectra for different return periods. Moreover, seismic disaggregation for different oscillation periods is performed to derive the contribution of the different scenarios.

ESC2018-S1-764

SYNTHETIC SEISMOGRAMS FOR SEISMIC HAZARD ASSESSMENT: CASE-STUDIES IN ITALY

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The ground shaking prediction for future earthquakes is the key issue of any assessment of seismic hazard. The most straightforward way to produce ground shaking scenarios makes use of Ground Motion Prediction Equations (GMPEs). The employment of the GMPEs, however, becomes questionable in near-fault conditions. Indeed, empirical models, even though calibrated on past records of acceleration waveforms, generally provide a simplified representation of the ground motion predicted around the source.

This is essentially due to the paucity of data for moderate-to-large events at short source-to-site distances. When a more detailed and realistic representation of the seismic shaking is required, numerical simulations can be a reliable alternative. Several simulation techniques have been proposed to this aim with different levels of complexity depending on the approximations introduced to represent seismic source, wave propagation and site response. The result is that the modeling of the same event with different techniques may produce ground motions differing in terms of amplitude, duration and frequency content. For this reason, before using numerical simulations to predict ground motion of future earthquakes, the adopted methods should be carefully validated through quantitative procedures based on the comparison between observed and simulated waveforms. One of the goal of the S3 project (INGV-DPC Agreement 2005-2007), coordinated by Francesca Pacor and Marco Mucciarelli, was the generation of shaking scenarios at bedrock and including site responses. Starting from these pioneer studies, several issues related to the use of synthetics seismograms for hazard assessment have been addressed. In this work, we present an overview of the modeling studies of the major Italian earthquakes (1980, M 6.9 Irpinia event; 1990, M 5.8 Sicily earthquake; 1997, M 6.0 Umbria Marche main-shock; 2009, M 6.3 L'Aquila events), carried out applying different simulation techniques (stochastic, deterministic-stochastic, broad-band). We also discuss some examples of scenario-events, generated at single and multiple sites, illustrating our approaches to handle the synthetic ground-motion variability. Finally, we show an hazard evaluation based on hybrid ground motion prediction equations, calibrated using synthetics waveforms at short distances and recorded waveforms, far from the source.

ESC2018-S1-892

SEASONAL VARIATION OF SEISMIC WAVES VELOCITY IN SOIL

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We perform interferometry analysis by deconvolution on borehole accelerometric data to investigate possible imprints of the change of seasons on the measured shear-wave velocities in soil. We process the datasets from two vertical arrays in Greece, i.e. the CORSSA array located on the southern shore of the Gulf of Corinth and the ARGONET array, recently installed on the Cephalonia Island. Our analysis verifies previous, independent findings that associate the alteration of seasons to variation in seismic velocities. The effect for both studied sites is mostly evident when the top pair of sensors is examined and gradually diminishes with depth. The location of the ARGONET array in the most seismically active part of the eastern Mediterranean and the fact

that it is in continuous operation (in opposition to the CORSSA array that was operating on trigger mode) resulted in an excellent dataset in terms of density of recorded events in time, that allows a day-by-day comparison of the measured seismic velocities to precipitation data. We observe abrupt velocity changes after the first rainfalls that follow dry periods in the studied areas. We associate these changes to variations in soil moisture content of the top layers. In the shallowest examined sensor pair of ARGONET (0-6m), measured velocity varies from circa 150m/s during the wet periods to more than 180m/s during the dry periods. This variation may be, in fact, even larger if we realistically assume that the effect is restricted within the top 2-3m, i.e. above the level of the shallow water table at the specific site. Such changes may be significant for a variety of site-effects related topics such as the understanding of high-frequency ground motion variability, soil anisotropy, kappa measurements etc. or even for more practical issues such as the shallow foundation of structures.

ESC2018-S1-921

FROM NOISE TO RISK: AN ATTEMPT TO USE AMBIENT VIBRATIONS AT GROUND LEVEL AND WITHIN BUILDINGS FOR URBAN SCALE DAMAGE ESTIMATES

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Among the very broad spectrum of research topics tackled by Marco Mucciarelli, a good deal has been devoted to the measurement and use of ambient vibrations at ground level and within buildings. As a tribute to all his accomplishments in this field, this presentation will present the latest results obtained within the Grenoble team concerning our attempts to take advantage of ambient measurements at ground level (H/V curve) and within buildings (building frequency) to propose physics-based damage estimates at urban level. It will start with a short presentation of the results a comprehensive numerical analysis to investigate the impact of site conditions on building damage. Buildings are modeled as single-degree-of-freedom oscillators resting on non-linear, 1D layered soil columns, impinged by vertically incident plane waves. The associated damage is in each case quantified through the "mean damage estimate" derived from the comparison of the maximum displacement structural to both yield and ultimate post-elastic displacements, following the mechanical approach proposed by the RISK-UE project (Lagomarsino and Giovinazzi, 2006). Such damage estimates have been computed for a set of 141 elastoplastic oscillators representative of the main Euro-Mediterranean building structures, founded on nearly one thousand of different soil columns and about 80 different rock reference waveforms spanning a wide range of magnitude and distance. The site response is considered either linear, or linear equivalent, or fully non-linear. Considering the huge number of considered cases, the correlations between the "input" parameters (loading: PGA or PGV; site response : site fundamental frequency, velocity contrast, VS30, H/V peak amplitude; building : fundamental frequency, yielding and ultimate displacement limits…) and the "output" (mean damage or mean damage increment between outcropping rock and site surface) are investigated with a neural network approach, which allows to investigate the respective performances of the various loading, site and building proxies. The results emphasize the key impact of the spectral coincidence between site and building fundamental frequencies, even when both are shaken strongly enough to experience large strains and non-linear behavior. An example implementation of this approach will be given for the city of Beirut (Lebanon). The availability of several hundreds of microtremor measurements at ground level provide a map of fundamental frequencies and associated H/V amplitudes (Brax et al., 2018). Ambient measurements within several hundred buildings (Salameh et al., 2016) allowed the derivation of period–height relationships, the combination of which with a comprehensive inventory provided the typology and frequency of more than seven thousand buildings within downtown Beirut. The expected damage maps will be discussed in relation to the loading scenario, the site response models (linear or non-linear) and the building typology.

ESC2018-S1-925

THE INSIEME NETWORK: A BROADBAND SEISMIC NETWORK TO STUDY THE INDUCED SEISMICITY IN THE HIGH AGRI VALLEY (SOUTHERN ITALY)

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The first time I met Professor Marco Mucciarelli was for my PhD defence in 2008, since he was one of the members of my examining commission, impressing me by his stimulating questions during the presentation of my dissertation. After few years, in 2012, I was honoured to starting a collaboration with him in the fields of engineering seismology and induced seismicity. In particular, thanks to the Marco's scientific perseverance, the induced seismicity from being an untreated theme in Italy has become a current national research field. In 2014 we both became members of the Scientific Committee on induced seismicity promoted by Ministry of the Environment and Protection of Land and Sea (MATTM); in the same period, Marco, together with other colleagues, helped me to write and submit the research project INSIEME (INduced Seismicity in Italy: Estimation, Monitoring, and sEismic risk mitigation), which was approved in 2015 by the SIR (Scientific Independence of young Researchers) program of the Italian Ministry of Education, Universities and Research (MIUR). Here we present one of the main research deliverables of the project, i.e. the experimental seismic network INSIEME. This network has been designed to study two clusters of human-induced events in the High Agri Valley (southern Italy), one of the areas of Italy with the highest seismogenic potential and with a fault system capable of generating up to M=7 earthquakes (i.e., the M=7, 1857 Basilicata earthquake). The INSIEME network is composed by 8 stations covering an area of about 16 km x 11 km, and arranged into two groups of four stations each located around the two clusters of induced events, respectively, i.e.: (1) the fluid-injection induced seismicity (Ml > 2) due to the wastewater disposal of the Val d'Agri concession - one the biggest onshore oil and gas production field in west Europe - at the Costa Molina 2 (CM2) injection well; (2) the continued-reservoir induced seismicity (Ml > 2.7) linked to the seasonal water level fluctuation of the artificial Pertusillo Lake. The seismic stations are all equipped with broadband sensors installed in PVC casings at different depths down to 50 m. In particular, 6 sensors are 20s-100Hz Trillium Compact Posthole seismometers and 2 sensors are 120s-100Hz Trillium Compact Posthole seismometers. The power supply is provided by solar panels and batteries. The sampling frequency of the continuous seismic data stream is 250 Hz, and all the data-loggers are Centaur digital recorders with a dynamic range of 140 dB. The acquired data are transmitted in near real-time to the data center at the CNR-IMAA institute through the third generation of wireless mobile telecommunications technology (3G) and managed through the SeisComP3 and WebObs software systems. The network has been registered at the International Federation of Digital Seismograph Networks with code 3F (doi:10.7914/SN/3F_2016) and the acquired data will be released through open access at the end of the project, according to the general principle so close to Marco's heart that all data and results produced during research projects, especially those with potentially high public impact, be made freely available to everybody.

ESC2018-S1-943

MARCO´S CONTRIBUTION TO SEISMOLOGICAL-ENGINEERING STUDIES IN SPAIN

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It was after the Mw5.2 May 2011 damaging earthquake in Lorca, SE Spain, when our group strengthened scientific cooperation with Marco Mucciarelli. The earthquake community recognizes his immense value as a scientist. To us, his immense value as a person, a colleague and a friend was even more. We were very lucky in our professional carrier to be able to cooperate with Marco and have the chance to enjoy him. Besides having applied together for a number of proposals he was leading, he joined us for several field surveys in the area of Lorca shortly after the 2011 earthquake. He came with a team of geologists, seismologists and engineers, fully equipped for

the field work. It was hard work in Lorca and surroundings to carry out ambient-vibration measurements, non-destructive engineering tests on representative building materials, and the evaluation of the dynamic characteristics of selected buildings (masonry and reinforced concrete) and structures (bridges and cultural heritage sites) in quite a short time. We concluded that site characterization results do not show significant resonance effects (i.e., soil amplification), and that lateral heterogeneities in the observed damage pattern most probably rely on different vulnerability levels of buildings. The time we spent together in Lorca was very fruitful, both scientifically and personally. He seemed never tired and shared his energy all around even when others would have been exhausted. Among the many issues that arose from the interesting very late evening discussions when coming back from the field, was the relatively large acceleration recorded at the nearest station to the epicentre, located in the city, and the different source models that were put forward in the literature. We decided then to start investigating the ground motion and the source-related near field variability for the 2011 Lorca earthquake. Next day we were already inspecting the accelerometer site located in a building belonging to the City Council, after having rushed for obtaining the permits to access it. We then, started performing very detailed analysis of the installation accelerometer site to discard any possible effects due to the particular site and/or station deployment. Further analysis has allowed us to arrive to a good fit of the data by modelling both, low- and high-frequency ground motion of the complex earthquake rupture process. Since then, we had continued our close cooperation, preparing project proposals, papers, tutoring students from University of Basilicata in Madrid and have shared interesting discussions on the occasions of meeting or conferences, like we did in Istanbul in 2014 enjoying water pipe and Turkish raki. Also, the meetings for the preparation of the 2016 General Assembly of the European Seismological Commission (ESC) in Trieste were always very fruitful and problem-solving with Marco was always straightforward. In this case, enjoying a bottle of nice wine with Marco made the working sessions a pleasure. Professionally he was the perfect broker between seismologists and engineers and both communities should not lose his legacy in this, sometimes complex, relationship.

ESC2018-S1-977

EMPIRICAL PERIOD FORMULAS FOR DIFFERENT BUILDING TYPOLOGIES IN MIDDLE EAST, USING AMBIENT VIBRATION RECORDINGS: COMPARISON WITH LOCAL SEISMIC CODES

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Among the different buildings parameters, the easiest to determine is the elastic fundamental resonance period, which is directly related to the building stiffness. Seismic codes propose empirical formulas to estimate the fundamental vibration period of buildings that are confirmed or not by in-situ measurements (earthquake and/or seismic noise recordings, Mucciarelli et al, 2003, 2004). Such formulas are very useful to help structural engineers in seismic design and can be used in large-scale seismic vulnerability assessment (e.g., Lagomarsino and Giovinazzi, 2006). There are different experimental methods to extract the fundamental period of buildings: earthquake recordings, mass impact, explosion, running oscillators, etc.. However, these methods are citizen perturbing and/or time consuming and/or expensive. As an alternative, the seismic ambient noise recordings have been more and more used to access quickly to fundamental period of buildings (Carder, 1936; Trifunac et al., 2010; Michel et al., 2008, 2010; Herak and Herak, 2010; Guillier et al., 2014), leading to generate numerous datasets over the world. Even if a lot of Middle-East countries have recently established Seismic Code (Iran, Lebanon, Turkey, Egypt,etc.), proposed formulas are generally derived from American or European codes (UBC, 1997; CEN, 2004; SIA, 2003) due to the lack of country-specific data. From different Middle-East building periods datasets (Salameh et al, 2016; Oghalaei et al., 2018), representing more than 1000 measured periods of RC and Steel buildings, we derive experimental formula of fundamental period (T)

as a function of the number of floors (N) for different building typologies that appear to differ from a country to another. Indeed, from the Iranian dataset, T=N/16 for RC buildings and T=N/13 for steel frame ones, while, for Lebanese data, T=N/19 for RC buildings. Then, we compare the various correlations (Periods vs. number of floors for different typologies) to the local codes. In general, the measured periods are found to be much shorter than the ones recommended by building codes, raising up the issue whether the application of the codes is more conservative when an earthquake occurs. Moreover, for a given typology, it seems that merging the building periods coming from different countries may lead to wrong estimation of period-height relationships and a very strong increase of the standard deviation. This is probably related to the different construction habits, which exist in the studied countries. From the analysis of these datasets, we also evidence that the building periods are not correlated to the horizontal dimensions of the buildings in Lebanon, while for Iran, we observe that the horizontal dimension is playing a minor role, especially when a buildings is embedded between other buildings.

ESC2018-S1-1006

DEALING WITH MARCO MUCCIARELLI'S INSATIABLE SCIENTIFIC CURIOSITY: EXCERPTS FROM A 30 YEAR-LONG FRIENDSHIP

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When we think of a scientist we think of a person who is curious but also honest, open-minded yet fair, and has a practical attitude towards the solution of the small and bigger problems that may arise in everyday experimental research. As many of us know, Marco compounded all these characteristics. He did not start his career as a scientist, however, despite his degree in Physics from the University of Bologna, a sanctuary for Italian geophisicists and seismologists. For twelve years, from 1987 to 1998, he was the coordinator of the "Seismology and Seismic Risk Unit" at ISMES, a private Italian firm specializing in developing infrastructures and models to be used in the power generation industry, before becoming a university professor in 1998 and a director at OGS in 2012. Hence, when I met him for the first time he was an applied seismologist who wanted to explore all the new possibilities arising from the development of experimental seismology in the 1980s and early 1990s. He was a full-fledged seismologist intrigued by geology and its potential to anticipate the location and characteristics of large earthquakes. I was a geologist trying to establish bridges with instrumental - and even more so, with historical - seismology. We spoke about anything, we planned all sorts of possible developments, we wrote projects and won grants for exploring our common interests; all with the shared goal of improving the assessment of seismic hazard and mitigating seismic risk. In simple words, I was Marco's counterpart for earthquake geology, and proud of it. And of course, we also became close friends. Like many of Marco's kaleidoscopic interests, our common concerns were sort of "off the beaten path" with respect to his main involvement in studies of earthquake engineering, building response and site amplification. This made our common ideas projects even more fascinating to pursue, and perhaps more fruitful in the end. It will be easy to provide examples of the ideas that we developed together, the best case probably being the publication in 2015 of a paper with an intriguing title: "Earthquakes and depleted gas reservoirs: which comes first?". Are large earthquakes and gas reservoirs mutually exclusive? We thought they were; we thought that our evidence for this behavior provided an exciting insight into the dynamics of the upper crust in active areas; and even more importantly for us, we thought that our findings could help decision-makers and stakeholders to make the right moves in the exploitation of hydrocarbon reservoirs. But the project was interrupted in Spring 2016, when Marco fell ill, and never resumed. Like many of us, I feel on obligation to bring it forward along with the other colleagues that we had involved; it will be our way to keep his memory alive.

ESC2018-S1-1009

TEMARISK FVG, A PROJECT TO COMMUNICATE ON NATURAL HAZARDS IN FRIULI VENEZIA GIULIA REGION (NE ITALY)

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Among Marco Mucciarelli's most recognized talents, there was certainly his great communicative ability. He believed that communicating science is a duty for each researcher, and as director of the Centre for Seismological Research of the OGS, he supported and encouraged any dissemination activity that could increase the awareness of seismic hazard and develop a culture of prevention in the community. The TEMARisk FVG project was conceived in his memory. TEMARisk FVG was a one year project, ended in March 2018, financed by the Friuli Venezia Giulia (FVG) Region in NE Italy, as one of the events for the dissemination of scientific culture in the FVG area. Its objective was to disseminate the present knowledge about the seismic hazard but also about some other natural hazards in an effort to develop a culture of prevention and resilience in the population. The originality of the project consisted in the organization of various kind of events, having the natural hazards in FVG as a common subject, but located in different towns, in different times, and organized such as to reach different types of audience, of different social areas, including the new immigrant communities. The issues addressed in the various events were about the hazard related to earthquakes, landslides, floods, climate change, melting glaciers, sea level rise. The link between human activity and natural risks was also highlighted, addressing topics of great present interest, such as induced seismicity, and chemical, biological, and microplastic pollution in the marine environment. Many researchers of the OGS were involved in the events, in cooperation with colleagues from the Italian Universities of Udine and of Trieste, of the International School of Advanced Studies (SISSA), of the Agencija Republike Slovenije za Okolje (ARSO), as well as various experts. In addition to the standard talks, we aimed at the direct involvement of the public through the immersion in the virtual reality of a 360° video, laboratory activities for children and adults, a mountain trip to visit a geodetic station, and multilingual brochures about the natural hazards of the FVG. TEMARisk FVG also promoted the diffusion of technical-scientific culture in schools, through the contact of researchers with students and involving the immigrant communities. We organized many thematic activities on natural hazards in various schools of the area, with the intervention of experienced researcher in each field. In addition to the seminar activity, some high school students came to the OGS laboratories, for in-depth study and internship. Advanced training workshops were also organized for teachers, engineers, architects, geologists, and journalists. As the last event of the project, we organized a public conference, specifically dedicated to the memory of Marco Mucciarelli who was also a blogger very active in debunking hoaxes, rumors and urban legends on earthquakes. We invited an Italian popular disseminator, Massimo Polidoro, debunker, and secretary of CICAP (Italian Committee for the Control of Affirmations on the Pseudosciences), an association for which Marco held several public conferences. Polidoro discussed with the experts of the OGS about the most widespread fake-news on earthquakes and other natural hazards. The participation of the celebrity attracted a lot of people as well as the local media attention, and that helped us to firmly remark, to a wide audience, the importance of the authoritative information and the necessity of the fact-checking for the news disseminated by the social media and by unlikely websites. To tell about TEMARisk FVG we used the local press and the social media (#temariskfvg), and we created a website site (temarisk.wordpress.com), as a repository of all the materials produced, in order to maximize our effort for increasing the awareness of the natural hazards, even after the end of the project, and build the culture of prevention.

ESC2018-S1-1026

THE GEOFON PROGRAM

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The GEOFON program started in 1992 with the aim to promote seismic data exchange and to foster standards in seismology. During the last two decades GEOFON developed in three main components: the global seismic network, the seismological data center and the global earthquake monitoring system. These three components are part of the scientific infrastructure of the Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences aiming at facilitating scientific research. GEOFON provides real-time seismic data, access to its own and third party data from the archive facilities as well as global and rapid earthquake information.

Many of these operations are carried out using the in-house developed software SeisComP3. The GEOFON global seismic network presently consists of more than 80 high quality stations with real-time acquisition via various communication types. The network plays a leading role in global real-time seismology providing valuable data for almost all fundamental and applied global/regional seismological research projects at GFZ and the wider seismological community. The data center provides a permanent and secure archive for data from the GEOFON stations and those of many partner networks and plate boundary observatories. GEOFON is currently archiving and distributing seismic data for more than 100 seismic networks, including passive temporary deployments using instruments of the Geophysical Instrument Pool Potsdam (GIPP). The global earthquake monitoring is carried out using all real-time data streams from GEOFON stations as well as ~900 additional real-time stations from international partners to determine rapid automatic location estimates for all globally recorded earthquakes and most regional ones. Since 2011 moment tensor solutions for major event are also provided. In this presentation we summarize the evolution of the GEOFON program and the contribution of Marco Mucciarelli to the global seismic network. Particular emphasis will be given to the recent developments and to the importance of open data and their usage not only for scientific research but also to foster initiatives devoted to increase the awareness of the general public with respect to natural hazards.

ESC2018-S1-1070

SITE CLASSIFICATION AND SITE EFFECTS IN THE SEISMIC NORMS: WORK IN PROGRESS FOR THE REVISION OF EUROCODE 8

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As for the other structural Eurocodes, Eurocode 8 (EC8) is undergoing a major revision process that in the next years will progressively involve its different parts. Part 1 of EC8 is among the first ones that is being updated, as regards the seismic actions for design, seismic design criteria and methods of analysis. One of the key and most debated problems for the seismic actions to be introduced into the norms is the definition of site amplification factors and its connection with classification of different soil types. The question is wide, and reflects the experiences and interests of different European regions with different prevailing site conditions, such as Scandinavia, where the dominance of thin soft clay layers may induce large amplification at high frequencies, or middle Europe, where at the opposite, geological conditions are dominated by thick soil sediments. The constrains are different: - the code should be simple and easy-to-use; - soil classification should be easily understandable by practicioners and directly related to well calibrated site amplification factors; - the classification should be quantitative and based on a limited number of parameters, possibly a single one; - in spite of its simplicity, the classification should be detailed enough to cover the variety of stratigraphic profile that may be present in whatever country of Europe; - the number of nationally determined parameters within the norms should be reduced, in order for the norm to be as widely as possible recognizable as a European norm; - there is a strong request that new norms do not involve an unnecessary increase of construction costs. As obvious, such requirements are very hard to be complied simultaneously. The present EC8 approach, based on the definition of different site classes, each associated to different site amplification factors and corner periods and low vs high seismicity levels, was questioned in various countries, which in some instances, such as Italy, Spain, Germany, proposed independently evaluated site amplification factors and different classification criteria with respect to the standard EC8 ones. The following issues are probably the most debated ones: - are additional parameters rather than Vs,30 alone needed to provide a more reliable soil classification, such as the fundamental frequency of the soil from microtremor measurements? – are available studies sufficient to associate to such additional parameters a reliable site amplification factor? – is it advisable to propose a continuous variation of site amplification factors as a function of Vs,30, in order to avoid strong jumps of seismic action when moving from one class to the other one? – are the present approaches to relate geotechnical parameters, such as results of SPT or CPT in situ tests, to site classification reliable enough? – what, if any, penalty to be prescribed if only a limited amount of information is available for site classification? – are the current site amplification

factors suitable to account for non-linear soil response, or they tend to overestimate site effects for large levels of input motion, and how to account in a simple way such non-linear effects? – in which conditions should site-specific response analyses be prescribed as mandatory? And, last but not least, if and how results of microzonation studies can be explicitly included as a possible alternative approach for the definition of soil subdivision and site amplification factors for specific areas, in order to let the quantitative work made in the microzonation process be applicable in the seismic norms. Marco Mucciarelli was one of the key researchers who emphasized the need for improving seismic norms in terms of a quantitative determination of site conditions and more reliable site amplification factors, with a strict connection with microzonation studies. The revision of the EC8 is hopefully going in such direction.

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SESSION 02

ESC2018-S2-204

RECENT SEISMOLOGICAL PRODUCTS AND SERVICES DEVELOPED WITHIN EPOS-SEISMOLOGY

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EPOS-Seismology is built upon the rich history of coordination projects and infrastructures in seismology and Europe. Especially, in EPOS, EMSC is the European infrastructure for seismological products. A summary of the latest seismological products developed is presented: the Seismic Portal (www.seismicportal.eu/webservices.html) is the main interactive gateway to access these services. The EMSC FDSN-event web service is conform to the FDSN web service standards and provides all the EMSC event data available. Event information can include all origins and all arrivals reported to EMSC by its member institutions as desired. The Flinn-Engdahl lookup web service identifies the Flinn-Engdahl region from a geolocalisation entry point. The Testimonies web service allows to download all testimonies collected from eyewitness during earthquakes through the EMSC websites and from its Lastquake mobile application. The Moment Tensors web service gives access to all the moment tensors collected at EMSC. The Rupture Models web service allows to query the earthquake source models of the SRCMOD database (P.M. Mai, 2012). The EventID web service dynamically maps event identifiers to allow the identification of a same event between different seismological institutions. All the web services developed for EPOS-Seismology are up and running. Each web service has its own URL and specification documentation. A service is composed of a graphical user interface (GUI) with a query builder / search engine and a mapping tool (when it is suitable).

ESC2018-S2-242

HELPOS: HELLENIC PLATE OBSERVING SYSTEM. SERVICES WITHIN THE FRAME OF THE HELLENIC EPOS RESEARCH INFRASTRUCTURE

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The understanding of physical processes responsible for earthquakes, volcanic eruptions, surface and tectonic processes, ground motion, wave propagation, seismic response of engineering structures and tsunamis requires the prompt and long-term availability of high quality data and services. The accessibility of these can accelerate the discovery of new earth science and earthquake engineering results and novel uses for societal benefit. HELPOS is a distributed network of geosciences and earthquake engineering observatories, running by the Greek Research Institutions and Universities. The backbone of the project is formed by permanent stations (seismic, GPS, strong motion) involved in global, regional and local networks, which feed high quality services mostly in real time. Permanent observatories are complemented with local stations and networks in selected regions of interest. In addition, the observational system is complemented with high quality laboratories and multiple mobile stations which are deployed for repeated measurements or field experiments within various national and international projects. The in-situ monitoring and forecast modeling services of the HELPOS Research Infrastructure are essential for earthquake, earthquake engineering, volcano and tsunami early-warning systems as well as for disaster relief, risk assessment, management and prevention. Open access to this multidisciplinary research infrastructure will not only stimulate innovative research on earth dynamics and processes leading to catastrophic events, but will result to new developments in engineering seismology towards more effective disaster prevention. EPOS as a Research Infrastructure is therefore, invaluable for improving hazard and risk assessment and forecasting. Understanding the processes as well as forecasting and mitigating the effects of such events require coordination of national facilities and expertise. HELPOS is an initiative responding to the current Greek and European need for a comprehensive and integrated solid Earth and Earthquake Engineering RI within EU–EPOS initiative. The HELPOS project aims to integrate following the EPOS initiative, the currently scattered, but highly advanced National Greek facilities into one distributed and coherent multidisciplinary Research Infrastructure. The scope is to enable sustainable long-term Earth science and earthquake engineering research strategies and an effective coordinated

monitoring facility that will contribute to EPOS efforts. The HELPOS partners list follows:

PARTNERS

1. National Observatory of Athens, Institute of Geodynamics
2. Aristotle University of Thessaloniki a) Department of Geophysics, b) Laboratory of Soil Mechanics, Foundations and Geotechnical Earthquake Engineering c) Department of Geodesy and Surveying
3. Earthquake Planning and Protection Organization (EPPO- ITSAK)
4. National Kapodistrian University of Athens, a) Department of Geophysics & Geothermy, b) Department of Informatics & Telecommunications
5. Technological Educational Institute of Crete, Laboratory of Geophysics and Seismology
6. University of Patras, a) Laboratory of Seismology b) Laboratory of Geotechnical Engineering
7. National Technical University of Athens a) Department of Geotechnics, Engineering Geology & Rock mechanics Unit b) Laboratory of Geodesy
8. Hellenic Centre for Marine Research

Acknowledegments:

The project “HELPOS - Hellenic Plate Observing System” (MIS 5002697) is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union.

ESC2018-S2-254

THE EUROPEAN GROUND SHAKING INTENSITY MODEL (EGSIM) SERVICE: CURRENT STATUS AND FUTURE DEVELOPMENTS

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We present eGSIM, the European Ground Shaking Intensity Model service oriented to the selection and comparison of ground motion models (GMM) for PSHA studies. eGSIM is developed in the framework of the Thematic Core Service Seismology of EPOS (European Plate Observing System) and, in particular, it is contributing to the European Facilities for Earthquake Hazard and Risk (EFEHR). This service allows a user to interact with a library including more than 350 GMMs, as implemented in the OpenQuake-engine (Pagani et al., 2014) and facilitated by the Strong Motion toolkit (Weatherill, 2014), in order to make comparisons both with other models and with data,and to guide the selection of suitable GMMs for application to PSHA in a region of interest to the user. The mechanism of selection includes both the selection of specific models from the comprehensive and growing OpenQuake archive, and the pre-selection of models adopted within previous projects (e.g., SHARE). Interaction with the service is mediated by a graphical user interface (GUI) running as web-application. Actions applied to the selected models include both the comparison in terms of a Trellis plot for user-defined rupture scenarios, and residual analysis using databases created from published flat files such as the one extracted from the EPOS service Engineering Strong Motion (ESM) database (Lanzano et al., 2018) or the PEER-NGA west2 flat file (Ancheta et al., 2013). Outcomes from the analysis of residuals also include measures of the model performance based on univariate (Scherbaum et al., 2009) or multivariate (Mak et al., 2017) logarithmic score methods. Moreover, the service is computing and delivering station- and event-specific residual terms evaluated for selected GMPEs, which could of interest for site-specific hazard assessment. Aim of the presentation is to show the current status of eGSIM and to open a discussion about foreseen developments and user needs.

ESC2018-S2-378

RECENT UPGRADE OF THE ISC BULLETIN AND ASSOCIATED DATASETS

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The International Seismological Centre (ISC) continues with its international mission of producing the most long-term, comprehensive and homogeneous summary of instrumentally recorded seismicity on a global scale, based on seismic bulletin reports from ~150 seismic networks worldwide. Several associated datasets such as the ISC-GEM, ISC-EHB, GT and the Event Bibliography further expand the ISC Bulletin data for use in different research fields. Recent

upgrades include the releases of - rebuilt ISC Bulletin for the 1964-1979 period, where all hypocentres and teleseismic magnitudes have been recomputed using the current standard event location procedure (Bondar and Storchak, 2011), ak135 velocity model and all reported seismic phases; previously missing data from permanent and temporary deployments have been added and general cleaning of the Bulletin has been done; - 5th version of the ISC-GEM catalogue most notably extended and improved during the 1904-1959 period; - re-worked and reviewed ISC-EHB dataset for 2000-2013; - first ISC-authored set of fault plane solutions for moderate earthquakes that occurred during April-June 2015; this also marked the beginning of routine use of freely available waveforms at the ISC to automatically determine and make available the polarities of first motions of P-waves, corresponding fault plane solutions as well as mixed polarity warnings to station operators. We show examples of these recent improvements in Europe and Mediterranean region.

ESC2018-S2-393

THE CYBERINFRASTRUCTURE USED BY IRIS DATA SERVICES: PROVIDING A SCALABLE ARCHITECTURE TO SERVE THE GLOBAL SEISMOLOGICAL COMMUNITY

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Overview: IRIS Data Services operates the largest repository of seismological data intended for academic research and monitoring purposes in the world. As such, the IRIS Data Management Center (DMC) in Seattle, USA has developed a service-based architecture that is robust, scalable, and reliable to serve both Level 0-1 time series data and Level 2-4 products. IRIS coordinates internationally and domestically with other data centers that are members of the International Federation of Digital Seismograph Networks (FDSN). In general IRIS coordinates its activities in a manner that benefits the global seismological community. As an example, IRIS supported developments within the German-developed SeisComP3 system that enables support for FDSN-standard web services at any data center using SeisComP3. IRIS is in the process of adding additional web services within SeisComP3. This presentation will highlight the cyberinfrastructure in place at the DMC. Topics will include 1) federation of data centers, 2) robustness of services, 3) product generation, 4) data quality assurance, and 5) Large-N data support. Federation of Data Centers: With 19 data centers currently supporting primary FDSN web services including 1) dataselect, to access time series data; 2) station, to access station metadata and; 3) event, to access earthquake catalogs, federation of data centers is now possible. For instance, the IRIS fetchdata script can access information from any or all of the 19 centers supporting these services. The popular GMAP utility at IRIS DMC can show locations of all the stations within the federated system on a Google Map and soon the very popular web application WILBER3 will as well. Robustness: IRIS services requests that result in the delivery of roughly one petabyte of Level 0 or Level 1 data to users each year. Since it has such a central role, IRIS actually runs two centers: the DMC in Seattle and the Auxiliary Data Center (ADC) in Livermore, California. A global load balancing system in place ensures that users can access IRIS resources with a high degree of success. The actual uptime of this system is greater than 99.99%. The redundant centers also guarantee the long-term availability of the data even if a fire or a natural disaster were to damage one of the centers. Products: IRIS has a vibrant system to produce higher-level products from IRIS data as well. The products are managed within the SPUD product management system (https://ds.iris.edu/ds/products/). Currently there are about 30 different types of products including those that have been developed by IRIS DMC staff and a greater number that were developed by researchers and contributed to the SPUD repository. Some of the products include ground motion visualizations, moment tensors from Columbia University, source time functions, event bulletins, magnetotelluric transfer functions, and images of scanned film chips from the 1960's. Quality Assurance: The vast amount of data entering the IRIS DMC everyday makes it impossible for manual review of the data to determine quality. For this reason, IRIS DMC developed an automated quality control system called MUSTANG that routinely measures roughly 46 metrics related to data quality. The system is also capable of determining when a metric

becomes stale due to a change in the time series itself, the metadata describing the data, or perhaps when the algorithm itself changes. One of the most diagnostic tools is the calculation of the power spectral density (PSD) and related probability density function (PDF) noise metrics. IRIS has developed tools to view and manipulate these metrics, which help network operators in identifying problems at their stations. Large-N Data: In the United States and other countries, the method of recording seismic data is moving from very expensive broadband sensors (and a corresponding limited number of recording stations) to less expensive nodal systems that are much cheaper and can be deployed in much larger numbers, on the order of hundreds of thousands of stations recording at higher sample rates. The data volumes will be measured in the hundreds of terabytes for relatively short deployment times. In the United States, Large-N data are being generated today with numbers expected to increase in the short term. Working with the IRIS PASSCAL Instrument Center, IRIS DMC staff are leveraging a new data format based upon the Hierarchical Data Format (HDF) to present large-scale experimental data to users with FDSN-standard web services. As a result, data from the traditional IRIS archive of SEED-formatted data and experimental data from HDF containers can be accessed in the same, seamless manner and will soon be jointly accessible from many of the IRIS tools used for data and metadata access.

ESC2018-S2-403

A REAL-TIME PGA AND PGR DISTRIBUTION APPLICATION FOR GREECE

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Greece is one of the most seismically active territories in Europe and worldwide. Therefore, real-time Peak Ground Acceleration (PGA) distribution, directly related to seismic damage, is of significant importance for the assessment and management of strong seismic event consequences. Real-time systems are on the rise as they offer an excellent opportunity in better managing a disastrous event and reducing the potential losses to civil protection agencies. Currently, worldwide systems, such as PAGER (Wald et al., 2010), developed by USGS, provide this information on Greek earthquakes using global Ground Motion Predictive Equations (GMPEs). In addition, Greek EPPO-ITSAK provides PGA distribution for moderate and large earthquakes using the ShakeMaps application within 30 minutes (Wald et al., 2005). In the present study, a Matlab algorithm is developed, calculating and publishing on the web in real-time, PGA distribution for the area of Greece, and for the first time worldwide, Peak Ground Rotations (PGR) for torsion and rocking, based on regional GMPEs, taking into consideration epicentral distance, moment magnitude, focal depth, soil and focal mechanism type. The GMPE for PGA is calculated based on corrected strong motion data of Greece for the period 1973-1999 (HEAD database, Theodulidis et al., 2004) and for significant earthquakes after 2000 (earthquakes of Lefkada 2003, Kefalonia 2014 and Lemnos 2014), according to the one-stage maximum likelihood regression method (Joyner and Boore, 1993). Time histories of rotational components are calculated from the same strong motion dataset, based on single station methods and considering Fourier spectra and local site conditions (VS30). Consequently, GMPEs for PGR (torsion and rocking) are calculated based on the one-stage maximum likelihood regression method (Joyner and Boore, 1993). The study of ground rotations, although observed for a long time, has been intensified the last years with the use of measurements from strong motion instruments, seismic arrays and new rotational seismographs. The study of rotational motions is considered an emerging field in seismology (Lee et al., 2009) with a wide range of interest in seismic instrumentation, earthquake engineering, strong motion and seismic hazard providing scientists with valuable information on seismic design standards for buildings and slopes. Earthquake parameters (epicenter, focal depth and earthquake magnitude) are derived automatically through real-time seismicity monitoring, from the Seismological Laboratory of the National and Kapodistrian University of Athens (http://www.geophysics.geol.uoa.gr/). PGA (cm/s2) and PGR (mrad/s2) shaking maps are calculated and published on the internet only for earthquakes with magnitude M>=4.0. Shaking maps are provided for the last 10 days. The algorithm is written in such a way that the user can

also monitor the correction in the epicenter location. The proposed algorithm performs with exemplary efficiency, requiring only a few seconds in any average personal computer. Shaking maps are published online in a user-friendly environment, using google maps as basemap (http://macroseismology.geol.uoa.gr/realtime/).

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ESC2018-S2-461

INTEGRATION OF ANTHROPOGENIC SEISMICITY DATA WITHIN THE EPOS IMPLEMENTATION PHASE (EPOS-IP) TO ENCOURAGE INTERDISCIPLINARY RESEARCH AND COLLABORATION

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The EPOS Thematic Core Service „Anthropogenic Hazards" (TCS AH) pursues the aim to provide a complete, comprehensive, wide-scale and high quality e-research infrastructure, integrating data and data processing services related to anthropogenic hazards and risks research, including exploration and exploitation of geo-resources. Furthermore, the TCS AH tries to enhance the collaboration between science and industry to reach the goal of a complete e-research infrastructure for advanced analysis and geophysical modelling of anthropogenic hazards. The TCS AH is based on the prototype built in the framework of the IS-EPOS project POIG.02.03.00-14-090/13-00 (https://tcs.ah-epos.eu/) and is currently being further developed within the EPOS Implementation Phase (H2020-INFRADEV-1-2015-1, INFRADEV-3-2015) through collaborative work of 14 European research institutions. One of the main service of the TCS AH is the provision of standardized induced seismicity datasets and data products (episodes) that are available to the scientific community, industrial partners and public via a collaborative online platform. The episode is a comprehensive set of time-correlated, standardized geophysical, technological and other relevant geo-data. The episodes include waveform data, critical parameters (e.g. magnitude, depth, hypocenter location), seismic source parameters (e.g. corner frequency, seismic moment, source size, static stress drop) and additional information such as downhole pressure, mining front location, etc. An additional core service of the TCS AH is the provision of a variety of data processing and analysis applications (e.g. spectral analysis, stress tensor and moment tensor inversion, correlations between seismicity and technological factors, time-dependent hazard assessments in industrial environment, to name a few), also accessible via the online platform. Users have either the option to download episode data or to directly work on the data within their own private workspace using the alluded services to obtain new additional data products. Data is stored in two local data centers (eNode): "CIBIS" in Poland and "CDGP" in France. These entities are responsible for curating and serving the data for IS-EPOS users. It is noteworthy that they also provide and manage all metadata, related to the datasets, allowing the data to be cited properly. Both data centers take responsibility for quality in terms of legal as well as scientific aspects. The integration of the heterogeneous and multi-disciplinary data is subjected to a strict quality control (QC) procedure, composed of five steps, that include

close cooperation between data providers, the quality control and IT teams. With the aid of the Redmine system, tasks and responsibilities are allocated and supervised by the quality control managers designated by each of the collaborating groups. The first three steps of QC are performed at the local data center and include the: (1) transfer of episode data to one of the two existing local data centers, (2) data standardization and validation of formats, and (3) metadata preparation according to the TCS AH metadata scheme. The final two steps of QC are already performed at the level of the TCS AH website and include the (4) contextual analysis of data quality followed by the appearance of the episode in the TCS AH maintenance area, and, finally, the (5) episode publication on the TCS AH website. Six episodes have already been successfully implemented during the IS-EPOS phase. Five more episodes have been integrated within the SHEER project. In addition, there are currently six, already integrated, new episodes of the EPOS-IP project that are currently only available for EPOS-IP partners and members on the TCS AH online platform. These episodes are related to conventional and unconventional hydrocarbon extraction, geothermal energy production, reservoir impoundment, underground gas storage and underground mining. Concurrently, six new episodes are in preparation for an imminent publication on the TCS AH platform within 2018, as well as 3 new episodes that will follow in 2019. Moreover, the list of EPOS-IP episodes will be soon extended by 3 new additional episodes provided and prepared by CDGP. In the future, the SERA project (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe), also under the auspices of the European Union's Horizon 2020 research innovation programme, will contribute to the enlargement of EPOS-IP episode data and data products. By adding new components on earthquake engineering and new services, SERA and EPOS-IP as well as the industrial stakeholders will benefit from both of the projects. First, by enhancing the data density and keeping up to date published episodes of the EPOS-IP project (http://www.sera-eu.org/en/about/EPOS/) and second, by having the access to the services and analyses results made upon the data related to anthropogenic hazards, which are crucial issues in the industrial activities.

ESC2018-S2-522

MULTIDISCIPLINARY UPPER SILESIAN EPISODE AS A NEW HOLISTIC APPROACH IN BUILDING RESEARCH INFRASTRUCTURE

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Measurement polygons for the integrated observation of geodynamic processes are going to be built in the framework of the EPOS-PL project. EPOS-PL is a multidisciplinary infrastructural project, but in broader perspective there are significant scientific goals, which built RI is aimed for. Data and data products obtained during EPOS-PL may be used in specialized geoscientific research r in the project as well as in multidisciplinary, holistic approach exemplified by Multidisciplinary Upper Silesian Episode. The first polygons from the group of MUSE will be built in mining and post-mining areas of Upper Silesian Coal Basin (Poland). The first step to create the MUSE is to build an integrated geodetic observation system, which uses a combination of various point and surface measurement techniques. Additionally, in MUSE areas an integrated geophysical observation and measurement system will be used in order to observe physical processes, which take place inside the rock mass. The system will include local and regional seismological, geodetic, gravimetric and other geophysical networks. Collected data and products will be combined as a Multidisciplinary Upper Silesian Episode and shared through the IS-EPOS platform in the form of 3 new episodes forming multiservice of TCS AH. These three integrated episodes of anthropogenic effects caused by long term underground mining will allow for complex scientific studies based on specialized observations of the geodynamic processes on the mining and post-mining areas. The integrated geodetic observation system is necessary for the purpose of such observations. This system will be a combination of various complementary measurement techniques, which

allow for validation and scaling. Simultaneously, the geophysical observations of the underground physical phenomena in rock mass and shallow subsurface layers will be carried out. Spatial and temporal integration of various measurement techniques will allow for complete geodynamical observations of the area. Multidisciplinary anthropogenic hazard studies of the chosen area will allow better understanding of the complex interaction between mining activities and the environment. In such case the research and measurements should be carried out with the Polska Grupa Górnicza (PGG) allowance on their facilities. Building the super sites of integrated measurements and research within MUSE is a new way of building RI as well as heralding an open platform for bilateral knowledge transfer between industry and science. The project called EPOS-PL (No POIR.04.02.00-14-A003/16) is co-financed by the European Union from the funds of the European Regional Development Fund (ERDF).

ESC2018-S2-712

RESIF SEISMOLOGY DATA CENTER: INFRASTRUCTURES, SERVICES AND DATA

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RESIF is a nationwide french project aimed at building an high quality system to observe and understand the inner earth. Implementation is on its way since seven years. The goal is to create a network throughout mainland France comprising about 600 seismometers and geodetic measurement instruments, 250 of which will be mobile, to enable the observation network to be focussed on specific investigation subjects and geographic locations. RESIF national data center (RESIF-DC;http://seismology.resif.fr, DOI: 10.17616/R37Q06) is a centralized data distribution facility which is fully integrated into the much wider European scale project EPOS. Data from RESIF is distributed through worldwide FDSN and European EIDA (http://www.orfeus-eu.org/data/eida/) standard protocols. RESIF data services provide open data access for 11 permanent networks and more than 50 temporary experiments, including OBS data. The data center is hosted by the Grenoble Alpes Université, on the intensive computing and data infrastructures operated by GRICAD, which provides a high level of redundancy and availability for datacentres, network, storage and virtual CPUs infrastructures, as well as close connections to the CIMENT GRID infrastructure (https://gricad.univ-grenoble-alpes.fr/). In our presentation we will focus on the following aspects :

- the middleware infrastructure and the means we deployed to guarantee a high level of availability for services and data : integrated monitoring system, redundancy for database systems, class of services for storage and virtual CPU, isolation of services (docker);
- the functional architecture of RESIF-DC, which has been designed to take into account the needs of RESIF's information system consisting of six data validation centers, that guarantee a high level of data quality and metadata. This architecture is based on public domain components but also on homemade components that allow us to master the operation of data integration and the evolution of features (https://github.com/resif and https://gricad-gitlab.univ-grenoble-alpes.fr/OSUG/RESIF);
- data evolutions: new datasets and recently released data, format and services.

Finally, based on our experience, we will present our vision of the advantages and drawbacks of this infrastructure.

ESC2018-S2-723

ORFEUS DATA SERVICES AND PRODUCTS: THE CORNERSTONE OF SEISMIC DATA DISTRIBUTION IN EUROPE

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ORFEUS (Observatories and Research Facilities for European Seismology; https://www.orfeus-eu.org/) is a collaborative non-profit foundation that promotes seismology in the Euro-Mediterranean area through the collection,

archival and distribution of digital seismic waveform data, metadata and derived products. ORFEUS is one of the three pillars of the Thematic Core Service for Seismology within the European Plate Observing System (EPOS-S). Among the goals of ORFEUS are: (a) the development and coordination of waveform data products; (b) the coordination of a European data distribution system, and the support for seismic networks in archiving and exchanging digital seismic waveform data; (c) the encouragement of the adoption of best practices for seismic network operation, data quality control and data management; (d) the promotion of open access to seismic waveform data, products and services to the broader Earth science community, in close collaboration with EPOS-S. These goals are achieved through the development and maintenance of services targeted to a broad community of seismological data users. Two Service Management Committees (SMCs) are established within ORFEUS devoted to managing, operating and developing (with the support of one or more Infrastructure Development Groups): (i) the European Integrated waveform Data Archive (EIDA; https://www.orfeus-eu.org/data/eida/); and (ii) the European Strong-Motion databases (SM; https://www.orfeus-eu.org/data/strong/). The establishment of a third SMC is being discussed to represent the computational seismology community within ORFEUS. Access to ORFEUS EIDA and SM products is ensured through state-of-the-art information and communications technologies (ICT), with strong emphasis placed on federated web services that considerably improve seamless user access to data gathered and/or distributed by ORFEUS institutions. The web services also facilitate the automation of downstream products. Particular attention is also paid to acknowledging the crucial role played by data providers / owners, who are part of the ORFEUS community and sign formal agreements with the data distributors, where data policies and licenses are clearly identified. All ORFEUS services are developed in coordination with EPOS and are EPOS compliant. The products and services delivered by ORFEUS will be assessed and improved though the technical and scientific feedback of a newly established User Advisory Group (UAG), comprised of active European Earth scientists with expertise encompassing a broad range of disciplines. This contribution presents the products and services of ORFEUS and introduces the planned key future developments. We encourage community feedback about the ORFEUS strategies aimed at the continuous optimisation of data quality, access, dissemination and use.

ESC2018-S2-749

DEVELOPMENTS ON THE EPOS-IP PAN-EUROPEAN STRAIN RATE PRODUCT

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Strain rates are of great importance for Solid Earth Sciences. Within the EU Horizon 2020 project EPOS-IP WP10 (Global Navigation Satellite System - GNSS thematic core services) a series of products focused on strain rates derived from GNSS data is envisaged. In this contribution, we present preliminary results from 452 permanent European GNSS stations, operating until 2017 and processed at UGA-CNRS (Université Grenoble Alpes, Centre National de la Recherche Scientifique). We calculate the strain-rate field using two open-source algorithms recommended by EPOS-IP, namely the VISR (Velocity Interpolation for Strain Rate) algorithm (Shen et al., 2015) and STIB (Strain Tensor from Inversion of Baselines), developed by Masson et al., (2014) as well as the SSPX software suite (Cardozo and Allmendinger, 2009). The vertical velocity component is ignored in this stage and other sources of deformation (GIA, hydrological, anthropogenic et al.) are not considered in the interpretation. We compare the results derived from different methods and discuss the similarities and differences. Overall, our first results reproduce the gross features of tectonic deformation in both Italy and Greece, such as NE-SW extension across the Apennines and N-S extension in Central Greece. It is anticipated that the significant increase of GNSS

data amount associated with the operational phase of EPOS project in the forthcoming years will be of great value to perform an unprecedented, reliable strain rate computation over the western Eurasian plate.

ESC2018-S2-766

THE NEW CFTI5MED - CATALOGUE OF STRONG EARTHQUAKES IN ITALY AND IN THE EXTENDED MEDITERRANEAN AREA: AN ADVANCED, USER-FRIENDLY WEB-INTERFACE TO ACCESS A UNIQUE DATABASE OF HISTORICAL SEISMOLOGY

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A new, largely revised and updated version of the Catalogue of Strong Earthquakes in Italy and in the extended Mediterranean area, termed CFTI5Med, was released in 2018 by Guidoboni et al. (http://storing.ingv.it/cfti/cfti5/). The catalogue collects the results of over three decades of research on historical seismicity in Italy and is listed as the reference study for the vast majority of damaging earthquakes in the Catalogo Parametrico dei Terremoti Italiani (CPTI15: Rovida et al., 2016; https://emidius.mi.ingv.it/CPTI15-DBMI15/) and for several earthquakes listed in the Archivio Storico Macrosismico Italiano (Italian historical macroseismic archive, ASMI), which is part of the European Archive of Historical Earthquake Data portal (AHEAD), the European node for the collection and distribution of historical earthquake data in the framework of EPOS. What makes CFTI5Med different from all other earthquake catalogues is that its database does not only contain parametric data and macroseismic intensities assigned to individual localities, but also textual descriptions of the seismic scenario for each investigated earthquake sequence. The information is organized in a set of historical-critical comments providing a complete account of the territorial impact and of the social and economic upheaval caused, through both general descriptions for the entire earthquake sequences and specific comments for each individual locality. In addition to the effects on the built environment, CFTI5Med provides also descriptions of the effects induced by earthquakes on the natural environment, such as ground cracks, chasms, landslides, rockfalls, changes in the discharge rate of rivers and springs, tsunami effects, overflowing of lakes, etc.

For every investigated earthquake sequence, CFTI5Med supplies also the relevant bibliography in an organized form, allowing the reader to navigate upstream from the parameters of a specific earthquake to the original sources that were used to investigate that event.

A totally re-designed and more efficient web- and web-GIS interface now allows the user to fully appreciate and exploit the wealth of information gathered in the Catalogue. CFTI5Med provides information on over 1100 events in Italy (250 with epicentral intensity equal to or larger than intensity VIII on the MCS scale) and about 470 additional events in the whole Mediterranean area. With the new web-interface, the contents of the Catalogue can be accessed through database queries on various parameters of earthquakes and localities; detailed information on each earthquake and locality of the Catalogue is reported in specific, dedicated pages.

We implemented also a page dedicated specifically to the information on the earthquake effects on the natural environment, allowing for an immediate use of these data in case of an emergency. This is particularly important, as it is known that earthquake-induced effects on the natural environment tend to occur where they have occurred in the past.

The new CFTI5Med website, therefore, does not represent just a simple web-interface to access the data contained in the Catalogue, but is in fact an advanced e-infrastructure to navigate the CFTI database at different levels, allowing users to access the whole data tree from the original sources to the parametric data.

Starting from CFTI5Med, specific tools have been developed for the investigations in space and time of

complex earthquake sequences and for the comparison of different historical earthquakes. Particular attention was paid to the ease of use in order to allow users with different backgrounds to easily navigate through the highly diverse contents of the Catalogue. It is therefore a versatile application open to both expert users for new elaborations and to the general public.

ESC2018-S2-776

THE NEW VERSION OF THE CATALOGUE OF STRONG EARTHQUAKES IN ITALY AND IN THE EXTENDED MEDITERRANEAN AREA (CFTI5MED): A MODERN TOOL FOR PREDICTING FUTURE GROUND SHAKING BASED ON HISTORICAL SEISMOLOGY OBSERVATIONS

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A decade after publication of CFTI4Med (Guidoboni et al., 2007) we are proud to present a new, largely revised and updated version of the Catalogue of Strong Earthquakes in Italy and in the extended Mediterranean area, termed CFTI5Med (Guidoboni et al., 2018: http://storing.ingv.it/cfti/cfti5/). The Catalogue collects the results of research conducted on the historical seismicity of Italy and of the extended Mediterranea area since 1983. It comprises a reference study for several significant earthquakes listed in the Archivio Storico Macrosismico Italiano (Italian historical macroseismic archive, ASMI), which is part of the European Archive of Historical Earthquake Data portal (AHEAD), the node for the collection and distribution of historical earthquake data in the framework of EPOS. While the historical earthquake record is an outstanding source of information, particularly for Italy, it also carries the inherent danger - and perhaps the parodox - of generating a distorted picture of the seismogenic potential, usually resulting in an underestimation of the earthquake potential, but also often an overestimation. Until recently, the results of historical research have been summed up in traditional parametric catalogues, a form of presentation that indeed provides the basic information required by the elaboration of conventional seismic hazard models, but inevitably impoverishes the available information, potentially introducing biases and misrepresentations of the earthquake activity. Basic principles or earthquake source physics and actual observations show that two crustal earthquakes of a magnitude 6.0 and 7.0 may cause the same peak acceleration and the same maximum macroseismic effects, but the area of strongest ground shaking will be much smaller for the 6.0 magnitude quake with respect to the 7.0 event. In the absence of instrumental data, the relative importance of the two earthquakes can be understood only by compiling a complete picture of their dynamic effects: something that traditional earthquake catalogues, focusing only on epicentral intensity, failed to supply. The Catalogue reversed this trend, allowing for a more complete appreciation of the total energy released by any given earthquake and of the finest characteristics of its territorial impact. It is hence an analytical catalogue, supplying all the information available for any given earthquake in a pre-defined and easily accessible format, and includes data and observations that may not be immediately relevant to seismic hazard applications. These additional data but may be of interest for broader seismic risk analyses and for a number of other applications such as the historical investigation of complex earthquake sequences in time and space, studies of the linguistic, social and economic history and of the evolution of local building, and the planning of interventions on the historical heritage. The Catalogue is hence the vault that preserves for the present and for future generations the wealth of information gathered through old and new research strategies over 35 years of research. In particular the new CFTI5Med (2018) features:

- 1,259 earthquakes that occurred in the Italian area between 461 B.C. and 1997, including 42,663 intensity datapoints obtained by analyzing and rating the effects on the built environment (macroseismic observations) and 2,338 datapoints obtained by analyzing and rating the effects on the natural environment (earthquake-induced environmental effects);
- 475 earthquakes that occurred between the years 760 B.C and 1500 in Italy and the Mediterranean area. For 223 earthquakes that occurred up to the end of the 10th century we provide only the epicentral location, whereas for those that occurred between the 11th and 15th

century we provide 635 original intensity datapoints obtained by analyzing and rating the effects on the built environment (macroseismic observations), based on sources in the original historical languages (Greek, Latin, Arabic, Syriac, Armenian, Coptic, carefully translated into English) and 68 datapoints obtained by analyzing and rating the effects on the natural environment;
- the retrieval and formatting of over 23,000 original bibliographic documents - transcribed or printed – nearly 50% of all those utilized in the CFTI5Med. These documents are now available on-line as fully searchable pdf files;
- a full geological reinterpretation, georeferencing and reprocessing of over 2,300 descriptions of earthquake-induced environmental effects, which are now all available and searchable in a user-friendly web-GIS environment;
- the elaboration of a number of texts and commentaries that were missing from the CFTI4Med version of the catalogue;
- a totally re-designed and more efficient web- and web-GIS interface, that allows the Catalogue contents to be consulted along with relevant topographic, geological and seismotectonic information (see presentation by Sgattoni e al., 2018: this meeting).

ESC2018-S2-788

EGD: THE EUROPEAN GEOTECHNICAL DATABASE

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The European Geotechnical Database (EGD) is one of the few EPOS services that are not already mature but are being designed and developed entirely within the EPOS-IP project and more specifically within Task 8 on “Hazard and Risk” of the project. The aim of EGD is to evolve to “a Europe-wide geotechnical, geological and site conditions inventory, collecting and harmonizing national/regional databases” and to disseminate this information by the use of appropriate web services. Collection of data is pursued for both the permanently instrumented sites and other, non-instrumented yet well-studied sites (i.e. sites whose profiles have been intensively studied through invasive and/or non-invasive geophysical techniques). Information in EGD is organized in two levels:
- 1st level information is considered basic for the geotechnical characterization of a site and is of interest to the broader engineering and seismological community and not strictly to researchers. Example 1st level parameters are the EC8 class of a site, its average shear-wave velocity over the top 30 meters of the soil column (VS30) and the resonant frequency of the soil column. An extensive list of 1st level parameters can already be found on the EGD web portal (egd-epos.civil.auth.gr/).
- 2nd level information aims to the detailed, research-oriented geotechnical description of a site and includes borehole information, full measured profiles (compressional and shear wave velocity, attenuation etc.) and other parameters often used in site characterization, resulting from geotechnical investigation tests such as Standard Penetration Test, Cone Penetration Test, classification and strength tests.
Regarding the implementation of EGD, EGD will act as a node that will be sending user-defined queries to existing national and/or institutional databases. If such databases do not exist or partners do not meet the minimum communication quality standards, pertinent data (upon agreement with the partner) will be stored in the EGD database. The web interface for viewing EGD data (egd-epos.civil.auth.gr/), along with a user interface to facilitate manual data entry whenever required, is under active development. The web-service is currently hosted by AUTH. EGD service is expected to be implemented within 2018 and to be integrated within the European Facilities for Earthquake Hazard and Risk (EFEHR) portal.

ESC2018-S2-814

IMPROVING THE ACCESSIBILITY OF DATA ON EUROPEAN HISTORICAL EARTHQUAKES

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AHEAD, the European Archive of Historical Earthquake Data, aims at i) supporting researchers in improving the knowledge on historical earthquakes by retrieving and relating existing data, and ii) making data findable and accessible

to both expert and non-expert users. The web portal of AHEAD (https://www.emidius.eu/AHEAD/), first opened in 2010, allows anyone to investigate the background information supporting earthquake parameters reported in earthquake catalogs, by means of a web graphical user interface, only. Such an interface is designed only for human interaction with the data, and does not support any fully-automated workflow, which would require to find, retrieve and manually transfer the data from AHEAD, an unacceptable procedure in a modern data-centric environment. An efficient system should instead allow to perform actions such as data searching in a machine-friendly way, and should optimize the data transfer to the bare minimum. Within the EPOS initiative (https://www.epos-ip.org/) a series of guidelines for interoperability were promoted in order to make data service providers interact with the Integrated Core Services (ICS) using the so-called web services. As AHEAD is the European node providing data to EPOS, a series of web services that allow for a machine friendly way to retrieve the archived data, are being created. Through the webservices of AHEAD, earthquake parameters as assessed in alternative catalogs can be accessed using either an FDSN-event compliant web service, or using an OGC (Open Geospatial Consortium) WMS (Web Map Service), or an WFS (Web Feature Service). Macroseismic intensity data can be accessed using a web service having the same query parameters as FDSN-event, with additional specific parameters to deal with macroseismic data and encoding them using the XML schema of the QuakeML 2.0 macroseismic package. Bibliographical metadata describing each data source archived in AHEAD can be accessed using a web service that is able to encode results in Dublin Core XML or BibTex. A list of AHEAD web services, as well as their documentation, is available at https://www.emidius.eu/AHEAD/services. To support regional nodes in their publication online of macroseismic data on historical earthquakes, an updated version of the open source tool called MIDOP (Macroseismic Intensity Data Online Publisher) was recently made available. The control panel of MIDOP is now more reliable and the engine is now able to produce a website allowing users to perform data filtering based on earthquake parameters such as magnitude, number or macroseismic data points or maximum intensity, or to perform a geographical selection directly on the maps. Data published with MIDOP can be made available in the usual formats (MS Excel or CSV) or as XML, based on the same QuakeML 2.0 macroseismic package schema used by the AHEAD macroseismic web service.

ESC2018-S2-847

WHAT ARE YOU TALKING ABOUT? TOWARDS HARMONIZING AND FORMALIZING VOCABULARIES WITHIN SEISMOLOGY AND BEYOND

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While seismologists in general likely would agree that they know what their peers mean when talking about an 'earthquake', this agreement is challenged as soon as the 'types of earthquakes' enter into the discussion. Looking a bit further, the term 'event' that we readily employ in our conversations, may be interpreted quite differently as soon as we leave our specific domain. As long as participants in these discussions are scientists with domain-relevant education, we usually can resolve ambiguities and clarify different interpretations by talking to each other, as cumbersome as that might sometimes be. However, once we involve machines (essentially, computer programs) to support and perhaps even automate discovery of, access to, and utilization of data and products, and in particular when we strive for cross-domain interoperability, we soon realize that a more formalized treatment of our terms and definitions is needed. Such a formalization is also required in order to develop and implement mechanisms (like ontologies or semantics) to map and relate terms across domains or any other boundaries. This

issue continues with higher-level standardizations as e.g. in the ISO/OGC standard Observation and Measurements (O&M) and its various applications, or with the code list register of the EU INSPIRE directive, where we often have difficulties to reconcile our domain-specific understanding and usage of particular terms with how they are defined or described in the more general concepts. Within the European Plate Observing System (EPOS), an effort has been started to look in detail at the vocabularies that are used in the various domains of solid Earth sciences (from standards or established use in a domain or created for EPOS), and from there develop strategies and plans how they might be integrated and/or harmonized and put into more controlled formats. The EPOS Vocabulary Task Force, an initiative of the EPOS Service Coordination Board, has participants from various domain-specific 'Thematic Core Services' (TCS) as well as the EPOS 'Integrated Core Services' (ICS). In addition to EPOS internal coordination we also seek to coordinate with and get involved in related initiatives around the globe like EarthCube or AUscope within the Earth sciences, or the Open Geospatial Consortium OGC and the Research Data Alliance RDA for the higher level standards and formats, in order to secure the widest possible community support and buy-in, and to ensure exploitation of synergies and optimization of resources. A first specific initiative was the initiation of the Geoscience Domain Working Group of the OGC by a group that included several EPOS partners (https://external.opengeospatial.org/twiki_public/GeoScienceDWG/WebHome). There, an interoperability experiment for borehole data will be launched in the near future and one for geoscientific models is planned. The EPOS Vocabulary Task Force as well as EPOS Seismology for the sub-domain are actively following these activities and engage where suitable. In this presentation we introduce our approach towards harmonizing and formalizing vocabularies across EPOS and discuss the challenges and envisioned benefits. We explain how we connect to other relevant initiatives and organizations and how we intend to establish community input and validation into the formalization process.

ESC2018-S2-881

EUROPEAN PLATE OBSERVING SYSTEM - NORWAY (EPOS-N): NORWEGIAN SOLID EARTH DATA INTEGRATION

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The European Plate Observing System (EPOS) aims to create a pan-European infrastructure for solid Earth science to support a safe and sustainable society (Horison2020 – InfraDev Programme – Project no. 676564). The main vision of the European Plate Observing System (EPOS) is to address the three basic challenges in Earth Science: (i) unravelling the Earth's deformational processes which are part of the Earth system evolution in time, (ii) understanding geo-hazards and their implications to society, and (iii) contributing to the safe and sustainable use of geo-resources. The mission of EPOS-Norway is therefore in line with the European vision of EPOS, i.e. monitor and understand the dynamic and complex Earth system by relying on new e-science opportunities and integrating diverse and advanced Research Infrastructures for solid Earth science. The EPOS-Norway project (RCN Infrastructure Programme – Project no. 245763) started in January 2016 with a national consortium consisting of six institutions. These are: University of Bergen (Coordinator), NORSAR, National Mapping Authority, Geological Survey of Norway, Christian Michelsen Research and University of Oslo. EPOS-N will during the next five years focus on the implementation of three main components. These are: (i) Developing a Norwegian e-Infrastructure to integrate the Norwegian Solid Earth data from the seismological and geodetic networks, as well as the data from the geological and geophysical data repositories, (ii) Improving the monitoring capacity in the Arctic, including Northern Norway and the Arctic islands, and (iii) Establishing a national Solid Earth Science Forum providing a constant feedback mechanism for improved integration of multidisciplinary data, as well as training of young scientists for future utilization of all available solid Earth observational data through a single e-infrastructure. A list of data, data products, software and services (DDSS) is already prepared. Integration of these elements with the EPOS-N data/web-portal has started. In addition to the

standard data and data products, such as seismological, geodetic, geomagnetic and geological data, there are a number of non-standard data and data products that will be integrated. A prototype of the EPOS-N data/web-portal is already developed and has been tested extensively through a dedicated user workshop. In parallel, advanced visualization technologies are being implemented, which will provide a platform for a possible future ICS-D (distributed components of the Integrated Core Services) for EPOS.

ESC2018-S2-926

SEISMIC SAFETY INSTRUMENTAL MONITORING SYSTEM

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In the given paper, the system for engineering-seismometric observations is described, developed by Institute of Geophysics and Engineering Seismology after A. Nazarov of the Republic of Armenia (IGES NAS RA). The study of the seismic regime and the assessment of the seismic hazard and risk of large cities, responsible energy and hydraulic structures, monitoring and earthquake forecasting, is an extremely important scientific and applied task. It has both socio-economic and strategic importance, since it is associated with the preservation of human lives and large material values. In this work the system of engineering seismometric observations developed by IGES NAS RA is described for remote seismic monitoring of the territories of large cities and especially responsible energy and hydraulic structures located in the seismically active regions, obtaining digital quantitative data on the degree of possible seismic impacts and their application when developing measures to reduce seismic risk and their seismic protection insurance.

ESC2018-S2-930

DEVELOPMENT OF ADVANCED INFRASTRUCTURE FOR EARTHQUAKE SCIENCE IN TAIWAN: THE TAIWAN EARTHQUAKE RESEARCH CENTER (TEC)

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Taiwan is located at the convergent plate boundary zone between the Eurasian and the Philippine Sea plates. As a consequence, intense earthquake activity and associated crustal deformation are manifesting in this region. In 1999, the disastrous Chi-Chi earthquake with Mw 7.6 hit central Taiwan and caused severe damage. Since then, the Taiwan government funded a 5-year program for research community to better understand the active seismogenic structures and prepare the residents for the next big one. In 2005, the Taiwan Earthquake Research Center (TEC) was sponsored by the Ministry of Science and Technology (MOST) to keep the momentum to not only initiate innovative researches, but also integrate available resources for earthquake science and education and outreach. TEC is governed by an executive committee that is composed of senior scientists from various research institutions. In addition, two TEC instrument pools providing Taiwan research community with portable seismometers, GNSS devices and geophysical instruments, and the TEC data center are funded as well. These research facilities are supervised by a steering committee and play as basic e-infrastructures for seismological researches. After an M4.2 earthquake occurred right beneath the metropolitan Taipei area in 2014, TEC had organized a Commission on Education and Outreach (CEO) to communicate with the public in several ways right after the occurrence of a significant earthquake in the Taiwan region or worldwide. In the past decade, TEC has successfully promoted plenty of important works on Real-time seismology, Earthquake Early Warning (EEW), Taiwan Earthquake Model (TEM) and citizen seismology developed in Taiwan. TEC is now hosting most of these web based platforms for scientists and general public. To take the future challenges, TEC is seeking for possible international collaboration on all aspects of earthquake science and education and outreach. More information about TEC is accessible at: http://tec.earth.sinica.edu.tw.

ESC2018-S2-956

THE EUROPEAN DATABASE OF SEISMOGENIC FAULTS E-INFRASTRUCTURE: PAST, PRESENT, AND FUTURE CHALLENGES

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The European Database of Seismogenic Faults was conceived in the framework of the EU FP7 project SHARE (http://www.share-eu.org) as an expansion of the Italian Database of Individual Seismogenic Sources (DISS; http://diss.rm.ingv.it/diss/), and published online in 2013. EDSF contains data about 1,128 records for ~63,775 km of crustal faults over the entire Euro-Mediterranean area deemed to have the potential of generating earthquakes of at least Mw 5.5, three subduction zones in the Eastern Mediterranean, and an extended list of contextual references. Crustal faults are represented with a down-dip planar geometry, whereas subduction zones are represented by a complex 3D geometry of the slab. The EDSF e-infrastructure allows the users to navigate the database through the web browser and download data for desktop GIS. Seamless access to data is also ensured through WFS & WMS OGC standards. The e-infrastructure is accessible at http://www.seismofaults.eu/. Data services are mapped in the EPOS-specific DCAT-AP extension "EPOS-DCAT-AP" in order to make EDSF data reachable through the EPOS ICS platform. EDSF metadata were compiled following the principles of the European Directive INSPIRE for spatial data and services. EDSF allows the user to easily convert the fault data for input in the OpenQuake platform and has been used already in a number of earthquake hazard applications and geodynamic models. Currently, this e-infrastructure is being enhanced for virtual access by the community of seismic engineers together with the AHEAD - European Archive of Historical EArthquake Data and ESM - Engineering Strong-Motion databases through the SERA-VA3 work package (http://sera-va3.rm.ingv.it) of the H2020 EU project SERA. Meeting the requirements and demands from the enlarging geoscience community and its integration within EPOS has challenged the current EDSF e-infrastructure, which is now undergoing a general re-design with a focus onto making it more flexible and scalable. With this presentation we want to discuss with all interested parties, users and contributors, how to tackle these new developments.

ESC2018-S2-963

ARISTOTLE (ALL RISK INTEGRATED SYSTEM TOWARDS THE HOLISTIC EARLY-WARNING)

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ARISTOTLE (http://aristotle.ingv.it/) is a Pilot Project funded by the DG ECHO (EU Humanitarian Aid and Civil Protection) that provides expert scientific advice on natural disasters around the world that may cause a country to seek international help to the EU's Emergency Response Coordination Centre (ERCC) and, consequently, to the Union Civil Protection Mechanism Participating States. The EU is committed to providing disaster response in a timely and efficient manner and to ensure European assistance meets the real needs in the population affected, whether in Europe or beyond. When a disaster strikes, every minute counts for saving lives and rapid, coordinated and pre-planned response is essential. The ARISTOTLE consortium includes 15 partner institutions (11 from EU Countries; 2 from non-EU countries and 2 European organizations) operating in the Meteorological and Geophysical domains. The project coordination is shared among INGV and ZAMG for the geophysical and meteorological communities, respectively. ARISTOTLE harnesses operational expertise from across Europe to form a multi-hazard perspective on natural disasters related to volcanoes, earthquake (and resulting tsunami), severe weather and flooding. Each Hazard Group brings together experts from the particular hazard domain to deliver a 'collective analysis' which is then fed into the partnership multi-hazard discussions. Primary target of the pilot project has been the prototyping and the implementation of a scalable system (in terms of number of partners and hazards) capable of providing to ERCC the sought advice. To this end, the activities of the project have been focusing on the establishment of a "Multi-Hazard Operational Board" that is assigned the 24*7 operational duty regulated by a "Standard Operating Protocol" and

the implementation of a dedicated IT platform to assembly the resulting reports. The project has provided routine and emergency advice services since February 2017 until January 2018. The presentation will illustrate the different modes of operation envisaged and the status and the solutions found by the project consortium to respond to the ERCC requirements. Since the reporting provided by ARISTOTLE avails of existing ORFEUS/EPOS-S web services, particular focus will be given to show the services used, the specific services developed within the project and those publicly available also used. It will be shown how by gathering different services the reporting for ERCC can be easily composed by a team of hazard experts working together simultaneously on the same document.

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SESSION 03

ESC2018-S3-44

OVERVIEW OF AUSTRIAN SEISMOLOGICAL SERVICE IN 2017

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The Austrian Seismic Network (network code OE) is currently composed of 37 strong-motion stations and 17 broadband stations. Among the 37 strong motion stations, there are 14 sites co-located with the broadband stations. These 14 strong-motion station already provide continuous data. In 2017, there are six strong-motion stations with triggered data upgraded to the continuous data mode. The remaining 17 strong-motion stations still providing triggered data will be upgraded to the continuous data mode in 2018/2019. An overview of seismic monitoring at the Austrian Seismic Network will be presented for the year of 2017. A comparison is made between automatic processing and manual evaluation results. Performance of the automated data processing, station performance, statistics and information about significant earthquakes and earthquake sequences in Austria will be presented as well.

ESC2018-S3-216

BULGARIAN SEISMOLOGICAL NETWORK-CURRENT STATUS, PRACTICAL AND SCIENTIFIC IMPLEMENTATION

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The reliable scientific information is one of the best bedrocks on which effective policy to combat and cope with natural disasters has to be built. Understanding, monitoring and information for future natural disasters is the way to assist government and society. One of the main priorities of seismic networks is directed to study seismicity of the Earth. The Bulgarian seismological network - NOTSSI (National Operative Telemetric System for Seismological Information) was founded in the end of 1980. Today the network comprises of 16 permanent seismic stations spanning the entire territory of the country and two local networks that are deployed around the town of Provadia and Kozloduy NPP in Bulgaria. Kozloduy NPP is the only nuclear power plant in Bulgaria and the main electricity generating plant providing more than one third of the total annual electricity output of the country. Environmental protection is a fundamental matter in the company's policy. Different types of networks provide reliable information on various natural disasters and can be considered as an important element of NPP's safe operation. A local network (LSN) of sensitive seismographs around Kozloduy NPP operates since 1997 and covers 3 stations, installed permanently within and close to the near 30 km region. The main goal of the local seismological network is to supplement the available seismological data with more detailed information on small earthquakes occurring in the near region of Kozloduy NPP. The intended use of System of Accelerographs for Seismic Monitoring of Equipment and Structures (SASMES) deployed in Kozloduy NPP is to register and record the seismic motions in featured points of the building structure and equipment. The registration is implemented in real-time whilst the absolute accelerations of the seismic motion at the selected points are recorded both in horizontal and vertical direction. In this study, we focus on practical and scientific implementation of seismological information from the Local Seismological Network (LSN) and System of Accelerographs for Seismic Monitoring of Equipment and Structures (SASMES).

ESC2018-S3-532

THE UPGRADED NATIONAL NETWORK OF SEISMIC STATIONS IN SLOVAKIA

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Before the year 2001 the Slovak National Network of Seismic Stations (NNSS) consisted of six permanent stations and the ability to localize seismic events was at very low level. The average number of localized earthquakes was 7! The NNSS

has been modernized and extended in the years 2001-2004. The breakthrough occurred in the year 2005 with the fully operational network when the number of localized earthquakes with epicentre on the territory of Slovakia increased up to 50. Currently the network consists of eight short period and five broadband seismic stations. Three basic types of stations can be classified like cave, well and surface stations. A typical seismic station was equipped with a sensor (short period or broadband), 16bit digitizers, GPS, classic PC and satellite at the beginning. Some of them are in operation without equipment changes since the installation, others have undergone upgrading process partly or completely (e.g. 24/32bit digitizers, 12V mini-PC). Some stations have been moved to new locations due to signal problem caused by increased level of background seismic noise. Now the average number of the localized tectonic earthquakes with epicentre on the territory of Slovakia is approximately 70-90 per year. Accurate localization of earthquakes allows precise definition of seismo-active areas, respectively. Due to modernized seismic network, precise localization of earthquake epicentres confirms recently active fault zones. Recent years of data acquisition and processing showed the necessity to build additional stations in various parts of Slovakia, particularly in Spiš and Kysuce regions. Several additional stations have already been added in cooperation with other institutions in the Little Carpathians, however adding some more stations would be useful. Keywords: seismic network, localization, Slovakia, Western Carpathians

References:

ESI SAS (Earth Science Institute of the Slovak Academy of Sciences) (2004): National Network of Seismic Stations of Slovakia. Deutsches GeoForschungsZentrum GFZ. Other/Seismic Network. doi:10.14470/FX099882

Acknowledgement: The authors have been supported by the Slovak Foundation Grant VEGA 2/0188/15 and The Slovak Research and Development Agency Grant APVV-16-0146.

ESC2018-S3-578

THE EIDA MEDIATOR WEB SERVICE

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EIDA (European Integrated Data Archive), standardized web services have been very successful in homogenizing access to seismic data in Europe: Waveforms (fdsnws-dataselect), instrumentation metadata (fdsnws-station) and data quality information (eidaws-wfcatalog) are available on harmonized web service interfaces from many observatories, and an eidaws-routing service points to authoritative information providers and service endpoints available for seismic networks, instrument types or regionally confined requests. However, many scientific data retrieval tasks (e.g. “retrieve gap-free waveform data from broadband stations in the western Alps which have been operated for at least 10 years”) remain a complex sequence of talking to different services, interpreting response, and using the results for subsequent retrieval steps. Within the EIDA-next generation initiative, the eidaws-mediator service has been designed as a core component to simplify scientific data retrieval: In its federation mode, it offers one endpoint for each of the classical FDSN and EIDA services, for data retrieval from all EIDA partners, transparently negotiating trust and discovering, retrieving and merging data from the authoritative data centers. In its mediation mode, it allows cross-domain queries, e.g. requesting waveform data (dataselect domain), selected by station properties (station domain) and waveform quality indicators (wfcatalog domain) in a single step. Besides a simple direct request mode, a registered mode is planned. Here, requests are flagged with persistent identifiers, allowing other scientists to retrieve the detailed definition of a retrieved dataset, alongside with processing logs and correct citation of the data. The new service should make access to and sub-selection of seismological data less time consuming and error-prone, and help improving the transparency and reproducibility of science. The mediator has been specified by the EIDA technical committee and is currently under implementation at the Swiss Seismological Service at ETH Zurich. The talk gives an introduction to the planned functionality as well as challenges of the implementation.

ESC2018-S3-683

SEISMIC MONITORING BY THE NORWEGIAN NATIONAL SEISMIC NETWORK

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The Norwegian National Seismic Network (NNSN) is operated by the University of Bergen (UiB) to monitor an area covering mainland Norway, the North Sea, Norwegian Sea, Barents Sea and the arctic archipelago of Svalbard. Today, the network consists of 34 seismic stations distributed over the Norwegian mainland and the arctic islands Jan Mayen, Bjørnøya, Hopen and Spitsbergen. The main purpose of the network is to monitor the local and regional seismic activity. The Norwegian mainland and coastal areas are only moderately active, and the largest regional earthquakes occur along the Mid-Atlantic ridge. North of Iceland, Jan Mayen is an active volcanic island with most recent eruptions in 1970 and 1985 that is monitored by UiB. With its distribution and station quality the network also provides data to various scientific studies. The network data are openly available and phase data are submitted to international agencies. This presentation gives an overview of the network history and current status, the data processing systems and the seismicity that is recorded.

ESC2018-S3-708

USARRAY TRANSPORTABLE ARRAY - DESIGN, EVOLUTION, AND IMPACT

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Between 2004 and 2015, the USArray Transportable Array (TA) comprised a rolling array of ~400 broadband seismic stations. TA stations consisted of observatory-grade broadband seismometers deployed on a regular grid spacing of ~70 km. Each station was occupied for at least 18 months. The initial footprint was established in the west and then “rolled” as stations along the western edge of the array were removed and redeployed along the eastern edge at a rate of about 19 per month, maintaining an array with a typical aperture of ~1,400 km. Altogether nearly 1,700 TA sites were installed and operated in the Lower 48 States. After several years of prototyping and testing, in 2015 the TA starting rolling out on a nominal 85 km grid in Alaska, completing deployment in 2017 utilizing 280 stations. The Transportable Array has implemented several types of ancillary data: barometric pressure, infrasound, strong-motion, and soil temperature profilers that serve to broaden interest in the observational approach. We will review some of the notable challenges and choices made during the execution of the TA experiment. A key theme of this project from inception, is the scale and speed at which operations take place, and the dedication and skill of those laboring to deliver the highest quality data possible. This places requirements on the manufacturability of a station, not just in the equipment, but also in the process and procedures from permitting, to installation and even removal. This scale also affords innovation to devise alignment tools, molded tanks, complex diagnostic monitoring and auxiliary electronics and pressure sensors to supplement the ground motion instrumentation. We will also describe some of the newest innovations we have applied for the Alaska deployment. In parallel, the TA computational design requirements and solutions for integrated real time software, hardware, networking, and data distribution will be reviewed. To date more than 30 terabytes of raw science data has been collected, enabling hundreds of presentations annually, and the growing library of journal articles and PhD dissertations. One of the core legacies of the data set are very long continuous segments from well-oriented and uniform sensors. This data is merged together from two separate sources, the real time telemetered volume and a locally stored volume, to produce the best overall continuity. This attribute makes possible many of the big data approaches to analysis, by eliminating gaps and other anomalies that would have created unnecessary challenges in analysis. Though there is a diversity of channels with different types of sensors and a large number of stations, the uniform and accurate metadata derives from professional curation and constant active utilization which enhances suitability for big data approaches.

ESC2018-S3-756

FAIRYTALE - TOWARDS FAIR SEISMOLOGICAL DATA MANAGEMENT IN THE EUROPEAN INTEGRATED DATA ARCHIVE (EIDA)

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As the production, availability and quantity of data has drastically increased in recent years the requirement for proper data management is widely recognised in all scientific disciplines. In seismology, EIDA maintains the largest European seismic data archive for continuous waveform data. Eleven data centers participate in a federation to provide standardised data discovery and access services. Besides the well-established services for station metadata and waveform data access, a service called WFCatalog was designed and implemented within the EIDA technical group to facilitate the discovery of waveform data. The WFCatalog (Trani et al., 2017) is a metadata catalogue that describes archived collections of continuous seismic waveforms available through EIDA. It enables users to discover seismic data based on a criteria including spatial and temporal constraints, quality metrics, availability, and other parameters. Ongoing work is made to improve the interoperability of seismic data with other geoscientific fields (e.g. volcanology; GNSS). This work is carried out under the H2020 project EPOS-IP. Some EIDA data centres have started with the assignment of persistent identifiers (PIDs) to their seismic archives. Such an identifier is associated with a dataset through its life cycle and will make seismic data reusable, support provenance, enable attribution in the derived scientific work and foster reproducibility. Thanks to the technologies and strategies adopted, EIDA is able to adhere to the four FAIR principles as summarised below. Persistent identifiers (ePIC1) are supported and a metadata catalogue (WFCatalog2) is implemented and exposed through a web API to make data findable. The PID resolver points users to the related landing pages for data, and an API powered by an AAAI enables the user community to obtain the data making it accessible. The standardized output formats (e.g. JSON, Stationxml, miniSEED) for data and metadata, and the use of semantic vocabularies, which are jointly designed with other disciplines close to seismology, ensure that seismological datasets are interoperable across domains. Current client tools provided by EIDA (e.g. fdsnwsscripts3) support also standard services to inform the user the status of data regarding licensing, citation, and usage policies that meet domain-relevant community standards, making the data reusable.

Trani et al., 2017 WFCatalog: A catalogue for seismological waveform data Computers & Geosciences vol. 106 10.1016/j.cageo.2017.06.008
1 http://www.pidconsortium.eu/
2 https://www.orfeus-eu.org/data/eida/webservices/wfcatalog
3 https://www.seiscomp3.org/doc/applications/fdsnws_scripts.html

ESC2018-S3-769

THE ALPARRAY-CASE SEISMIC EXPERIMENT: INVESTIGATION OF THE CENTRAL ADRIATIC LITHOSPHERE STRUCTURE

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The Adriatic microplate forms the upper plate in the collision front in the Western and Central Alps whereas it forms the lower plate in contact with the Apennines and the Dinarides. However, the tectonics of Adriatic microplate is yet not well constrained and remains controversial, especially at its contact with the Dinarides. While the northern part of the Adriatic microplate will be accurately imaged within the AlpArray project, its central and southern parts deserve detailed studies to obtain a complete picture of its structure and evolution. We set up the Central Adriatic Seismic Experiment (CASE) as an AlpArray Complementary Experiment with a temporary seismic network to provide high-quality seismological data as a foundation for research with state-of-the-art methods and high-precision seismic images of the controversial area. The international AlpArray-CASE project involves four institutions: the Department of Earth Sciences and the Swiss Seismological Service of ETH Zürich (CH), the Department of Geophysics of the Faculty of

Science at the University of Zagreb (HR), the Republic Hydrometeorological Service of the Republic of Srpska (BIH) and Istituto Nazionale di Geofisica e Vulcanologia (I). The established temporary seismic network will be operational for at least 18 months. It combines existing permanent and temporary seismic stations operated by the involved institutions together with newly deployed temporary seismic stations, installed in November and December 2016, managed by ETH Zürich and INGV: five in Croatia, four in Bosnia and Herzegovina and one in Italy.
We present our scientific aims and network geometry as well as newly deployed stations sites and settings. In particular, the new stations show favourable noise level (power spectral density estimates). The new network improves considerably the theoretical ray coverage for ambient noise tomography and the magnitude threshold shown in the Bayesian magnitude of completeness threshold map.
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ESC2018-S3-858

ACQUIRING, ARCHIVING, ANALYZING AND EXCHANGING SEISMIC DATA AT THE SEISMOLOGICAL RESEARCH CENTER OF THE OGS IN ITALY

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After the 1976 Friuli earthquake (Ms = 6.5) in Northeastern Italy that caused about 1,000 casualties and widespread destruction in the Friuli area, the Italian government established the Centro di Ricerche Sismologiche (CRS). This is now a department of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), and it is specifically devoted to the monitoring of the seismicity of Northeastern Italy. Since its inception, the North-East Italy Seismic Network has grown enormously. Currently, it consists of 24 broad-band and 17 short-period seismic stations, all of which are telemetered to and acquired in real time at the OGS-CRS data center in Udine. Data exchange agreements in place with other Italian, Slovenian, Austrian, Croatian and Swiss seismological institutes lead to a total number of 114 seismic stations acquired in real time, which confirms that the OGS is the reference institute for seismic monitoring of Northeastern Italy. Since 2002, CRS has been using the Antelope software suite as the main tool for collecting, analyzing, archiving and exchanging seismic data. SeisComP is also used as a real-time data exchange server tool. A customized web-accessible server is used to manually relocate earthquakes, and automatic procedures have been set-up for moment-tensor determination, shaking-map computation, web publishing of earthquake parametric data, waveform drumplots, state-of-health parameters, and quality checks of the station by spectra analysis. Scripts for email/SMS/fax alerting to public institutions have also been customized. The real-time seismology websiteof the OGS CRS is: http://rts.crs.inogs.it/

ESC2018-S3-874

CGS BROADBAND NATIONAL NETWORK, STATE OF ART

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As part of its monitoring activities, the National Center of Applied Research in Earthquake Engineering Algeria (CGS) includes a National strong motion accelerometers network (335 stations), and a National Broadband seismic network (five stations) located in northern part of the country. In the effort to install the Broadband stations a methodology was adopted, inspired from the international standard and adopted with local needs. As first step administrative contacts was made with the local authorities in concerned Wilaya (departments), then in sites visit and primary site selection, followed by geophysical field studies, then shelter building and final installation. Three sites was obtained and geophysical studies at each site was undertaken. Biskra, called Sahara door, located south east of Algeria is the first studied site; we installed two broad band seismological stations for continuous recording during four weeks, enabled us to

calculate daily PSD (Power spectral density) for each station and signal noise ratio SNR (signal to noise ratio) using local and regional seismic event recorded by the stations. For under ground recognition at selected site we applied some geophysical methods such as seismic, electric, gravimetry and H/V technique. All these studies allowed us to establish an underground profile below the site planned for future station installation. The results show that the site consists of 3 layers reach more than 16 meter depth. The first layer develops until 2,5m depth with 300-1000 m/s and 100-900 Ω·m resistivities, the second layer is 6 to 11m thickness with velocity 2700m/s average and 10-65 Ω·m resistivity, the last layer reached 11-16m depth with 4000-5000 m/s velocity and 150-5000 Ω·m resistivity increase with depth. The residual anomaly estimated with gravimetry method shows two negative anomalies respectively about -20 µgal and -52 µgal which do not indicate cavity presence confirmed by electric method. The analysis of H/V ratio shows three dominant frequency's, between 0,6-2Hz indicating amplification function, between 6-9,5Hz indicating deep velocity contrast, finally between 21 and 32Hz representing surface layer response. All these characteristics represent a consolidate sol acceptable for seismological station installation. The seismic shelter was built under four meters deep on a surface of 4 m² and divided in two levels, the bottom one host the broadband sensor and the electronics are installed on the top-level. The seismic pier was made with cyclopean concrete within 2,25m² surface and the shelter walls are in reinforced concrete surrounded with a stone wall to improve thermal isolation. Data are collected manually at each regular visits to stations. Actually we are working on a real-time data telemetry using mobile phone networks internet connection and Seiscomp3 as a data acquisition system.

ESC2018-S3-878

CURRENT STATUS OF SEISMIC DATA MANAGEMENT AT KNMI

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The Royal Netherlands Meteorological Institute (KNMI) R&D Seismology and Acoustics Department is the national authority for information and hazard evaluation on natural and induced seismicity and sources of infrasound in The Netherlands. Our department operates and deploys sensor networks that provide high quality data for 24/7 real-time monitoring and research purposes. The operations of the KNMI seismic and acoustic networks are currently moving from a traditional 'processing' centric view to a 'data' centric view. The new IT strategy of the institution supports this change by promoting the adoption of Data Management Plans (DMPs). Thanks to DMPs we aim to improve the FAIR-ness of our datasets and products. Examples of datasets include digital and analog waveforms, inventory of stations, earthquake catalogues, strong motion parameters, shakemaps and hazardmaps. The current seismic Data Management at KNMI leverages solutions broadly adopted in the seismological community and includes: standard (meta)data formats; data models, conventions and vocabularies; storage requirements; data dissemination and policies; use of persistent identifiers; provenance information; etc. The major challenges are the data volume (15 TB/year) and the description of datasets that lack of community standards. In this contribution we will provide an overview of the seismic Data Management at KNMI and describe its features and the challenges encountered.

ESC2018-S3-1016

GEODATANODE: APPLYING LESSONS FROM DATA MANAGEMENT BEYOND THE SEISMOLOGICAL COMMUNITY

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Digital Object Identifiers (DOIs) are ideal for the citation of seismic networks and are increasingly used by the international seismological community. The GFZ Seismological Data Archive (GEOFON) currently provides access to seismic

waveform data of 29 permanent and over 72 temporary networks (as of April 2018). These data are fully described following the "FDSN recommendations for seismic network DOIs and related FDSN services" by the Federation of Digital Seismic Networks (FDSN) and offers DOI minting services to the community. Scientific communities beyond seismology can potentially utilize similar approaches. The GeoDataNode Project (GDN) is a two year project at the GFZ German Research Centre for Geosciences, funded by the German Federal Ministry of Education and Research. The overall aim of the project is to improve data management practices at GFZ, inspired by the "FAIR guiding principles for research data management". The project utilizes the synergy with communities employing advanced data management practices and highly standardized data, i.e. GEOFON and the Geophysical Instrument Pool Potsdam (GIPP), and the Library and Information Services, which serves as a central point for (DOI referenced) publication services for data, documents, and software. Lessons learned and best practices developed by these communities will be promulgated at GFZ and beyond. Among the objectives of GeoDataNode is the development of workflows for integrating heterogeneous datasets of active seismic and magnetotelluric experiments into the most uniform format possible; attribution of Persistent Identifiers to GIPP instruments which are utilized for real time calibration of GEOFON data; and the development of Data Management Plan Templates for seismic datasets in archives which encompass different use cases (own/third party data; temporary/permanent seismic networks; measured with instruments of GIPP or without; with different access rules: open, embargoed, restricted). The GeoDataNode project therefore, represents a bridge of best practices, considerations, and experiences to a variety of geoscience disciplines. This engagement helps the drive toward FAIR data, improves the visibility of seismic data management practices, and provides an example of successful knowledge transfer benefitting the scientific community in general.

ESC2018-S3-1022

PAST, PRESENT AND PERSPECTIVE OF MEDNET

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The Mediterranean Very Broadband Seismographic Network (MedNet) constitutes a backbone network of highest quality very broadband (VBB) seismological stations in Euro-Mediterranean Region. The Mediterranean region is characterised by a very complex tectonic setting and by high seismicity due to the overall convergence of two major plates. The seismographic MedNet network was established since the end-80s. At first, it was build as a pure research infrastructure, which would allow to study Earth structure, earthquake sources and the seismo-tectonics setting of the region. The network was based on high-end, state-of-the-art seismographic instrumentation, which was deployed with special care and according to best practice at seismically quite and thermally stable sites. Later, technological evolution and upgrades established data connectivity to the stations, transforming this network into a multi-purpose infrastructure and making it a valuable asset for seismic monitoring purposes in Italy and other the Euro-Mediterranean countries. From the very beginning, MedNet also established a strong network of international partnership, scientific collaboration and transfer of knowledge, which was key to the successful building of the technical infrastructure. The project gained supported from World Laboratory di Lausanne, Swiss, which made it possible to install stations in North Africa, i.e. Morocco, Algeria, Tunisia and Egypt. After the political processes made it possible the focus extended to the Balkan Peninsula. Mednet always provided data openly to the scientific community and established protocols and tools for their exchange. In collaboration with peer-network operators (Geoscope, Geofon, GSN) and umbrella organizations like FDSN and Orfeus, the program contributed to the establishment of an Open Data culture, which still sets the seismological community ahead of other disciplines in Earth sciences. After more than 30 years of operations we can affirm that MedNet has managed to establish a long-lasting and well-recognised infrastructure, as well as a respected brand. However, we are also facing technical challenges due to the ageing instrumentation. On the other hand, innovation regarding both, instrumentation and deployment techniques, but also growing experience in the operation of VBB instrumentation and observatory practice offer

new opportunities for MedNet. Reinforcing the scientific and technological collaboration with the partners of the MedNet program is key to the continued success and sustainability of this valuable research infrastructure going forward. We also plan to revisit and update the operational procedures and practice. Currently, the focus is on consolidating and improving the sustainability of the existing infrastructure. However, we are also looking forward to explore new opportunities and launch challenging projects in near future. In our presentation we revisit the history and evolution of the MedNet program and network. We report on the present-day status of the MedNet network and on the on-going activities. Finally, we outline the perspective of the program and discuss future developments and projects. We also believe that this presentation constitutes an appropriate context to discuss future collaborations with existing and potential partners of the program. The MedNet network can by cited by using its Digital Object Identifier, DOI:10.13127/SD/fBBBtDtd6q.

ESC2018-S3-1034

SEISMOLOGICAL OBSERVATORIES IN ANTARTICA: AN UPDATE ON THE ITALIAN PROGRAM AND THE EVOLUTION OF THE OBSERVATORIES

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Antarctica represents one of the most extreme and exceptional environments on Earth. It is the most remote continent and in terms of logistics probably the most challenging spot to reach, in particularly when considering locations at the internal of the continent. As a consequence, the availability of scientific data is rather scarce and the density of instrumental observation points for geophysical phenomena is low. This makes any geophysical observatory extremely valuable. At the same, time these environmental conditions and practical constraints require special approaches and operational practice. The Italian National Antarctic Research Program (Programma Nazionale di Ricerche in Antartide, PNRA) contributes to the operation of two permanent seismological observatories and one semi-permanent remote station. The observatory at Terra Nova Bay (station code TNV) at the Mario-Zuccelli Station (MZS, 74°42'S 164°07'E) is operated by the Istituto Nazionale di Geofisica e Vulcanology (INGV). First seismological experiments started shortly after the establishment of the Italian scientific station at Terra Nova Bay and led to the construction of the permanent observatory in 1988/1989. Currently, two independent sensors and acquisition chains are operated at the observatory itself. A semi-permanent autonomous seismic station is operated at Starr Nunatak at a distance of approximately 150 km from the Station MZS. This station is powered by solar panels and hibernates during Antarctic winter. The Concordia scientific base (75°06'S 123°20'E) is collaboratively operated by the Italian PNRA program and the French polar institute, Institut Paul-Emile Victor (IPEV). It is located at Dome C on the East Antarctic Ice Sheet. The seismological observatory (station code CCD) at this base is jointly operated by INGV and École et observatoire des sciences de la terre (EOST), Strasbourg. First seismological experiments started already before the opening of the permanent base in 2005. Two independent sensors and acquisition chains are currently operated at the permanent observatory. Moreover, in preparation of a major upgrade, experiments with two additional sensors are performed. During the ongoing project and the recent campaigns we have performed various upgrades to the observatories and the seismological instrumentation, and we are constantly updating the operational procedures and practice. Further activities are planned for the foreseeable future. In particular, the projects for CCD observatory are ambitious and envisage the extension of the observatory with a post-hole installation of a sensor at approximately 130m depth. These activities are aimed at constantly improving the reliability and quality of the observatories or address the obsolesce of components of the scientific equipment. In our presentation we intend to provide a general overview of the operations of seismological observatories and stations in the challenging environment of Antartica. We report on recent updates and the present-day status of the observatories, and we present the on-going and planned activities. Finally, we outline the

perspective and possible future developments of the program.

ESC2018-S3-1044

DATA POLICIES DEFINITION FOR A SEISMOLOGICAL DATA CENTRE. THE GEOFON EXAMPLE.

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Seismological data centres have experienced in the last decade an ever growing complexity in the data management of the seismic waveforms to be archived. The capability to use higher sample rates as well as the instruments being more affordable imply also an increase in the volume of data to be archived. Despite that this brought new challenges on how to manage the storage, it did not cause a strong change in the data management itself. In the past, data centres were focussing their efforts on the bit stream preservation of data. However, this situation changed in the last years towards the concept of long-term preservation, which means not only to preserve the bits, but to also to preserve metadata to ensure that the content of an archived object can be interpreted in the future, despite changes in access technologies. New activities related to data (from all scientific disciplines) are becoming more important for discovery, accessibility and reproducibility. The list of requirements related to data expressed in the FAIR principles (Wilkinson et al, 2016) are one of the best examples of this new approach to scientific data management. In this direction, the identification of seismic networks by means of Digital Object Identifiers (DOI) from a FDSN Recommendation (Clark et al, 2014) was a step towards standardisation of data citation and proper attribution in a context broader than the seismological community. In GEOFON, we have identified and formalised internal Data Policies to better describe our data workflows and to express the need of new metadata, which could make the data more visible and usable for researchers from other communities. Automatic workflows for waveforms from different networks were defined and implemented for replication policies, ingestion of data in different information systems (e.g. portals, EPOS project), and identification of data files with Persistent Identifiers (PIDs) among other examples (Quinteros et al, 2016). The definition of a proper License for different datasets is also one of the most important topics to tackle in the short-term. Data is no longer being used by the community generating them, but are also usually requested from new cross-discipline users and even in the context of citizen science. Such an expansion of the data usage outside from the community requires a clear statement from the data producers in order to specify what can and cannot be done with the data. How to distribute data coming from many data suppliers, who could in theory select different licenses for their data sets is also a challenge for the near future.

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SESSION 04

ESC2018-S4-177

OCEAN GENERATED MICROSEISMS RECORDED BY AN OBS NETWORK OFF-SHORE IRELAND

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Microseisms in the frequency range of between 3 to 20 seconds are known to be related to ocean wave activity. This frequency band is predominantly composed of surface waves (Rg and Lg) though some body wave energy also exists. While the generation of Rg waves is well understood the generation of Lg waves is less clear. Previous studies typically show the source regions for such surface waves as being in shallow water regions within the continental shelf. However, as these sources can also be generated in deep water regions propagation effects are thought to account for the absence of deep water sources. Using data from a temporary broadband ocean bottom seismometer network located to the North-West of Ireland and a terrestrially based seismic array we explore both the generation and propagation of such signals. To aid in interpretation the propagation of both the seismic and hydro-acoustic wave-fields have also been modeled using SPECFEM3D.

ESC2018-S4-337

OCEAN BOTTOM SEISMOGRAPH TECHNOLOGY AND APPLICATION IN ACTIVE AND PASSIVE SEISMIC OBSERVATIONS

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The ocean bottom station (OBS) that will be presented below is a stand-alone seismic unit contained in a 17 inch glass sphere. It can withstand water pressure to 6700 m depth and the sensors are a 3C gimbal mounted geophone unit of 4.5 Hz natural frequency and a deep sea hydrophone. Depending on recording requirements, the geophones can be replaced by broad band seismometers. The analog sensors output is digitized by variable sampling rates and stored on SD cards. A thermo-stabilized quartz clock in the station has a time stability of 10-8. The station is triggered by a GPS signal that initiates the time in the OBS. This process is applied before deployment, and repeated after retrieval of the station. Thus drift of the clock is defined, which is small and linear. This OBS is a free falling unit and is attached and coupled on the seafloor by an anchoring weight. The retrieval process is activated by an acoustic signal from the operating vessel. OBS is located on the sea surface by radio and at night also a flash light is used. In this paper we present two applications of this OBS system, a 2D active seismic experiment offshore east Africa, and a passive one for microseismicity monitoring offshore west Cyprus. Aim of the 2D active seismic study offshore Kenya was to define the geometry of the sedimentary basins and locate the continent/ocean transition. We observed a 180 km seismic refraction/reflection line using 87 OBS. Seismic data were compiled in Common Station Gathers and used to develop a velocity model with first break tomography and forward modeling, kinematic and dynamic. The Vp-velocity structure of the sedimentary basins and crust was obtained and the continent/ocean transition defined. Crustal thickness at the continental domain ranges from 18 Km close to the African coast, thinning to 11.4 Km at its transition to the oceanic crust. Average thickness of sediments with Vp-velocities ranging from 1.8 to 4.5 Km/s, covering the stretched continental crust, is 4.8 Km. The oceanic crust is 10.8 Km thick, covered by 3.8 Km of sediments with Vp-velocities ranging from 1.8 to 3.3 Km/s. The upper part of the continental crust is laterally inhomogeneous with Vp-velocities increasing from 5.8 to 6.1 Km/s, from west to east. The oceanic crust is divided into three layers: layer 2a has Vp-velocity 4.7 Km/s, while layer 2b has Vp=5.3 Km/s, and layer 3 is fairly homogeneous with Vp-velocity 6.8 Km/s. Evaluation of PS converted phases defined a Vp/Vs ratio ~1.78 in the upper continental crust, while in the oceanic domain this ratio is ~2.00. The stretched continental crust extends eastwards for nearly 290 Km from the coast of Kenya to the oceanic domain. A passive seismic experiment using an amphibious array of 37 OBSs and stand-alone seismic stations was performed in the Paphos area, west Cyprus. The array was active for a period of six months and recorded the normal

daily microseismicity but also the foreshock and aftershock acrtivity of the M6.8 event of 9/10/1996 offshore Paphos. Immediately after the main event the array was relocated and optimized to better observe the aftershock activity. Definition of the 6.8 event coordinates and timing was significantly improved compared to the parameters published in the international bulletins since the earthquake occurred nearly in the center of this amphibious local seismic array. The OBSs recorded also a monochromatic seismic phase that arrived a few seconds after the S-waves. This was interpreted as a T-phase (Tertiary phase) and was for the first time observed in the Mediterranean Sea. Recorded data were used for velocity tomography and seismic hazard assessment.

ESC2018-S4-488

STRONG OFFSHORE SITE EFFECT REVEALED BY A BROAD-BAND SEISMOMETER INSTALLED ON THE NICE AIRPORT SLOPE AT 17 M WATER DEPTH (SOUTH-EAST OF FRANCE)

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Using earthquakes and seismic noise recordings on a broad-band station installed in October 2016 on the slope of the Nice airport at 17 m depth, we find a strong site amplification of the seismic waves (factor 10 around a frequency of 1Hz). The effects of superficial layers on the amplitude, frequency and duration of seismic waves (often called site effect) has been extensively studied during the last two decades because it is responsible of large damages. Until now, site effect studies were only realized inland; the potential offshore site effect generated by sediment layers has therefore never been studied specifically. Nonetheless, a correct estimation of the amplification caused by offshore sediments is of great importance for three main applications:

- Landslides and tsunamis : seismic waves can trigger submarine landslides, that themselves can trigger
tsunami waves. In numerical simulations and geotechnical experiments, it is then important to take into account the potential input wave amplifications.
- Offshore paleoseismology: strong vibrations generated by large earthquakes can trigger turbidite landslides. Turbidite stratigraphy is then a powerful tool often used to evidence and characterize the occurrence of ancient earthquakes. A correct amplitude of the seismic ground motion that takes into account site effects, has then to be estimated in models to correctly infer the magnitude of ancient earthquakes.
- Offshore infrastructures: in many highly populated zones, in order to gain new space, buildings and/or infrastructures are more and more often constructed on offshore areas.

In order to test and quantify these potential amplifications under the sea, we installed a broad-band seismometer “PRIMA” on the slope of the airport of the city of Nice (south-east of France) at a depth of 17 meters. The seismological station PRIMA belongs to the EMSO-Nice cabled observatory (EMSO: European Multidisciplinary Seafloor and water-column Observatory). We then analyze the recordings of local and regional earthquakes and ambient seismic noise on this station, and compare them with the recordings of nearby stations inland (max 3 km away). We find a clear amplification of waves of a factor of ~10 (compared with inland station situated on rock) at a frequency of 0.8-1Hz, as well as smaller amplification peaks at higher frequencies for local earthquakes. These amplification will be compared with data from high resolution seismic profiles in order to better understand their origin. This result is particularly important for the city of Nice. Indeed, the airport slope already experienced a large landslide in 1979, which triggered a tsunami wave that killed 10 persons and caused extensive damages all along the coast. It is them of upmost importance to be able to evaluate if a future earthquake could cause the same domino effect.

ESC2018-S4-506

EVIDENCES OF THE PANAREA-STROMBOLI LINKAGE FROM ACOUSTIC SIGNALS

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The Aeolian arc is composed of 7 volcanic islands including active and extinct volcanoes. One of them, the island of Stromboli is well known because of its permanent volcanic activity marked by blasts and rare lava flows. The island of Panarea, located 12 miles away from Stromboli, hosts the most active shallow-depth hydrothermal system of the Mediterranean Sea (Maugeri et al., 2010). Although it was long considered an inactive volcano (Gillot, 1984; Gabbianelli et al., 1986), a submarine low-energy explosion occurred in November 2002 (Caracausi et al., 2006). A possible tectonic link between the two volcanic islands has been proposed, however only recent technological advances in multidisciplinary seafloor observatories allowed to answer the important and debated question about the connections between the two volcanoes that appear to be not simply tectonic but also volcanic, involving the deep magma feeding systems. The unusual geochemical features of the submarine hydrothermal system located two miles off Panarea island, such as venting of CO2-dominated gas and thermal waters with temperatures up to 140°C, pH less than 3 and electrical conductivity higher than the sea-water, make this extreme environment a natural laboratory for multidisciplinary seafloor observation for geohazard and environmental monitoring (Italiano, 2009; Italiano et al., 2012; 2015). Moreover, the shallow-depth Panarea area is a peculiar observation site to gain a better insight into the volcanic and tectonic processes driving the submarine hydrothermalism. A multidisciplinary observatory, connected to a surface buoy, has been deployed over the hydrothermal vents ten years ago, and its technological capabilities improved with the time (Italiano et al., 2011). The observatory is able to operate in near-real-time mode and it has been equipped with a heterogeneous sensors suite (hydrophone, dissolved CO2, dissolved O2, EC, turbidity, pH, temperature and pressure) in order to evaluate the observatory performances in different conditions of use and over long time intervals. The actual settings allow of collecting data three times per hour along with 20 seconds of hydroacoustic signals to reduce power consumption and data transmission issues. The whole system consists of two main modules, a surface buoy and a seafloor module. The former hosts the power supply (solar panels and rechargeable batteries), a weather station, a GPS receiver, a surveillance IP camera and the electronics that collect and transmit data over the 3G HSPA network. The latter is composed of a Power Management System, an high resolution 10 synchronous channels 24 bit Sigma-Delta Digitizer and an Embedded Computer aimed to trigger acquisition, monitor electronics, process and store data (Italiano et al., 2015). The multidisciplinary observatory has collected acoustic signals (Reson TC4037 hydrophone) as well as data of the dissolved CO2 and oxygen, temperature of the hot vents and the sea water, ph, EC over the last three years with rare data missing. The original aim of acoustic data was to study the bubbling frequencies variation, typically in the range between 70 Hz and 1 kHz, related to the changes of the gas flow rate from the hydrothermal vents as a proxy of changes of the total submarine gas output. As the submarine vents are affected by periodical changes due to tides and seasonal trends, the data analysis is performed after data filtering and validation. Information from changes observed in the bubbling activity, physical-chemical parameters as well as in very low band frequencies, highlighted some anomalous events not always related to local submarine hydrothermal activity. Very good correlations can be indeed recognized between soil CO2 flux emission measured at the crater of Stromboli and the acoustic signals in the 2-25 Hz band. This relationship can be discussed in terms of volcano-tectonic link with the active volcano of Stromboli, as suggested by Heinicke et al. (2009) or related to the deep magma feeding system. Those observations, along with the behavior of He isotope marker, showing similar values for both the volcanic edifices, suggest a common magmatic source at Panarea and Stromboli, strongly controlled by NE-SW striking structures (Italiano F. 2009).

ESC2018-S4-565

THE PECULIARITIES OF ENGINEERING SEISMOLOGY INSTRUMENTAL STUDIES IN SHELF AND COASTAL REGIONS: THE AUTOMATIC DETECTION OF MICROEARTHQUAKES ON CONTINUOUS NOISY SEISMIC RECORDS OF LOCAL OBS AND COASTAL NETWORKS

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The number of industrial projects being designed on the shelf and in the coastal zone is constantly growing, which increases the relevance of tasks related to theoretical and instrumental researches in the framework of seismic hazard assessment of such areas. Records of local OBS or coastal seismic networks obtained on construction sites, as a rule, are very noisy. Such typical for these areas noises as high-amplitude spikes, different anthropogenic noises connected with engineering works on the site, explosions, land and sea transport noises, microseisms, high-frequency ambient noise, make it very difficult to detect earthquakes and, in particular, microearthquakes on continuous records of local seismic networks by common algorithms, such as, for example, STA/LTA, in their original form. The purpose of this work is to find a suitable algorithm for automated detection of useful signals on continuous seismic records of local OBS or coastal networks on the construction sites. To achieve this goal, the typical useful and noise signals at such sites are described; a brief analysis of the application of the well-known methods to solve the problem was carried out; and finally; on the basis of known methods, an algorithm for the detection of useful seismic signals has been developed; it is based on the joint use of the following criteria for detection: an increase in the signal amplitude, correlation over different seismic stations, and the signal duration. The cumulative envelope function is used for signal duration estimating in order to distinguish useful seismic signals from short high-amplitude spikes. Approbation of the algorithm on real test records obtained during engineering seismological study by local network in north Egypt coast zone has shown its effectiveness and application in practice for automated detection of both weak local and regional events on local OBS and coastal seismic networks records. This studywas supported by the Russian President Grant for young scientists (project MK-5963.2018.5).

ESC2018-S4-566

EMPIRICAL GREEN'S FUNCTION TECHNIQUE FOR ACCELEROGRAM SYNTHESIS: THE PROBLEM OF THE USE FOR MARINE SEISMIC HAZARD ASSESSMENT

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Instrumental seismological researches in water areas are complicated and expensive, that leads to the lack of strong motion records in most offshore regions. In the same time the number of offshore industrial infrastructure objects, such as oil rigs, subsea pipelines, is constantly increasing. The empirical Green's function technique proved to be very effective for accelerograms synthesis under the conditions of poorly described seismic wave propagation medium. But selection of suitable small earthquake record in offshore regions as an empirical Green's function is a problem because short seafloor instrumental seismological investigation results usually with weak microearthquakes recordings. An approach based on moving average smoothing in frequency domain is presented for preliminary processing of weak microearthquake records before using it as empirical Green's function. The method results with significant waveform correction for modelled event. The case study for 2009 L'Aquila earthquake was used to demonstrate the suitability of the method. This work was supported by the Russian Foundation of Basic Research (project 18-35-00474 mol_a).

ESC2018-S4-590

USING OBS RECORDINGS TO INFER THE DEPTH OF VOCALIZING FIN WHALES WITH THE LLOYD'S MIRROR EFFECT

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Ocean bottom seismometers (OBS) that are deployed for long-term monitoring surveys constitute platforms of opportunity to study baleen whales, specifically blue and fin whales, given the frequency range of vocalizations. OBS have been used to detect and track both species using the arrival times at multiple sensors, while for fin whales, methods have been developed to range calls with a single OBS. Furthermore, traditional density estimation methods have been applied also to data from OBS. Most of the whale research that uses OBS consider that the vocalization depth is shallow and fixed, which is a reasonable approach when the instruments are deployed in deep water, at 2000 m depth or more. However, knowing the diving depth of fin and blue

whales is important to assess their foraging habits and the impact of environment changes. The ocean acoustic Lloyd's Mirror effect (LME) is produced by interference between the direct-path and the sea surface reflection of a sound as observed at a receiver. It results in a frequency dependent interference pattern that can be observed in a spectrogram. Since the surface reflection coefficient is symmetrical for pressure (recorded by the hydrophone) and particle velocity (recorded by the vertical channel of the seismometer) these interference patterns will be of opposite sign in these two channels. In this study we investigate a sequence of regular ~20 Hz calls from a finback whale. The vocalization ranges are estimated using the time difference between the direct-path and the first multiple reflection (after one bounce at the bottom and top of the water layer) surface reflection after some signal enhancement. The depth of the sound source is inferred by spectral cross-correlation between observations and a set of synthetic spectrograms computed for the same ranges and variable depths. The best average depth is the one that fits both the hydrophone and vertical seismometer spectrograms. Many studies have found variations of spectral characteristics of the 20 Hz 'regular' fin whale call, which seem to reflect geographic differences. However, variability of spectral measurements may occur due to the LME. Our results suggest there is a degree of variability in fin whale calls that could be related to the LME. This publication is supported by FCT- project UID/GEO/50019/2013 – IDL

ESC2018-S4-612

INGV OBS-LAB'S FLEET OF MARINE INSTRUMENTS FOR RESEARCH AND MONITORING

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This work is aimed to present the INGV OBS-Lab's fleet of marine instruments for offshore research and monitoring. Since 2005 the development of marine instruments is among the main missions of the OBS & Earth Lab (formerly OBS Lab), a laboratory with a specialized team working at the Gibilmanna Observatory of the Istituto Nazionale di Geofisica e Vulcanologia (INGV). Because the marine environment presents such specific challenges, the OBS & Earth Lab cannot rely only on commercially available solutions. In fact the team's effort is focused on finding new system-level solutions, designing custom mechanics and electronics, adapting terrestrial sensors and customizing existing marine devices. The development was founded by the DPC 2005-2007 convention and by different research projects, especially NERIES (from 2006 to 2010) and EMSOMedIT (from 2013 to 2016) projects. The Broad-Band Ocean Bottom Seismometer (BB-OBS) version-A was the first instrument developed by the OBS & Earth Lab, aiming to extend the seismic monitoring to offshore areas (the acronym BB-OBS/H is used to designate the same instrument, when equipped with a low-frequency hydrophone too). Over time, the design was revised and improved. The last generation of BB-OBS/Hs, actually the third, reaches 15 months of autonomy and is rated for 6000 meters of depth. It can be equipped with a three component broad band seismometer (like Trillium Compact OBS 120s 100Hz or Guralp OBS 6TC 60s 100Hz) and with a low-frequency hydrophone or a Cox-Webb Differential Pressure Gauge (DPG). At the time of writing and considering the three generations, the number of BB OBS' produced is 20. These instruments were used for different missions in the Mediterranean basin, recording volcanic and hydrothermal data on the seabed. In the last years, INGV is becoming more and more involved in seismic surveying. The TOMO-ETNA experiment is an example of a seismic survey, performed for scientific purposes using ground and marine seismic stations. The Ocean Bottom Seismometer for Prospecting (OBSP) is especially intended for active seismology. This instrument is equipped with a set of three geophones and a low frequency hydrophone. As geophones are short-period sensors, they are unsuitable for long-range seismology, but well suited for recording small explosions at short range, like those produced by air-guns. In 2014 18 OBSPs were produced. The OBSPs can be equipped with a newly designed amplifier, which extends the geophone period to 5 s, enabling medium-range seismic monitoring. The recent monitoring requirements in shallow waters have led to the design of a particular model of BB OBS, denominated "trawl resistant" for its ability to resist to trawl nets. Soon 4 units will be

made. The OBS & Earth Lab contributed to the realization of an Ocean Bottom Magnetometer (OBM) for geomagnetic monitoring. Three OBMs were built and equipped with a triaxial and a scalar magnetometer. Among the most ambitious OBS & Earth Lab projects, surely there are 2 multi parametric stations with near real time data transmission. These stations, already tested in the dock, will soon be installed in the Mediterranean sea and connected directly to the INGV Tsunami Alert Center, which is part of the Osservatorio Nazionale Terremoti (CNT). Each multi parametric station consists in a submarine module, connected to a jumper buoy through an electromechanical cable. An elastic cable connects the jumper buoy to the surface buoy, which hold the batteries, the power generation units (solar panels and eolic generator) and the control and communication systems (WI-MAX, UHF and satellite, HSDPA). Recently the OBS & Earth Lab produced a feasibility study for the deployment of a submarine multi parametric module in proximity to hydrocarbon extraction platforms. The module would stay inside the safety zone associated to the platform, a circle with a 1 km diameter centered on the platform itself. A marine cable, connecting the module to the platform, would carry data and power. The submarine module would have a couple of seismic sensors, a hydrophone, an absolute¬ pressure sensor, a Conductivity Temperature and Depth (CTD) sensor and a CO2 sensor. Data would travel from the platform to a control centre on land, which would send them to INGV monitoring centers in Rome, Catania and Naples. While the majority of terrestrial instruments are unsuitable for the sea, the opposite is not true. The Portable Geophysical Station version 1 (PGS1), developed by OBS & Eart Lab in 2017 is an example. The station includes a data acquisition system, a medium period seismic sensor (5s to 100Hz) and a photovoltaic panel. All the electronics fits inside a small suitcase, derived from a commercial product. While the sensor housing is a custom mechanical design and the suitcase is customized, the most part of the electronics consists of existing designs, initially intended for the sea. As a consequence PGS1 has a very low power consumption and achieves up to 40 days of autonomy with photovoltaic panel disconnected.

ESC2018-S4-613

A GENERALIZED THEORY FOR FULL MICROTREMOR H/V(Z, F) SPECTRAL RATIO INTERPRETATION IN OFFSHORE AND ONSHORE ENVIRONMENTS

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Advances in the field of seismic interferometry have aided in providing a basic theoretical interpretation to the full spectrum of the microtremor horizontal-to-vertical spectral ratio (H/V(f)). The interpretation now applies to ambient seismic noise data recorded both at the surface and at depth. The ambient noise wavefield contains information on the underlying subsurface structure due to multiple scattering and therefore can be used for imaging. The new algorithm, based on the diffuse wavefields assumption, has been used in an inversion scheme to estimate the seismic wave velocity profile that is a useful input in engineering seismology for hazard estimation, and in exploration and earthquake seismology for estimating the effects of near surface sediment layers. However, until now, the developed algorithms are only suitable for on land environments with no offshore consideration. Here, the microtremor H/V(z, f) forward modeling algorithm is extended for applications to marine sedimentary environments. This is accomplished by computing the directional energy density for a 1D layered media. The layer propagator matrix formulation is used for the estimation of the Greens' functions. Therefore, in the presence of a water layer on top, the properties of the propagator matrix for the surface layer are modified to account for the properties of the water column. As application example for the proposed algorithm we analyze eight simple canonical layered Earth models. Frequencies ranging from 0.2 to 50 Hz are considered as they cover a broad wavelength interval and aid in practice to investigate subsurface structures in the depth range from a

few meters to a few hundreds of meters. The modeled H/V(z, f) results indicate that the theoretical formulation is valid for the interpretation of the full spectrum of the microtremor H/V(z, f) estimated from 3C ambient noise data recorded in marine environment as well as for on land records. Results show a marginal variation of 5% at most for the fundamental frequency when a water layer is present. The main changes in the modeled H/V spectral ratio are observed in the amplitude. The water layer lead to decreases in H/V peak amplitude of up to 50% atop thesolid layers.

ESC2018-S4-679

SEDIMENT CHARACTERISATION AT THE EQUATORIAL MID-ATLANTIC RIDGE FROM P-TO-S SEISMIC PHASE CONVERSIONS RECORDED ON THE PI-LAB EXPERIMENT

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Studies of marine sediments are typically based on the analysis of core samples extracted from ocean drilling and seismic experiments. Accurate sediment characteristics, e.g. thickness and seismic velocity, are important not only when constraining climate change, but also for seismic imaging of deeper structures. Despite the numerous data sets made to date, measurements are sporadic across the oceans. Here we analyse P-to-S seismic phase conversions from the sediment-crust boundary recorded by the recently deployed ocean-bottom seismic experiment PI-LAB (Passive Imaging of the Lithosphere-Asthenosphere Boundary) at the equatorial Mid-Atlantic Ocean. The network consisted of 39 stations deployed from March 2016 to March 2017 on 0-80 Myr old seafloor. The stations were broadband 120 and 240 seconds period, deployed on both sides of the ridge and centred on the Chain Fracture Zone. We measure 87 P-to-S conversions from 16 earthquakes with magnitude > 6.0 MW. The average Pds-P delay times range from 0.04-0.37 seconds. We estimate the sediment velocity and thickness beneath each station and infer the sedimentation history of the region. The sediment thickness increases with age from 5 to 82 metres and generally agrees with global estimates for young (15-20 Myr) seafloor. Our estimates are substantially thinner than expected on older lithosphere. The discrepancy can be explained by location differences, those of the ocean drilling measurements located in basins, whereas the PI-LAB stations where on topographic highs. Our result suggests the rate of sediment deposition decreases from 5 mm/Kyr to 1.2 mm/Kyr at about 10 Myr implying a recent increase in productivity. The observed changes in the rate of deposition may be due to factors such as changes in climate, changes in the eolian dust fluxes from Africa to the Atlantic, and/or changes in biogenic marine activity.

ESC2018-S4-693

LOCKING STATE OF THE SHALLOW CASCADIA MEGATHRUST FROM SEAFLOOR BOREHOLE TILT AND SEISMIC MEASUREMENTS

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The Cascadia subduction zone has a history of great earthquakes and tsunamis but the extent of inter-seismic locking at the up-dip end of the megathrust is not well constrained by onshore geodetic measurements. In July 2016, a team from WHOI, U. Miami, and Ocean Networks Canada (ONC) installed a suite of seismic, geodetic and geothermal sensors in IODP Hole U1364A on the Cascadia Accretionary Prism offshore Vancouver Island with the objective of providing long-term, real-time monitoring of this part of the megathrust. The borehole observatory, located ~3 km from Ocean Networks Canada Clayoquot Slope site CQS64, was connected to the ONC cabled observatory in June 2017, and real-time data has been flowing to ONC and IRIS data repositories since then. Hole U1364A is located ~20 km from the deformation front and sits ~4.5 km above the thrust interface. The borehole ground-motion sensors consist of a broadband seismometer and two geodetic-quality (nano-radian resolution) two-axis tilt sensors clamped to the borehole casing wall at a depth of ~277 m below the seafloor. The tilt sensors were selected to detect

non-seismic, strain-related transients. A 24-thermistor cable extends from the seafloor to just above the seismometer and tilt-sensor package. Hole U1364A also hosts an ACORK (Advanced Circulation Obviation Retrofit Kit) observatory, installed in 2010, that allows monitoring of rock formation pressure and the sampling of fluids from four screens located at 304 m, 244 m, 203 m, and 156 m below the seafloor. Formation pressure is a sensitive measure of volumetric strain. Despite the short amount of time the borehole station has been in operation, observations suggest that the up-dip end of the Cascadia megathrust does not slip in triggered tremor or slow-slip events when subjected to large dynamic stress transients, unlike the up-dip ends of Nankai and Hikurangi. Borehole tilt and seismic data from four recent teleseismic M8 earthquakes demonstrate a lack of triggered slow-slip even at the Mw 4.0 level and an absence of triggered tremor despite shear-stress transients of 0.1-0.5 MPa. Our observations are most consistent with a model where the Cascadia fault is locked all the way to the trench.

ESC2018-S4-696

LOCKING STATE OF THE SHALLOW CASCADIA MEGATHRUST FROM SEAFLOOR BOREHOLE TILT AND SEISMIC MEASUREMENTS

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The Cascadia subduction zone has a history of great earthquakes and tsunamis but the extent of inter-seismic locking at the up-dip end of the megathrust is not well constrained by onshore geodetic measurements. In July 2016, a team from WHOI, U. Miami, and Ocean Networks Canada (ONC) installed a suite of seismic, geodetic and geothermal sensors in IODP Hole U1364A on the Cascadia Accretionary Prism offshore Vancouver Island with the objective of providing long-term, real-time monitoring of this part of the megathrust. The borehole observatory, located ~3 km from Ocean Networks Canada Clayoquot Slope site CQS64, was connected to the ONC cabled observatory in June 2017, and real-time data has been flowing to ONC and IRIS data repositories since then. Hole U1364A is located ~20 km from the deformation front and sits ~4.5 km above the thrust interface. The borehole ground-motion sensors consist of a broadband seismometer and two geodetic-quality (nano-radian resolution) two-axis tilt sensors clamped to the borehole casing wall at a depth of ~277 m below the seafloor. The tilt sensors were selected to detect non-seismic, strain-related transients. A 24-thermistor cable extends from the seafloor to just above the seismometer and tilt-sensor package. Hole U1364A also hosts an ACORK (Advanced Circulation Obviation Retrofit Kit) observatory, installed in 2010, that allows monitoring of rock formation pressure and the sampling of fluids from four screens located at 304 m, 244 m, 203 m, and 156 m below the seafloor. Formation pressure is a sensitive measure of volumetric strain. Despite the short amount of time the borehole station has been in operation, observations suggest that the up-dip end of the Cascadia megathrust does not slip in triggered tremor or slow-slip events when subjected to large dynamic stress transients, unlike the up-dip ends of Nankai and Hikurangi. Borehole tilt and seismic data from four recent teleseismic M8 earthquakes demonstrate a lack of triggered slow-slip even at the Mw 4.0 level and an absence of triggered tremor despite shear-stress transients of 0.1-0.5 MPa. Our observations are most consistent with a model where the Cascadia fault is locked all the way to the trench.

ESC2018-S4-724

A NEW VELOCITY MODEL IN THE WESTERN IONIAN SEA FROM EARTHQUAKES RECORDED BY NEMO-SN1 SEAFLOOR OBSERVATORY (ITALY)

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The Western Ionian Sea is an area of great interest from the seismological point of view due to the occurrence of the highest magnitude earthquakes which affected the Italian territory in historical and recent times, followed in some cases by violent tsunamis (e.g. 1193, M 6.6; 1693, M 7.4; 1908, M 7.2; 1990, M 5.7). Although these earthquakes have been studied by many Authors for the great societal impact they produced, their sources and mechanism of generation are still strongly debated due to lack of an adequate seismic stations coverage extending to the

seafloor. In recent years, there has been a renewed interest in seismotectonic processes occurring on the seafloor, supported by means of many experiments including Ocean Bottom Seismometers (OBS) monitoring in the Ionian Sea. In addition, from 2002 the NEMO-SN1 seafloor observatory was deployed about 25 km off-shore from the eastern coast of Sicily, at a depth of 2100 m. Besides a set of geophysical and oceanographic instruments (gravimeter, hydrophone, CTD, 3C single-point current meter), the observatory was equipped with a three-component broadband seismometer. NEMO-SN1 recorded continuous and high quality data, comprising local (both of tectonic and volcanic origin), regional and teleseismic events over the period from 2002 October to 2003 February, in concomitance with a strong Etna's eruption, and over the period from 2012 June – 2013 May. To improve the knowledge on the velocity structure in the Western Ionian Sea, offshore Mt. Etna volcano, we computed a 1D velocity model starting from earthquake data recorded by both NEMO-SN1 seafloor observatory and the land seismic stations managed by the Istituto Nazionale di Geofisica e Vulcanologia. The seismological dataset consists in more than 550 crustal earthquakes recorded by both land seismic stations and the seismometer hosted in NEMO-SN1 seafloor observatory. We collected waveforms of earthquakes contemporary recorded by land stations and NEMO-SN1 and repacked the arrival times of bothland and marine seismic recordings. Then, we performed a preliminary integrated location of the earthquakes, using at the same time different velocity models that permit to resolve the problem linked to the strong structural heterogeneity and velocities in Sicily. From the inversion of these integrated locations, we computed the new 1D velocity model, consisting in ten layers above the Moho which is located at a depth of 21 km. Accuracy in the location of seismic events occurring at sea is strongly dependent on the velocity model. We have used the velocity model deduced through our analyses to relocate the earthquakes of the entire dataset. Comparing the preliminary location of earthquakes recorded both by land and NEMO-SN1 stations and the same relocated dataset using the new velocity model, a location improvement using the new velocity model for the Ionian Sea is evident in term of mean RMS and Standard Deviation (SD) values. The velocity model of the Western Ionian Sea resulting from this study will be used to properly locate earthquakes in this seismically active marine domain in the center of the densely populated Mediterranean region. In particular, the seismic activity of offshore faults will be better constrained and the related hazard optimally assessed.

ESC2018-S4-774

SURFACE WAVE IMAGING OF THE OCEANIC LITHOSPHERE IN THE EQUATORIAL ATLANTIC FROM THE PILAB EXPERIMENT

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The relatively short and simple history of the oceanic lithosphere make it an ideal laboratory to investigate what makes a plate, plate-like. The Passive Imaging of the Lithosphere Asthenosphere Boundary (PILAB) experiment is investigating the nature of the young tectonic plate in the equatorial Mid Atlantic on 0-80 M.y. seafloor. The experiment deployed 39 ocean bottom seismometers and 39 ocean bottom magnetotelluric instruments near the Chain and Romanche Fracture Zones crossing two segments of the Mid Atlantic Ridge (MAR). Here we present results from the surface wave imaging from the experiment. Combined ambient noise and teleseismic Rayleigh wave tomography reveals a thickening fast lid, with velocities up to 4.7 km/s. The fast lid is 20-30 km thick beneath the MAR, thickening to 80 km beneath the oldest seafloor in the region. In the low velocity zone, the lowest velocities are 4.1 km/s near the ridge axis. The velocities are slower than predicted for mantle peridotite, suggesting partial melt may be retained in the asthenospheric mantle. Inversion for Rayleigh wave azimuthal anisotropy reveals 2-theta terms with 1-2% peak-to-peak anisotropy, with fast direction in the absolute plate motion of the African Plate. The 4-theta terms were not significant. Love wave analysis indicates radial anisotropy is required with Xi values of up to 1.08. Comparison to results from the MELT/GLIMPSE experiment in the fast spreading East Pacific Rise

at 17°S highlights the contrast between the two end member spreading systems. The presence of a fast lid at the ridge in the Atlantic, suggests lateral conductive cooling is an important process here, whereas in the fast spreading EPR no lid was required beneath the ridge. The Rayleigh wave azimuthal anisotropy observed here is also weaker that then 3-5% peak to peak anisotropy observed beneath the EPR, suggesting that olivine alignment is a function of plate velocity. The lowest velocities in the asthenosphere beneath the EPR were ~4.0 km/s, which is lower than observed here, suggesting less partial melt is required beneath the MAR. The lowest velocity regions are more focused and discrete, consistent with the notion of active upwelling beneath the MAR. Taken together, spreading rate strongly controls the dynamics of mantle flow and plate evolution.

ESC2018-S4-775

S-TO-P RECEIVER FUNCTION IMAGING OF THE 0 - 40 MY OLD ATLANTIC PLATE FROM THE PI-LAB EXPERIMENT

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The concept of the lithosphere-asthenosphere system is well defined as the rheological boundary between the rigid lithosphere that transfers coherently with the weaker asthenosphere. A better understanding of this transition, the lithosphere-asthenosphere boundary (LAB), is essential as it may have implications for the driving forces of plate tectonics and mantle dynamics. Ocean lithosphere is the ideal place to study this plate transition. The Passive Imaging of the Lithosphere-Asthenosphere Boundary (PI-LAB) was designed to better characterize and understand the lithosphere-asthenosphere boundary of the oceanic plate at a range of resolutions. We deployed 39 broadband ocean bottom seismometers (OBS) and 39 ocean bottom magnetotellurics (OBMT) on 0 – 80 My seafloor at the mid-Atlantic Ridge near the Chain fracture zone from March 2016 – March 2017. In this study, we use S-to-P receiver functions to image the discontinuity structure. We use teleseismic earthquakes recorded by our stations with magnitude >5.8Mw from epicentral distance of 545 – 90 degrees. We image a ~7 km thick oceanic crust across our study region. We image a negative discontinuity, likely the lithosphere-asthenosphere boundary, which deepensthickens progressively away from the western ridge segment from 30 to 80 km beneath 0 to 40 My old lithosphere. Although thinning of this phase below the eastern ridge segment is not prominent. We do not observe much shallowing of this phase below the eastern ridge segment. However, we observe a weaker shallow positive phase close to the eastern ridge segment along the transform boundary. The depths are consistent with thermally controlled thickening with age. However, Although compositional variation is expected, the lithosphere-asthenosphere transition is not likely defined by composition alone which would likely result in a constant depth discontinuity at ~60 km depth. The amplitude and sharpness of the phasesanomaly we observe also suggests melt may be present at the base of the lithosphere.

ESC2018-S4-780

SEISMIC IMAGING OF THE LESSER ANTILLES SUBDUCTION ZONE WITH THE VOILA PROJECT

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The Volatiles in the Lesser Antilles (VOILA) project is a multidisciplinary experiment to understand the pathway of fluids and volatiles in the Lesser Antilles subduction system, where oceanic lithosphere from the slow-spreading Mid Atlantic Ridge is descending in the mantle. Here we present results from the passive seismic ocean bottom deployment of 32 instruments on the back arc and forearc regions. We use teleseismic Rayleigh wave dispersion and S-to-P receiver functions to image the slab, upper plate, and wedge structures. We calculated receiver functions using a multitaper method. We measure dispersion from 18-111 s period, which increases from 3.64 at 18 s period to 4.21 at 111 s. Receiver

functions image the Moho that varies from 29 to 40 +/- 4 km depth beneath the arc. In the northern and central section of the arc we image the base of the upper plate at 73 +/- 5 km depth beneath the arc and backarc. The slab itself dips too steeply to be imaged using this method. In the southern arc we image a negative phase that may be related to a more gradually dipping slab at 101 – 117 +/- 5 km. The receiver functions are in good agreement with constraints from surface waves. At 18-33 s period we observe low velocities beneath the arc across the region, with higher velocities on either side, consistent with thickened crust and possibly a low velocity mantle wedge region beneath the active arc region. At 40-81 s period a N-S trending high velocity region, ~100 km wide, is observed, which shifts position westward with increasing period, migrating from the forearc to beneath the arc, which we interpret as the slab. At longer periods (81-111s) the high velocity anomaly persists north of Guadeloupe, suggesting the slab may persist to greater depths in this region.

ESC2018-S4-813

FACING THE 3D CRUSTAL-SCALE IMAGING VIA FULL-WAVEFORM INVERSION OF THE OCEAN-BOTTOM SEISMOMETER DATA

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The current paradigm on how onshore, crustal-scale velocity models based on long-offset stationary-receiver surveys are built relies on ray-based methods such as first-arrival traveltime tomography (FAT). This is mainly because such methods offer acceptable resolution for delineating the main crustal units while remaining affordable in terms of data acquisition and processing. In practice, this means that during a typical marine wide-angle reflection/refraction (WARR) survey, ocean-bottom seismometers (OBS) are placed 5-10 km apart. As an alternative approach, full-waveform inversion (FWI) allows one to develop subsurface models with high resolution and has the potential to be utilized for multiparameter reconstructions. Moreover, it does not require the identification and picking of individual phases, since the ultimate goal of FWI is to automatically account for all types of arrivals. In 2017 we published a high-resolution 2D velocity model of the eastern Nankai Trough which was obtained via FWI of the SFJ OBS data (100 OBS deployed with spacing of 1 km). The obtained model reveals many complex structures consistent with the overall geological characteristics of the subduction zone. We have recently performed Pre-Stack Depth Migration (PSDM) of the streamer data acquired along the OBS profile using the FWI model as background model. Although the reflection data provided limited illumination in the deeper crust (4.5 km streamer length) the consistency between the migrated section and the FWI background velocities supports that crustal-scale FWI models derived from OBS data are amenable to PSDM of streamer data. Moreover, the high resolution of the FWI models fosters a joint interpretation of the deformation style revealed by PSDM and the seismic properties reconstructed by FWI. On the other hand, our imaging has relied on the 2D assumption which implies some important limitations: structures are imaged along vertical section with possible artifacts resulting from limited fold and illumination, 3D propagation effects, empirical 3D-to-2D amplitude and phase corrections. This raises the issue of designing next generation of 3D sea-bottom acquisitions for high-resolution deep crustal investigations. In order to move towards high resolution 3D imaging of the whole crust and to broaden our knowledge about the structural factors that govern active geodynamical processes in various environments, we must first define the specifications of new-generation OBS surveys that are amenable to FWI at crustal scale. Among others, different key points are related to the acquisition geometry in particular in terms of sampling and spread, the computer implementation of FWI for large-scale optimization problems (parallelism, time versus frequency domain modeling engines, compressive sensing), the development of optimization strategies to mitigate the nonlinearity and ill-posdeness of the inverse problem etc. Considering logistic aspects of the acquisition it is true that the gathering of large OBS pools for crustal scale imaging remains challenging, although the ability of the academic community to perform OBS acquisitions is increasing. This in turn limits the amount of real 3D datasets which could potentially serve as a benchmark for different imaging schemes proving their robustness and stimulating their expansion in the community. As

a byproduct we get limited interest in development of the massively parallel FWI implementations, allowing to tackle large 3D inversion problems and providing efficient exploitation of the available computer resources. To mitigate the mentioned issues we start with building of a realistic 3D marine crustal-scale model amenable to evaluate different acquisition geometries and processing techniques suitable for deep crustal imaging. The model has been inspired by the geologically complex structure of the Nankai subduction zone combined with the previous results of geophysical investigations of this area. It contains wide range of realistic features like strong bathymetry variations, oceanic ridges, subducted topography highs, low-velocity zones, velocity gradients, complex accretionary prism, large faults and thrusts with local damage-zones as well as shallow sedimentary basins. Additionally we incorporate different stochastic components to mimic more realistic wave propagation. We further obtain S-wave velocity and density models using polynomial functions derived from empirical relations between P-wave velocity and other physical parameters. These elastic models are consequently modified according to our assumptions about local heterogeneities in the model. The model is cast in 3D cube which dimension is 30x170x105 km with 25 m grid interval. Such parameterization of the model leads to more than 34 billion degrees of freedom imposing challenge from the point of view of computational resources and the high performance computing implementations. We demonstrate the procedure that has been designed to generate this structural model, provide the insight into obtained structure and aim on the acoustic and elastic wavefield and ray tracing modeling as well as the first acoustic FWI tests. We believe that through the development of this synthetic model and the following visco-elastic dataset we have chance to better understand the determinants of the crustal-scale imaging via FWI of the OBS data and stimulate its popularization in the communities aiming on regional data acquisition and imaging. The presentation of this work during the ESC General Assembly 2018 was partially supported by TIDES-COST Action ES1401 within the framework of ITC Conference Grants

ESC2018-S4-856

OCEANIC CRUSTAL STRUCTURE NORTH OF THE GLORIA FAULT, NORTH ATLANTIC

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The Gloria fault is a major strike-slip oceanic plate boundary fault, which links the Azores triple junction, in the west, to the oblique convergent boundary between Iberia and NW Africa, in the east. This fault hosted some of the largest strike-slip earthquakes in the oceanic domain, notably the 1941 M8.3 earthquake. In 1975, a M8.1 earthquake hit the intraplate region south of the Gloria fault, in the intersection between an old transform fault and the Madeira-Tore rise. In spite of its seismo-tectonic relevance, the Gloria fault has remained poorly studied, due mostly to its remote location in the north Atlantic. An exploratory array of 12 broadband Ocean Bottom Seismometer (OBS) was deployed approximately 100 km north of the Gloria fault within the DOCTAR project (Univ Potsdam, Univ. Hamburg) between 2011 July and 2012 April. The DOCTAR Gloria fault array was used to show that the fault is seismically active and frequently generates small earthquakes. The dataset was also used to image crustal and mantle discontinuities using receiver function analysis and to infer the S-wave velocity structure of the oceanic lithosphere north of the Gloria fault from P-wave polarization. The seismic structure studies indicate a typical oceanic crustal and mantle structure, influenced by the nearby Gloria fault. In particular, these studies indicate a slight crustal thickening towards the Gloria fault, as well as an increase in uppermost mantle S-wave velocities towards the fault. In this work, we continue to explore the crustal and uppermost mantle oceanic structure north of the Gloria fault by applying the techniques of ambient noise tomography. We extract empirical Green's functions (EGFs) from ambient noise phase cross-correlation, followed by phase weighted stack of continuous seismic and hydrophone data recorded at the array. In a first step, we explored both the vertical and hydrophone components of the recorded data. Our results indicate that the

EGFs have a higher signal-to-noise ratio when they are computed from hydrophone-hydrophone or hydrophone-vertical channel data. Based on the EGFs, we computed group velocities for each pair of stations, from which we obtained an average S-wave velocity of 1.6 km/s. Based on the ambient noise tomographic analysis, the three-dimensional structure below the DOCTAR Gloria fault array will be discussed.

ESC2018-S4-923

SEISMIC WAVE OBSERVATIONS ON THE CTBT IMS HYDRO-ACOUSTIC NETWORK

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The Comprehensive Nuclear-Test-Ban Treaty's (CTBT) International Monitoring System (IMS) consists of a network of four different sensor technologies deployed and designed to detect nuclear explosions worldwide. Eleven of these stations are hydro-acoustic stations, five of which are equipped with seismometers to detect underwater signals converted to seismic waves and may also contribute as auxiliary seismic stations. The other six stations are based on hydrophones deployed underwater to monitor the oceans for signs of nuclear explosions. Each hydrophone station is typically composed of two triplets of hydrophones suspended in the Sound Fixing and Ranging (SOFAR) channel. Placing hydrophones at this depth ensures optimum performance of the hydro-acoustic stations in detecting signals from very long distances as a result of the low attenuation that a signal undergoes when propagating in the SOFAR channel. These signals may either be T-phases originating from underground events and coupling into the SOFAR channel or signal originating in the water either from natural phenomena such as volcanic eruptions or underwater explosions, which are the signals of interest for the mission of the CTBTO. The seismic waves such as P-phases propagating in the ground and coupled into the ocean undergo much higher loss but can still be detected at the hydrophone stations. Statistics on the various types of waves (T and P) seen at the hydrophone stations to the multi-year Reviewed Event Bulletin (REB) produced at the CTBT International Data Centre (IDC) shows that they contribute in a non-negligible way. Since most of the stations are located in remote areas of the ocean, they complement the global picture of seismicity. Hydrophone stations also contribute to the detection of in-ground nuclear tests although designed mainly to detect in-water events. Several hydrophone stations detected the nuclear test DPRK6 on 3 September 2017 conducted by the Democratic People's Republic of Korea (or North Korea). The DPRK6 test had such a high magnitude that evidence of a weak T-phase arrival from the nuclear explosion is present on HA11, which most likely originates from coupling of the seismic signal to a hydro-acoustic signal in the ocean at the south-eastern Japanese slope. Although in general, P-phases detected on hydro-acoustic stations are not considered further in the processing of the IMS data, they may be useful in providing evidence in addition to the P-phases detected at seismic stations.

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ESC2018-S5-113

THE BAY OF ALGIERS (ALGERIA) SEISMIC SEQUENCE OF AUGUST 1ST, 2014 (MW 5.3)

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The Algiers's capital city was struck by a moderate-sized earthquake on August 1st, 2014 (Mw=5.3). The main shock occurred at 04:11:17.6 (GMT) was followed by several aftershocks. The main shock has been recorded by the Algerian accelerograph network and by national and international seismological networks. Few hours after the main shock, the National Center of Applied Research in Earthquake Engineering (CGS) deployed a temporary network in order to survey the aftershocks activity. In this work. we aim to develop the following points: (i) We study the mainshock using records of the Algerian accelerograph network to determine the earthquake parameters by inversion techniques. (ii) Analysis of the aftershocks that suggests offshore location, ENE–WSW trend and NNW dipping of the causative fault. Our results suggests that the causative fault may correspond to the offshore continuation of the known Sahel active reverse fault.

ESC2018-S5-115

SCENARIO BASED SEISMIC RISK AND LOSS FOR THE CAPITAL OF SANTORINI (GREECE)

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A seismic risk and monetary loss scenario is presented for Fira town, the capital of Santorini Island. Santorini is exposed to different natural hazards mainly linked to its volcanic and seismotectonic environment. The Plinian volcanic eruption in ~1600 BC created the outstanding caldera that attracts thousands of tourists every year. The vernacular architecture of Fira, developed along the tip of the caldera constitutes of a unique beauty's scenery, yet of risk not thoroughly investigated. A campaign of free-field microtremor measurements was conducted for characterization of the site response. In addition, an in-situ survey allowed for the compilation of the structural exposure model, comprising 435 buildings, making use of expert's judgment and locals' inquiry. The study is concentrated at the most vulnerable caldera sector and the newer central part of the town. The seismic scenario developed in the framework of the Deterministic Seismic Hazard Analysis applied herein, is based on the seismic activity related to the 2011 unrest of the volcano. Accurate relocation of hundreds well recorded small earthquakes allowed for the definition of the activated seismic source, about 8 km length and 6 km width, being a segment of Kameni Line. The inferred fault is found capable of producing an earthquake in the vicinity of Fira with M5.6. Site conditions were approximated by the Horizontal-to-Vertical-Spectral-Ratios (HVSRs) from free-field ambient noise measurements, following the popular method of Nakamura (Nakamura, 1989). Amplification ratios are found to be significant, exceeding 2, at all measuring points, while in the vicinity of the steep caldera higher amplifications are recorded at high fundamental frequencies, likely due to topographic effects. By implementation of the stochastic ground motion simulation by the EXSIM algorithm (Boore, 2009), simulated Peak Ground Acceleration (PGA) and EMS-98 equivalent Seismic Intensity (SIEMS-98) were derived for the selected earthquake scenario taking into account the deduced site amplification. Moderate values of PGA between 180 and 250 cm/s^2 are yielded, with the equivalent SIEMS-98 between 6.8 and 7.8. Structural vulnerability was assessed using the empirical-macroseismic RiskUE-LM1 method, (Milutinovic and Trendafilloski, 2003). The method applies the vulnerability model of EMS-98 (Grünthal, 1998) for the typological characterization of the building stock using vulnerability indices within a probability range, adapted by behavior modifiers accounting for the structures' particularities. The building taxonomy created for the exposure model of Fira comprises 6 main categories. The 60% of the available building stock is classified in three reinforced concrete typologies, depending on the Earthquake Resistant Design code in force during the erection period, while the 40% is bearing masonry, i.e. stone or cement brick. Mixed buildings undergone important interventions also exist, for which expert's judgment was applied for

their assignment into a EMS-98 vulnerability category. The presented seismic risk scenario in terms of the expected Damage Grade with the corresponding probability of occurrence was then developed by means of the beta distribution of the mean damage grade, a semi-empirical function that convolutes the hazard and vulnerability outcome. In the current study, although recognizing the uncertainties associated with all modules of the risk assessment process, deterministic results are given for the most probable case, in order to provide results exploitable by the civil protection authorities. The largest amount of structures is expected to experience no, or slight damage (55% and 29%, respectively), while 12% and 4% is expected to experience moderate and substantial-to-heavy damage, respectively. Loss assessment was based on damage ratios available from the literature with replacement cost value equal to 900€/m^2. The total expected loss is of the order of 4 million euros, while impact to the touristic business activity, not considered herein, may have long-term adverse effects to the country's GDP. The outcome of this work, presented in maps using GIS tools, can be of use from the local authorities for the establishment of emergency management plans based on realistic scientific scenarios.

Acknowledgments
We acknowledge support by the Special Account for Research Grants of the National and Kapodistrian University of Athens.

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ESC2018-S5-140

STRONG GROUND MOTION SIMULATION IN CEPHALONIA ISL. (IONIAN SEA) AND COMPARISON WITH OBSERVED CONSEQUENCES OF THE 2014 EARTHQUAKES

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The effects of the 2014 Cephalonia dual earthquakes are investigated by exploiting a large amount of data obtained after these events. The scope of this effort is to examine the contribution of parameters such as ground motion characteristics, site effects and the structures' vulnerability to the damage distribution. The Cephalonia Island is the most hazardous region of eastern Mediterranean, capable of producing earthquakes with M>7, as in 1953, when the whole island and surrounding regions were devastated by a cascade of three strong earthquakes. In the aftermath of the huge catastrophe and lessons learned, Cephalonia was rebuilt with new constructions to efficiently bear the large regional seismic hazard. The most recent earthquakes occurred on 26.1.2014 (Mw=6.1) and on 3.2.2014 (Mw=5.9) in the vicinity of Lixouri and produced extremely high PGA values, largely exceeding the provisions of the National Seismic Code, which, however, did not severely impact the built environment, with a proportion of damage mainly related to secondary effects such as liquefaction. The used data are constituted of ground motion recordings, buildings inventory, registered damage, geotechnical/geophysical seismic soil characterization, and ambient noise measurements. The two main-shocks and their aftershocks were recorded by a local seismological network of four broadband stations installed by NOA situated within the broad epicentral areas. The structural exposure model was based on the 2011 buildings census data. Real damage was obtained by the local sector of earthquake rehabilitation regarding the usability characterization of the affected buildings (green, yellow and red tags) based on their structural safety. Geotechnical/geophysical data available from the literature as well as data from borings

conducted after the 2014 earthquakes for the scope of roads' rehabilitation were employed. Free-field ambient noise was measured at 80 positions in the epicentral area obtained through a campaign conducted after the occurrence of the two earthquakes and HVSRs were computed. The reliability of the HVSR measurements was examined by comparing them with borehole data and seismic velocities from field measurements. Analysis of buildings' inventory was performed on a building-by-building level for the towns of Argostoli (capital of Cephalonia) and Lixouri, and on aggregated-basis per municipal district for the rest of the island. Structural vulnerability was assessed using the RiskUE-LM1 method (Milutinovic and Trendafilloski, 2003), which applies EMS-98 (Grünthal, 1998) vulnerability classes and respective behavior indices. Damage data was analyzed to estimate EMS-98 macroseismic intensities on the island. We note that due to the short time between the two earthquakes, it was possible to assess only the cumulative consequences of the two events upon the buildings. Damage was concentrated in the western part of the island. Old stone masonry constructions were worst affected. Several reinforced concrete buildings were also heavily damaged. Damage in Lixouri was more severe relative to Argostoli due to the town's epicentral location. This fact, apart from the stronger ground motion recorded in Lixouri, may also be due to larger vulnerability, given that 20% of its buildings were attributed to high vulnerability class as opposed to 4% in Argostoli. EMS-98 macroseismic intensities (I) were assessed from the structural damage data. The western part of Cephalonia (Paliki peninsula) exhibits I=VI-VIII while in the Argostoli peninsula I=VII was assessed. The northeastern, central and southern parts of the island experienced lower intensities (I=IV-V). In order to shed light on the effects of the 2014 earthquakes in the natural and urban environment, deterministic ground motions were obtained using the stochastic simulation approach implemented in the EXSIM algorithm (Boore, 2009). Synthetic PGA and EMS-98 equivalent Seismic Intensity were derived for the selected earthquake scenario taking into account HVSR as site response proxies (Nakamura, 1989). The derived intensity measures were found consistent with the observed environmental and macroseismic intensities. Scenario damage grades derived from the RiskUE-LM1 approach were then compared to the accumulated damage of the dual 2014 earthquakes, manifesting a satisfactory overall behavior of the constructions throughout the island.

Acknowledgments

We acknowledge support of this study by the project "HELPOS - Hellenic Plate Observing System" (MIS 5002697) which is implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

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ESC2018-S5-167

GROUND MOTION PREDICTION EQUATIONS FOR ALGERIA AND SURROUNDING REGION USING SITE CLASSIFICATION

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The present work is exclusively based on recorded data provided by the Algerian and the European strong ground-motion database. These data contain 1391 records homogeneously processed with more than 700 records in Algeria and the rest from essentially the Mediterranean region, with

distance and magnitude ranging respectively from 5 to 150 Km and 3.0 to 7.4. An emphasis is given to the proposal of appropriate ground motion prediction equation (GMPE) for Algeria and surrounding region considering site classification. This latter is based on the predominant period computed using average horizontal to vertical spectral ratio response (H/V). Four site categories are defined according to Zhao et al. (2006) classification scheme. Due to the insufficient number of records for very soft soil, one considers three soil classes for the computation of the empirical predictive spectral ground motion relations: rock, firm and soft. Two cases are studied; the first one considers only local data (52.84% with) which serves to illustrate the limits of considering only the country's borders, while in the second case, the regional data is added (47.16% with) to investigate its influence on the reliability and the robustness of the developed model. A truncation distance criteria is applied with respect to the magnitude and the distance values associated with each data. The obtained results show that (i) the model based on local data overestimates the predicted accelerations for larger magnitude, while the model based on regional data is in good agreement with the last published models; (ii) among the four soil classes, the amplitudes and the shapes of the mean H/V spectral ratios are significantly different. Furthermore, the peaks in the period range are reasonably similar to those of site periods defined for each site class by Zhao et al. (2006); (iii) the standard deviation decreases compared to the original rock/soil classification scheme and the obtained mean site coefficients for stiff and soft soil are in good agreement compared to those defined in EC-8; (iv) At short distance, the proposed GMPE for Algeria predicts relatively smaller spectral acceleration compared to recent published models possibly due to the differences in the lower magnitude bounds of these models; (iv) In addition to the proposed model, this study makes in evidence that Boore et al. (2014) and Akkar et al. (2013) models are appropriate for the computation of the seismic hazard in Algeria.

ESC2018-S5-257

DELINEATION OF THE POTENTIAL SEISMIC SOURCES OF THE EARTHQUAKES M6+ IN THE MAGHREBIDES

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The system of mountain ranges in North Africa composing the Maghrebides is studied with a goal to identify seismogenic nodes capable of generating earthquakes M6+. Due to the high population density and the complex oil/gas infrastructure developed in the region, a knowledgeable seismic hazard assessment is of high importance for mitigation of human and economical losses from large earthquakes. Nodes, earthquake-controlling structures, have been delineated with morphostructural zoning method on the basis of topographic, tectonic, and geological data. The seismic potential of the delineated nodes was estimated using the pattern recognition technique. Nodes already marked by M6+ earthquakes have been used for learning the pattern recognition algorithm Cora-3. On the basis of morphometric, morphostructural, and geological parameters uniformly characterizing all the nodes the algorithm pinpointed the nodes where the target M6+ events may occur in the future. We also made an attempt to identify nodes prone to M6.5+ using criteria of seismicity typical for such nodes that were delivered from the pattern recognition in the highly seismoactive Tien Shan-Pamir region. We expect that, the incorporation of seismogenic nodes information in seismic hazard computation will improve performance of the resulting maps for the studied region especially for the sites of rare or no seismic activity so far.

ESC2018-S5-273

SEISMIC STUDIES IN WESTERN PELOPONNESE AND IONIAN SEA, GREECE

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From July 2016 to May 2017 we investigated the seismicity in Western Peloponnese, Greece, to analyze the crustal deformation of the region. We deployed a local seismic network composed of 15 temporary stations (Short Period Lennartz LE-3Dlite 1s) and 9 permanent seismic stations of the

Hellenic Unified Seismological Network (HUSN) between 39°N to 37°S and from 20°W to 22°E. 1515 earthquakes were recorded and located building a catalogue of events with magnitudes ranging from M L 1.1 to M w 4.7. The events catalogue was constructed using the STA/LTA method and auto-picked using PhasePApy python package (Chen and Holland 2016). The matlab tool PSPicker (Baillard et al. 2014) was applied to refine the P and S arrivals. The study area was deliniated into 4 regions to constraints 1D optimum local velocity models with the location errors minimization technique. The relocated events show a complex crustal architecture with seismisicity from 2 to 30km depth. The kinematics was highlighted by the major events (i.e. M>3) moment tensor solution computations. Notable seismogenic structures of the offshore Western Peloponnese were detected when combining the focal mechanisms and the relocated microseismic activity. Finally, we present the preliminary results of an ambient noise tomography pointing out the shallow velocities anomalies within the Greek Ionian sea.

ESC2018-S5-379

SEISMO-TECTONIC INFORMATION SYSTEM FOR THE ANALYSIS OF TECTONIC AND GEOMORPHOLOGICAL VARIATIONS IN THE SE-CARPATHIANS

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For geoscientists, one of the most interesting areas in the Eurasian plate are the South-eastern Carpathians due to the post volcanic activity of the Ciomadul volcano and the seismicity of the Vrancea region. These areas show an important indication about the ongoing subduction and the accompanying roll-back. In this region, there have been many geophysical and geodetic measurements for investigating surface- and internal processes which are connected to the recent deformations based on magnetotelluric and seismic measurements and GNSS-observations. The recent surface deformations can be assessed using interferometric synthetic aperture radar. Currently, the analysis mainly based on archive SAR-images is in progress in the vicinity of the Ciomadul volcano. Supporting these activities, we have decided to create a seismo-tectonic information system. We have collected thematic maps (e.g. digital elevation model, tectonic maps), measured and preliminary data (e.g. archive ENVISAT-images and stress data derived from focal mechanism solutions) to study the vertical and horizontal motions in this area. The authors hope that this database will provide help in understanding the coupling between internal processes and the surface movements and the recent deformations resulting from tectonic and geomorphologic variations. Moreover, these data could make it possible to study the seismic hazard assessment of Romania.

ESC2018-S5-383

AN EFFECTIVE WORST CASE SCENARIOS SEISMIC HAZARD ASSESSMENT IN EGYPT

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In fact this work is an extension of the previous works in the field of seismic hazard assessment for Egypt in order to make the results are more accurate and effective, taking into account the worst possible scenarios to assess the seismic hazard. This work comes to light to clarify these scenarios and results. To achieve the desired objectives of this work, the deterministic seismic hazard approach (DSHA) was applied to assess the hazard. An updating seismic catalog of Egypt has been prepared and the aftershocks have been screened and removed followed by the conversion of all the magnitude scales to moment magnitude (Mw). The earthquake catalog was used to identify and locate with extremely accurate the possible multi-seismotectonic scenarios in and around Egypt. The controlling earthquake was determined from the effective seismic sources. The suitable indigenous attenuation relationship was used in calculating seismic hazard from each seismotectonic zone. Seismic hazard was calculated from each seismic source with the maximum expected earthquake and the shortest distance (worst scenario) from these sources to the strategic and important cities in Egypt. Hazard maps are illustrated for spectral acceleration as well as 0.1, 0.2, 0.5, 1 and 2 seconds spectral

periods for 50th and 86th percentile levels for the selected probabilities of exceeding the median peak ground acceleration on bedrock condition for each seismotectonic model. We compared the results obtained from worst case scenario (this study) with the published probabilistic hazard results. Key words Seismic hazard, deterministic seismic hazard, spectral acceleration, Egypt

ESC2018-S5-426

STRESS FIELD VARIATION IN THE WESTERN PART OF AFRICA-EURASIA PLATE BOUNDARY FROM THE AZORES TO TUNISIAN ATLAS DERIVED FROM FOCAL MECHANISMS INVERSION

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The Africa-Eurasia plate boundary displays, a transition from simple deformation at the Azores triple junction in the Atlantic Ocean to a complex and deformed zone in Atlas Mountains in Morocco, Algeria and Tunisia. Most of the studies concluded to a convergence movement between African and Eurasian plates in the NW-SE direction with anticlockwise rotation. Moreover, the general stress regime shows extension in the Azores region, right-lateral strike slip motion in the Gibraltar strait and Alboran Sea, and compression in the Maghreb Area. The aim of this work is to present a new insight of the tectonic stress regime along the plate boundary zone from the Azores triple junction to Tunisia, derived from the orientation of principal stress axes (Shmax, Shmin) and the shape factor calculated from focal mechanism inversion. We inverted just the main shocks without the aftershock focal mechanism sequences that occurred in the study area. We used the slickenside analysis package of Michael's (1987) method to invert our focal mechanisms and we present a focal mechanism database used which has been compiled from all earlier published studies and International Agencies. The present stress field obtained in this study switches progressively from extensional in the Mid Atlantic and Terceira Ridges-Azores Islands, to strike slip from Gloria Fault to the southern Spain crossing Gorringe Bank and Golf of Cadiz, progresses towards the Rif crossing the Alboran Sea. It turns to compressional regime in the western Algeria, and to Strike in the eastern and southern Tunisia, excluding the northern of Tunisia where the present stress is a reverse behavior. At the end, we present a kinematic model based on focal mechanism inversion compared with previous published models.

ESC2018-S5-470

PROBABILISTIC SEISMIC HAZARD ASSESSMENT OF PRAGUE (CZECH REPUBLIC)

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Prague is the capital of the Czech Republic with 1.3 million of inhabitants. It is situated in the intraplate region with low seismicity. The seismic hazard there is low, but not negligible. During its evaluation we face the following challenging issues:

1) There are no M>6 events during the period covered by historical catalogue, although there is an evidence from paleoiseismic research, that there were earthquakes with magnitude at least 6.5. It is difficult to do a reliable statistics from a small amoungt of data.

2) There are no GMPE determined for the region of interest. We studied the attenuation from recent weak earthquakes in order to determine which of published GMPEs are suitable for the region. Moreover, we show that the attenuation in strongly dependent onf the earthquake azimuth.

3) There are plenty of faults in the city and its neighborhood, all of them believed to by inactive. We have to quantify the probability of an unexpected earthquake on such faults.

4) The hazard is dominated by 140km distant West Bohemia Source Zone with earthquake swarm activity, which does not follow classical mainshock-aftershock model nor Poisson distribution in time.

We used classical Probability Seismic Hazard Assessment with two independent source models, one with area sources based mainly on clustering of historical earthquakes and another consisting of traces of seismoactive faults. The results show that the seismic hazard for Prague (expressed in

terms of peak acceleration) is below 0.1g for the returning period 10 000 years.

ESC2018-S5-485

SEARCHING FOR THE SEISMOGENIC SOURCES OF THE 1693 SEISMIC SEQUENCE IN SOUTH-EASTERN SICILY: A MULTIDISCIPLINARY APPROACH.

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We performed a multidisciplinary study in south-eastern Sicily by means of seismic and DInSar data investigations and morphometric analyses, with the aim of looking for the seismogenic sources of the 1693 earthquakes. In the past, south-eastern Sicily was affected by strong earthquakes such as the 1169, 1542 and 1693 events, with intensity Io up to XI (MCS) and Mw up to 7.3 (Rovida et al., 2016). Since earthquakes occurred before seismic instrumental time and given the lack of known surface faulting, the location of their seismogenic sources is not well defined. As sources of these earthquakes, various Authors propose several geological structures, differing in location, attitude and kinematics. Among the others: the NNW-SSE normal to oblique Malta Escarpment Fault System, located in the Ionian offshore; the N-S strike-slip Scicli Fault, the ENE- WSW normal Monte Lauro Fault, the NE-SW normal Avola Fault located in the central, northern and south-eastern sectors of the Hyblean Plateau and lastly the NNW-dipping Sicilian Basal Thrust across the central-eastern Sicily and the Ionian offshore (see DISS Working Group, 2015 and references therein). We performed a revision of the macroseismic data of the 1693 main shocks (9 and 11 January, Mw≈6.1 and Io = VIII-IX MCS; Mw≈7.3 and Io XI MCS, respectively; Rovida et al., 2016). The study confirms that the source of the 9 January earthquake is located in the area between Palazzolo -Canicattini and Augusta. On the other hand, the source of the 11 January earthquake seems to be located more to the north, compared to literature data. However, cumulative damage effects bias the macroseismic field of the main event. Therefore, considering that the 11 January was followed by a strong tsunami, its source could be located off shore. In order to highlight cluster of seismicity around probable seismogenic faults, we analysed a catalogue of about 1500 earthquakes, with 0.4≤M≤4.6, recorded in the period 1994-2017 by the local seismic network of Istituto Nazionale di Geofisica e Vulcanologia. Over the considered period, south-eastern Sicily was affected by a seismicity with low-to-moderate energy release and hypocenters mainly located at depth between 10 and 25 km. The most active areas are: off shore: i) the Ionian sector between Catania and Siracusa; on land ii) the Augusta area; iii) the Palazzolo - Canicattini area; iv) the sector across the Avanfossa Gela-Catania. The area of the Scicli Line is affected by a moderate and shallow seismicity. Most of the earthquakes show either strike slip or transtensive mechanisms (Musumeci et al., 2014). With the aim of investigating present day surface movement and fault activity, we have also undertaken new DInSar investigations. In particular, we are processing all the available Sentinel 1a-1b SAR dataset (2014-2018 time spanning), using a A-DInSAR (Advance DInSAR) processor based on multi-temporal approach (Ventura et al., 2014). In the areas of maximum seismic activity and maximum surface displacement, we undertook aerial photos and DTM analyses along with morphometric investigations of the river courses. The area between Palazzolo, Canicattini and Augusta is affected by NW-SE, NE-SW and almost NNE-SSW faults. Preliminary results reveal that these structures are active and responsible of the recent modification of the river courses, in particular as it regards faults with NE-SW and almost NNE-SSW trends. The study is in progress, however currently seismic, A-DInSar, morphometric and structural evidence match together very well. Data highlight two areas where the sources of the 1693 earthquakes could be located: the first between Palazzolo and Canicattini and the latter near Augusta. Despite none of the cropping out faults show sufficient geometrical characteristic and dimension to be the real source of the 1693 earthquakes, they could be the superficial expression of a deeper and larger fault that should be analyzed in depth.

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ESC2018-S5-604

THE 1790 ORAN (ALGERIA) EARTHQUAKE, A SEISMIC EVENT IN TIMES OF WAR: A CRITICAL REVIEW FROM THE EUROPEAN AND ALGERIAN SOURCE MATERIALS

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This research appraises the most known destructive earthquake that occurred in the second important Algerian city, along its seismic history. The earthquake, which struck Oran in 1790 and was at the origin of the departure of the Spanish who were colonizing the city since the 16th century, spilled a lot of ink. It is cited in innumerable documentary sources; however few studies were devoted to the 1790 Oran earthquake. These studies, which in general are exclusively based on Spanish sources, show that the 1790 Oran earthquake is quite different from the known destructive seismic events that occurred in Algeria in its historical and recent times. To better constrain the 1790 earthquake parameters, an investigation of Algerian documentary sources is performed in the surviving heritage series. In this paper, a) the historical details are assessed in the perspective of the social and political situations contemporaneous with the event; b) all the earthquake effects, among which the tsunami triggered on the Spanish coast, are presented; c) the macroseismic field is reconstructed by using, for the first time, the Algerian sources jointly with the European sources. The reappraisal of the 1790 Oran earthquake has shown how difficult it is to assess the characteristic parameters of an earthquake which occurred amid war, because the macroseimsic information is strongly influenced by the conflict situation and the reliability of the data sources is thereby limited. This study highlights how important is to take into consideration the historical and sociological context when analyzing the macroseismic information of any historical earthquake. The critical review of this seismic event and its comparison with the Algeria destructive earthquakes made us think, at first sight that the seismic event was not as large as people have been made to believe, and led us to lower the maximum intensity from IX-X EMS in previous studies to VIII EMS.

ESC2018-S5-634

SOURCE CHARACTERISTICS OF THE 2014 ARZEW EARTHQUAKE (MW3.9), WESTERN ALGERIA

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The Mw3.9 Arzew earthquake that occurred on 20 march 2014 shortly after midnight (local time) about 5 km west of the city of Arzew is one of the first well recorded earthquakes that occurred in the western part of Algeria. The maximum intensity was IV-V in Arzew-Oran area. The instrumental epicenter was located at 35.825° latitude and -0.366° longitude and the depth at 5 km. On February 1st of the same year (2014), a foreshock of MD3.1 occurred at the same place than the 20 March event (mainshock). The focal mechanism calculated for the mainshock from the first motion polarity shows an almost pure strike-slip mechanism with ~E–W and ~N–S vertical nodal planes. We investigated the single foreshock and the mainshock using SP and BB data recorded at short distances. The empirical Green's function analysis shows a relative source time function (RSTF) of about 0.1-0.2 sec duration and the maximum relative amplitude was observed east of the epicenter. The analysis also shows two interesting features: a clear rupture directivity to the east-northeast which favor the ~E–W nodal plane to be the fault plane, and a not simple

rupture. Indeed, the relatively high cross-correlation coefficients between the foreshock and the mainshock waveforms at sites located in the east-northeast of the epicenter suggest that the rupture propagated in this direction and that the two events are co-located and have similar focal mechanisms. Furthermore, following the Brune seismic source model, the corner frequencies estimated using P-wave data range from 0.7 to 3.0 Hz; the source dimension ranges from 678 to 2907 m; the seismic moment (Mo) from 0.15e15 to 4.36 e15 N m, which corresponds to Mw 3.4–4.4; the stress drop is 0.1–8.1 bar; and the average displacement is slightly more than 0.6 cm. The 2014 Arzew earthquake study may provide a better constraint on the distribution of crustal deformation and the local seismic-hazard map in the western Algeria.

ESC2018-S5-812

PRESENT DAY SEISMICITY AND DEEP PROCESS IN THE HOGGAR (ALGERIA)

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The Hoggar shield is a broad area of exposed Precambrian basement bounded by Paleozoic and Mesozoic basins. Maouche et al. (2014) show that the region is characterized by various tectonic features including normal, thrust and strike-slip faults affecting Cenozoic sedimentary series. Recent field analysis shows an extensive normal fault network that affects both the sedimentary series and the volcanic rocks that spread over the central Hoggar in various districts. The normal fault distribution seems to be related to post-volcanic tectonic activity, within a time span from Miocene to Quaternary. The Hoggar region is composed of three contrasted lithostructural and metamorphic domains separated by N-S trending shear zones that form the central Hoggar, the Pharusian belt and the In-Ouzal domain. The seismic tomography performed by Ayadi et al. (2000) shows the existence of hot material (large thermal anomaly) under the central Hoggar extending down to the lithosphere. These observations are also supported by gravity anomalies (Lesquer and Vasseur 1992) attributing the large low density anomaly to the melting at the lithosphere/asthenosphere interface under the central Hoggar. Although no recent tectonic movements were reported in the Hoggar shield, the Quaternary volcanism and background seismicity with magnitude reaching ML 4.5 testify for an active intraplate continental domain and the Hoggar shield experienced two seismic events in 2010 and 2013 with respectively ML 4.0 and ML 4.5. The origin of this seismicity is under debate whether it is due to tectonic activity or to thermal processes associated with the Quaternary volcanism in the area. In this study, we analyze the background seismicity of the Hoggar region and study the correlation with the tectonic structures.

ESC2018-S5-882

ACTIVE TECTONIC IN MEDITERANEAN COAST: NEW INSIGHTS FOR THE ORAN-ARZEW SALINES, NORTHWEST ALGERIA

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The Tell Atlas trending belt is one of the most seismically active region in Northern Africa. Located in the western Mediterranean area, along the Africa–Eurasia convergent plate boundary, the Algerian coast displays evidences of active thrusting and coastal uplift associated with large earthquakes. The Mw 6.9, 21 May 2003 Zemmouri and Mw 7.3, 10 October 1980 El Asnam earthquakes were among the strongest events recorded in the area. The Oran basin, located in Northwest Algeria extends from Aïn Temouchent to Mostaganem, experiences a low to moderate seismicity. In this study, we focus on the Salines d'Arzew coastal area, which shows similitudes with seismogenic structures in northern Algeria (i.e Oued Fodda fault (El-Asnam) and the Sahel fold and related reverse fault near Algiers). The geological structures of Arzew Salines correspond to folds and reverse faults, affecting the quaternary formations. Although occurrences of obvious surface breaks have not been shown so far, morphotectonics features provide evidences of cumulative vertical movements associated with NW-SE shortening. They correspond to tilted

deposits, and uplifted marine and/or alluvial terraces. These morphological features provide a reference and chronological data to constrain the coastal active tectonics in the Oran-Arzew region.

ESC2018-S5-890

VARIATION OF VELOCITY MODELS FROM SEISMOLOGICAL DATA AND A REVIEW OF CRUSTAL STRUCTURE IN TURKEY AND SURROUNDING REGION

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Turkey and surrounding region, which suffer from active seismicity for many years, is located in the Alpine-Himalayan orogenic belt. Within this belt different continental and oceanic branches related to the opening and closure of the Paleozoic and Mesozoic oceanic basins can be found. The complexity of the region lacks the possibility to define the region with a one simple velocity model. On the other hand, the precision of the hypocenter parameters depends significantly on the P and S wave velocity models and bring the necessity to obtain site specific velocity-depth models on a variety of different regional crustal structures in Turkey. Determination and use of site specific crustal velocity model during the computation of moment tensor solution, is also a critical point for obtaining reliable source mechanisms. This situation indicates the importance of using site specific velocity models for local and regional researches. In the region several studies performed with the installation of local and regional temporary networks in order to estimate the one-dimensional velocity models. However, these studies generally lie on short term data limited with the regions of network deployment. In this study, a review of previous studies performed for understanding the deficiency of the knowledge on the variation of crustal structure. The number of recorded earthquakes increase day by day with the improvement of the seismic networks operated in the area. Kandilli Observatory and Earthquake Research Institute (KOERI) which operates a seismic network with more than 250 stations in the region, recorded almost 140,000 events between 2012 – 2018. In order to compute one dimensional velocity models for different lithospheric fragments, seismicity catalog of KOERI, recorded in this time period were compiled. A high quality data-set that can be grouped in several distinct clusters were used and the earthquakes are re-located using these local velocity models. Determination of the detailed crustal structure on different lithospheric fragments and the re-location of earthquakes by using these new models improves the correlation of these earthquake locations with the existing active faults. The results of the study will also be a fundamental step towards not only in seismic tomography studies but also for the determination of three dimensional (3-D) Vp and Vp/Vs models in the area.

ESC2018-S5-900

SIMILARITIES BETWEN THE HAMMAM MELOUANE FAULT SYSTEM AND THE THENIA FAULT ZONE: SEISMOTECTONIC IMPLICATIONS FOR THE MITIDJA BASIN, NORTHERN ALGERIA

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Geological and sismological investigations performed in the area of Hammam Melouane (Southern border of the Mitidja basin) allowed us to incriminate a dextral strike-slip fault zone as playing a role in the seismicity of the southern border of the Mitidja basin. This allowed us to characterize the fault zone at outcrop and map-scale. Similarities in terms of bearing, length, structure and distributed character have been observed with the Thénia strike-slip fault zone located 50 km Northeast, at the eastern end of the continental Mitidja basin. In the present contribution, we compare and discuss results obtained from the study of both Thénia fault zone and Hammam Melouane fault system.

ESC2018-S5-917

MONITORING MICROSEISMIC ACTIVITY WITH AN ARRAY OF MINI-ARRAYS IN THE DEAD SEA REGION

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The seismicity generated by the Dead Sea Transform (DST) in the Dead Sea region is

presently moderate to low. The region, however, has an extended historical record of devastating events, the last one of which was the 1927 (M 6.2) Jericho Earthquake, with over 500 casualties. A replay of the 1927 event, in a politically volatile region which hosts over 8 million people today, would have the potential to trigger a major humanitarian crisis. DeadSeaNet, an experimental array of mini-arrays deployed in the Northern Dead Sea region was used to monitor local microseismicity in realtime over the past 4 years. Hundreds of (4.2>Ml>0.0) events were located and characterized. Despite the complex substructure of the DST and the lack of adequate velocity model, advanced cross-correlation based algorithms provide reliable spatial estimates for events detected by at least 3 mini-arrays. The spatial distribution of DST-generated seismicity has been used to map presently active faults. The distribution of presently active seismicity incidentally corroborates iso-amplification lines of microzonation mapping for the Northern Dead Sea region.

ESC2018-S5-971

NEO-DETERMINISTIC SEISMIC HAZARD ASSESSMENT IN KOSOVO AT THE REGIONAL AND LOCAL SCALE

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The Kosovo region belongs to the Alpine-Mediterranean tectonic belt and is one of the most seismically active regions in Europe. Historical records exist of several catastrophic earthquakes in the region with epicentral intensity IX. At the same time, due to high population density, type of traditional building materials and insufficient enforcement of building codes, it is also one of the least resilient to earthquake damage. Thus more research is needed in order to develop reliable seismic hazard scenarios that will allow government and non-government agencies to enforce effective and sustainable prevention efforts. In this study we present seismic hazard maps (at bedrock) for the Kosovo region based on the innovative neo-deterministic seismic hazard approach (NDSHA). NDSHA generates complete time series, relying upon the fundamental physics of wave generation and propagation in complex geologic structures, as input for the computation of several ground motion parameters, integrating the available knowledge of seismic history, seismogenic zones and structural models. Finally we present few examples of site-specific hazard assessment at relevant locations followed by the local scale NDSHA that provide estimates of spectral amplifications on local soil conditions.

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SESSION 06

ESC2018-S6-109

INSIGHTS INTO THE 20 JULY 2017 MW 6.6 BODRUM-KOS EARTHQUAKE FROM SEISMOLOGY AND SATELLITE GEODESY

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The 20 July 2017 Bodrum–Kos earthquake (Mw 6.6) is the largest instrumentally-recorded earthquake in the Gökova graben, one of the primary physiographic features of SW Turkey. Using seismology and satellite geodesy, we investigate its source characteristics, aftershock distribution, relationship with earlier instrumental seismicity, and association with known surface faulting. We show that the earthquake ruptured a planar (non-listric) normal fault that dips gently (∼37°) northward beneath the northern Gulf of Gökova coastline, initiating at a depth of ∼11 km and rupturing upwards and bilaterally. Aftershocks concentrate around (but not necessarily on) the western, eastern, and down-dip edges of the ∼25 km-long rupture plane, and have maximum focal depths of ∼15 km. Aftershock focal mechanisms exhibit a predominance of ~E–W trending normal faulting,with nodal planes generally sub-parallel with those of the mainshock. We see no evidence for subhorizontal nodal planes, as might be expected if the mainshock faulting graded into a low-angle detachment at depth. In addition, aftershocks in close proximity to the proposed left-lateral GökovaTransfer Fault show no indication of NE–SW left-lateral slip or N–S oriented P axes.NE–SW left-lateral slip or N–S oriented P axes; most have ~E–W-striking normal faulting mechanisms and thus ~N–S-oriented T axes.The mainshock surface trace bounds a bathymetric ridge east of Kos island, and may be one of several faults imaged previously in this area using seismic profiling and multibeam sonar. The fault thus lies within the hanging wall of the lower-angle (∼20° N-dipping) South Datça fault, which it presumably cross-cuts at depth. Through calibrated relocations, we confirm that sequences of moderate (Mw 5–5.5) earthquakes in 1989, 2004 and 2005 occurred in the eastern and central Gulf of Gökova, many of them likely within the hanging wall of the S-dipping c fault.Overall, our results indicate a switch from dominant S-dipping normal faulting in the eastern graben to dominant N-dipping faulting in the west, but we find no support for a proposed NE–SW-trending left-lateral fault in the central Gulf. Finally, the Bodrum–Kos mainshock adds to growing set of examples from across the Aegean region of large normal faulting earthquakes that cut the seismogenic layer as simple planar structures.

ESC2018-S6-247

A DETAILED STUDY OF THE 12TH JUNE 2017 MW=6.3 LESVOS EARTHQUAKE

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Lesvos Island is part of an old volcanic center in the east Aegean Sea that was active 15-19 My ago, located west of the coast of NW Asia Minor (Turkey). Geological, seismological and geodesy data indicate that the region's deformation is driven by transtensional tectonics, including E-W normal and NE-SW strike-slip faulting. The abovementioned complex deformation has been associated with intense seismicity in the past, documented in catalogues of historical and instrumental seismicity. On 12 June 2017, a shallow strong earthquake with magnitude Mw=6.3 occurred offshore, south of Lesvos (12:28 GMT), causing one fatality, severe structural damage and several secondary effects in the SE part of the island (Papadimitriou et al., 2018). This event was one of the largest that have occurred in the vicinity of Lesvos Island since the antiquity, as

well as during the 20th century. It was strongly felt in the north Aegean islands and the neighboring Turkish coasts, while it was also felt in the Greek mainland. In this work we attempt to highlight the nature and dynamics of the earthquake sequence, the driving forces that acted during its evolution and potential consequences of its occurrence on the regional hazard. To this aim, a comprehensive dataset of recordings from the Hellenic Unified Seismological Network (HUSN), a local temporary network deployed by the Geodynamic Institute – National Observatory of Athens and the Kandilli Observatory and Earthquake Research Institute (KOERI) was compiled and the following tasks were carried out: (a) determination of precise hypocentral locations employing a custom velocity model, followed by double-difference relocation, (b) spatiotemporal analysis of the sequence, (c) regional moment tensor inversion for the determination of the source parameters of the mainshock and the larger events, (d) inversion of focal mechanisms to investigate the local stress-field distribution and (e) computation of Coulomb stress transfer to identify regions that were loaded with additional stress. After the manual determination of P- and S-wave phase arrivals, a dataset of 900 earthquakes, between 12 and 30 June 2017, was compiled and a local velocity model was calculated. Locations were following recalculated with the new model and relocated with the use of a double-difference algorithm. The spatial distribution of epicenters revealed seven clusters that are in general agreement with the geometry of known mapped faults and compatible with the strike of Quaternary faults along the southern coast of Lesvos. Seismicity gradually migrated towards the NW and SE, away from the main rupture. Additionally, on 17 June, the largest aftershock (Mw=5.2) triggered a secondary sequence on a separate fault segment, oriented NW-SE. Regional moment tensor inversion revealed a focal mechanism with a strike of N122°E, a dip of 40° and a rake of -83°, indicating SW dipping normal faulting. Most of the determined focal mechanisms of the sequence followed this trend. Nevertheless, the largest aftershock displayed strike-slip characteristics. In addition, 82 focal mechanisms, including events of past activity (Kassaras et al., 2016), were inverted (Hardebeck and Michael, 2006). A complex stress field south of Lesvos, related both to normal and strike-slip faulting was revealed. Results from the Coulomb stress transfer procedure indicate placement of all aftershocks outside the main rupture within positive lobes of static stress transfer. Furthermore, the occurrence of the Mw=5.2 aftershock to the SE of the island and the seismicity that accompanied it, can be attributed to stress loading on optimal faults under a strike-slip regime.

Acknowledgments

We acknowledge support of this study by the project “HELPOS - Hellenic Plate Observing System” (MIS 5002697) which is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

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ESC2018-S6-259

POTENTIAL EARTHQUAKE SOURCES OF THE LARGEST M7+ EARTHQUAKES IN THE GREECE MAINLAND

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The study is an example of the interdisciplinary approach for identifying the possible locations of the largest M7+ events. This approach combines

the geomorphic analysis and mathematical methods. We used geomorphic methodology, specifically, morphostructural zoning for delineating morphostructural nodes that are viewing the earthquake-controlling structures. Nodes formed at the intersections of lineaments bounding homogeneous morphotectonic blocks and tracing along the zones of active deformations expressed in the topography. The epicenters of M7+ earthquakes in the Greece mainland correlate with delineated nodes. To identify capable nodes for M7+, we used the mathematical approach, namely, the pattern recognition techniques. For discrimination of the nodes into seismogenic and non-seismogenic ones we have used a wide range of geological-geomorphic information. Nodes experienced M7+ earthquakes were treated as the samples for training the recognition algorithm. As a result, we have properly recognized all nodes hosting M7+ earthquakes and a number of potential nodes where events of such size have not happen so far. The work contributes to the assessment of the seismic hazard in Greece. The reported study was partly funded by Russian Foundation of Basic Research (RFBR) according to the research project 16-55-12033.

ESC2018-S6-395

CRUSTAL DEFORMATION AND FAULT MODEL OF THE 2017 GULPINAR-BABAKALE EARTHQUAKE SEQUENCE (BIGA PENINSULA, NE AEGEAN REGION): SEISMOLOGICAL AND INSAR EVIDENCE

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We investigate the shallow earthquake sequence onshore Biga Peninsula (NW Turkey, NE Aegean region) that occurred during February-April of 2017 near the villages of Gulpinar-Babakale. We use seismological data (parametric data and Moment Tensor solutions from NOA and KOERI catalogues) and InSAR differential interferograms (Sentinel-1 satellites) to identify the east-west striking seismic fault and to refine its geometry and kinematics using inversion techniques. The catalog earthquakes were relocated with the HypoDD software and the use of a local velocity model. A southdipping fault is not retrievable from InSAR but it is clear from seismology and the aftershocks distribution. The spatial distribution of relocated events shows the activation of one fault with a total length of about 12 km.

ESC2018-S6-526

STOCHASTIC GROUND MOTION SIMULATION OF THE 2017 M=6.3 LESVOS EARTHQUAKE: EXPLAINING THE DAMAGE PATTERN OF THE HISTORICAL VRISA SETTLEMENT

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We examine the structural damage pattern of the recent Lesvos earthquake of June 12, 2017 (M6.3) in the historical settlement of Vrisa (Lesvos island, Greece). While Vrisa is located on the foot-wall of the Lesvos M=6.3 2017 earthquake, which took place at sea ~10 Km southwest of Lesvos, it caused extended structural failures (and one death) in the village of Vrisa, where most damage was observed. More specifically, in the northwestern part of Vrisa, located in a local Holocene sediments basin, nearly all masonry (historical and recent) houses collapsed or were severely damaged. On the contrary, in its southeastern part, located on Neogene sediments, masonry houses were significantly less seriously affected. While the earthquake also caused low to moderate damage in a few towns and villages of the southern coast of Lesvos (e.g. Akrasi, Plomari, etc.), especially those closer to the fault, no other settlement exhibited such significant damage levels. To explain such localized earthquake-induced damage, we employed the stochastic finite-fault modelling approach of Motazedian and Atkinson (2005), as adapted by Boore (2009), simulating the Fourier Amplitude Spectra (FAS) of the 2017 Lesvos earthquake. To calibrate the stochastic finite-fault method parameters, we used waveform data from both acceleration and broadband-velocity sensors within ~100km from the epicenter. We computed an updated 1-D

velocity model for the study area and relocated the aftershock sequence to determine the main geometrical features of the earthquake's fault. Preliminary relocations were performed with HYPOINVERSE (Klein 2000), while the final hypoDD relocations (Waldhauser and Ellsworth 2000; Waldhauser 2001) allowed to improve the aftershock sequence distribution. These relocations allowed to constrain the main fault dimensions, strike and dip, to be used for the simulations, in good agreement with fault plane solutions published for this event. Using the previous seismic source constraints, as well as appropriate path and generic site-effect information for the Aegean area, we solved for the mainshock stress-parameter value (??), using a trial-and-error approach, through comparison of simulated and observed acceleration Fourier spectra. To assess the local site effects within the Vrisa settlement, we employed a dense grid of ~70 noise measurements to derive single-station Horizontal-to-Vertical Spectral Ratios (HVSR). The results revealed a strong spatial variation of the soil fundamental frequency, f0, and maximum HVSR amplitudes, A0HVSR, with almost flat HVSR curves in the southeast Vrisa (Neogene sediments) and large A0HVSR values (locally >4) in the Holocene sediments at frequencies f0~2.5-3 Hz. Since A0HVSR values generally provide a low threshold of true site-amplifications, we expect seismic motions to be significantly amplified in the Holocene sediments section of the village. This was confirmed by Standard Spectral Ratios (SSR) computed from aftershock records for both Neogene and Holocene deposits, which showed that peak amplifications, A0, were almost double than A0 HVSR values, though the resonant frequency, f0, and spectral shapes of the SSR and HVSR curves were nearly identical. Quantitative comparison of HVSR and SSR results for several sites allowed to derive an appropriate scaling factor and match HVSR curves to equivalent SSR curves. Using these equivalent SSR amplifications, we employed the stochastic simulation method for the determination of complete ground motion synthetics throughout a dense virtual receiver grid in the Vrisa area, and reconstructed the detailed spatial variation of several ground motion measures (PGA, PGV, etc.), as well as expected macroseismic intensity (IMM). Results showed that the while the southeastern part of the Settlement (Neogene deposits) exhibited values around IMM=6+ to 7, the northwestern Holocene section experienced damage levels of the order of IMM=8+ to 9, in very good agreement with the observed damage distribution. A post-earthquake survey conducted by ITSAK-EPPO, surveyed 160 old masonry structures and 12 R/C buildings within the Vrisa settlement (partial photo documentation available at http://arcg.is/2sPnlrf), and the EMS98 intensity scale was employed to quantify the observed damage. The majority (~60%) of old masonry buildings, classified as vulnerability class A and founded on the Holocene sediments, presented heavy damage (EMS98 grade 5), referring mainly to out-of-plane failure of the masonry walls, while a considerable number of partial or total collapses was also recorded. On the contrary, most of the masonry structures founded on the Neogene formations sustained considerably less, localized types of failure (EMS98 grade 2 or 3). This damage pattern is well correlated with the computed amplification levels of seismic motion for these two zones. Moreover, R/C buildings showed negligible or no damage (grade 1 of EMS-98), independently of their foundation soil conditions, indicating that the actual seismic loads were inferior to those prescribed in the Seismic Codes for the area under the design earthquake scenario. The above correlations lead to an overall assessment of EMS98 intensity between VIII and IX for the northwestern part and between VII and VIII for the southeastern part of Vrisa.

ESC2018-S6-609

THE SURGE OF SEISMIC SWARMS IN 2012 ON THE EAST AEGEAN SEA AND WESTERN TURKEY

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The seismicity of East Aegean and Western Turkey is studied in the context of triggered swarm activities. Earthquake catalogs from various agencies are combined for the period of 2006-2017 to form a unified database. The quarry blasts are detected and eliminated. The common events to any two catalogs are identified and duplications removed. A magnitude correction is applied to guarantee a unique magnitude scale for the final combined catalog. The common earthquakes are

used to compare magnitudes from different agencies and generate a correction rule for each. The completeness threshold is observed to vary slightly with time and space. The swarm areas are selected and their seismic production rates are analyzed using monthly histograms. The results show that, in normal time, up to 3-4 swarms significant at regional scale, are triggered each year. We have observed that an intense seismic crisis occured during the year of 2012, with 25 distinct swarms triggered at various locations on the Aegean coast of Turkey. The swarms started gradually in 2011, reached its peak in 2012 and continued to be triggered during 2013, but less in number. The swarms were scattered over a large region, but did not followed any particular ordering in space. The time separations between distant swarms were relatively short, meaning that the deformation has spread rapidly over a broad area. This points to a deep-rooted source possibly related to plate motion. Various physical processes that may contribute to the observed increase in seismic production are discussed. In particular large subduction events are studied as a likely signature of a sudden plate movement.

ESC2018-S6-645

THE 2017 KOS SEQUENCE: AFTERSHOCKS RELOCATION AND IMPLICATIONS FOR ACTIVATED FAULT SEGMENTS

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On July 20, 2017, an Mw6.6 earthquake took place offshore Kos Island, producing severe damage and loss of life in the city of Kos, and several smaller cities and villages both in Kos Island and in the Bodrum peninsula (Turkey). Numerous aftershocks following the main shock were clustered at least in three distinctive patches creating a zone of a total length about 40 km in an almost east west direction. The high rate of aftershocks likely reflects the large geometrical fault complexity and perhaps a relatively high stress due to a significant length of time elapsed since the last major event. The sequence was recorded adequately by seismological stations located both in Greece and Turkey. All the available data until the end of October 2017 were gathered, namely waveforms and P and S phases for the relocation process. Single event location was initially performed for improving the performance of the regional velocity model and for calculating station residuals. Then, the aftershocks relative locations were estimated by applying the double difference technique using both differential times from phase picked data and waveform cross correlation. The spatial and temporal distribution of the highly accurate relocated data along with the determined focal mechanisms of several aftershocks, were used to reveal the seismotectonic features in the area. This research has been supported by the project “HELPOS–Hellenic System for Lithosphere Monitoring” (MIS 5002697) which is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014–2020) and co–financed by Greece and the European Union (European Regional Development Fund).

ESC2018-S6-672

THE AFTERSHOCK SEQUENCE OF THE JUNE 12, 2017 KARABURUN-LESVOS EARTHQUAKE (MW=6.3)

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Data from 8-station local aftershock deployment supported by The Scientific and Technological Research Council of Turkey (TUBITAK) is utilized to study the aftershock sequence of the Karaburun-Lesvos earthquake that took place on June 12, 2017 at 12:28 (UTC) offshore to the South of Lesvos island resulting in damage and loss of life in the island. The instruments were installed in the frame of a TUBITAK Project named Real-time Aftershock Forecasting in Turkey (RAFT). The project network was augmented by the nearby seismic stations of Kandilli Observatory and Earthquake Research Institute (KOERI), the seismic network operated by Prime Ministry Disaster and Emergency Management Authority (AFAD) and the permanent Greek seismic network

stations running on the island surrounding the aftershock source area. The integrated data provided significantly improved azimuthal coverage locations which were firstly detected by the automatic event detection algorithm Scanloc running as a module of Seiscomp3 data acquisition software; then, the hypocenters were manually revised. The mainshock associated with a rupture on the Lesvos Fault show predominantly normal faulting mechanism. The largest aftershock on the sequence was the Mw=5.3 event located in the eastern part of the source area and the second largest event occurred to the West of the mainshock epicenter. During the first month of the aftershock activity from June 12 to July 12, 2017 totally 2,597 aftershocks were estimated with magnitudes ranging between 0.3 and 4.9. Magnitude of completeness, Mc, and the Gutenberg-Richter parameter characterizing the seismic activity, namely the b-value, were investigated with an aim to explore the spatial and temporal behavior of the aftershock activity. The influence of the RAFT deployment is obvious from the comparison of the time variable Mc and b-value parameters. In the time span between the mainshock and prior the deployment of the local RAFT network one can observe strong fluctuations in the Mc estimates lying within a range of 1.8 and 2.2 and b-values between 0.5 and 1.3; however, after the deployment of the local seismic stations Mc became stable around Mc=1.7 and the b-value around b=1.02. These parameters in turn affect drastically the forecasting results which lead to erroneous number and size of the expected aftershocks along with their uncertainties. The relocated hypocenter distribution obtained from the integrated KOERI, AFAD, NOA and RAFT stations reveals two distinct cluster of events located to the east and west of the hypocenter of the mainshock, i.e., the mainshock released the seismic moment on a patch located in the mid of the two clusters. Vice versa it can be stated that the Coulomb stress increase associated with the mainshock triggered the seismic activity represented by the two clusters. A prominent feature of the aftershock sequence on the two clusters is the predominantly strike-slip mechanism of the largest two aftershocks despite the normal faulting mechanism of the mainshock.

ESC2018-S6-738

GROUND MOTION ANALYSIS OF THE 2014 GöKçEADA AFTERSHOCKS AND 2017 AYVACIK EARTHQUAKES AROUND ÇANAKKALE, TURKEY

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Çanakkale province of Turkey suffered from destructive earthquake in the past. The latest strong event occurred on the westernmost extension of the North Anatolian Fault. 24 May 2014 Gokceada earthquake (Mw 6.9) with an epicenter in the west of Gökçeada Island northern Aegean Sea occurred on the North Aegean Trough in the northwestern Marmara region. 2014 Gökçeada earthquake was felt in Turkey, Greece and Bulgaria. After the mainshock, 12 earthquakes Mw > 4.0 mainly with normal faulting occurred within 6 days. On the other hand, five earthquakes occurred with 5.3 > Mw > 5.0 in Ayvacik (SW Çanakkale city) February 6-12, 2017. Those earthquakes were felt VII intensity and caused several damages in rural areas. Strong ground motions of the earthquakes were recorded by Turkish national AFAD seismic network. In this study, characteristic of the 2014 Gökçeada earthquake aftershocks and 2017 Ayvacik earthquakes ground motions were analyzed for local stations at different azimuthal directions.

ESC2018-S6-808

ESTIMATION OF REGIONAL SEISMIC ACTIVITY BY HIDDEN MARKOV AND RELATED MODELS. A CASE STUDY IN EASTERN AGEAN SEA.

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Probability forecasts regarding the occurrence of earthquake activity are very useful to civil protection Organizations for operational purposes. The forecasts involve making statements about the expected number of events during the following time period. Hidden Markov models (HMMs) are a class of statistical models with many applications to geophysical and seismological data, which have gained increasing interest in recent years. Discrete time, discrete valued HMMs have been used as a tool to model earthquake occurrences. In the discrete case the

observational sequence of an HMM consists of the number of earthquakes occurring regionally in daily and monthly time intervals. Each observation in an HMM is generated by a state dependent stochastic process which process is independent of any previous states or observations. The sequence of states that underly the observation sequence consists a Markov chain. We recommend HMMs as a possible class of candidate models for daily earthquake forecasts. We apply the models to produce daily forecasts after the occurrence of the recent strong earthquakes in June and July 2017 offshore Lesvos (M6.3) and offshore Bodrum Kos (M6.6), respectively, using the catalogue of the Institute of Geodynamics, National Observatory of Athens. The forecasting ability of HMMs is evaluated to the forecasting ability of the well accepted epidemic type aftershock sequence (ETAS) model. The log probability gain for the HMM as compared to the ETAS models is calculated.

ESC2018-S6-827

RECENT SIGNIFICANT SEISMIC ACTIVITY IN EASTERN AEGEAN SEA

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Greece is characterized by high seismicity mainly due to the collision between the European and the African lithospheric plates. During the recent years (2016-2018) moderate to strong earthquakes occurred in regions with different seismotectonic regimes. The focal mechanisms of the main events were determined using regional moment tensor inversion. The geodynamic setting of the northern Aegean is governed by the superimposition of NE-SW strike-slip deformation, associated with the propagation of the North Anatolian fault zone towards the west, and N-S extension, caused by the suction of the Aegean realm towards the south due to deep seated processes of trench retreat and slab rollback. The basins of North Aegean Sea and their spatial relationships to the fault pattern representing the diffused termination of the North Anatolian fault system, which is consistent to the mechanical principles of the strike-slip tectonics (Koukouvelas and Aydin, 2002). A significant earthquake of Mw=6.3 occurred on the 12th of June 2017 (12:28 GMT) offshore, south of the SE coast of Lesvos Island, at a depth of 13km. Manual analysis of more than 900 events of the sequence between 12 and 30 June 2017 were used to obtain an optimized local velocity model. Double-difference relocation revealed distinct spatial seismic clusters, forming two linear branches, at ~N130°E direction (Papadimitriou et., 2018b), compatible with the strike of Quaternary faults along the southern coast of Lesvos Island which are related to Lesvos-Psara pull-apart basins, as previous studies have shown (e.g. Kiratzi, 2014). A gradual migration of epicenters towards NW and SE from the margins of the main rupture is evident by the performed spatiotemporal analysis, while a strong secondary sequence at a different fault patch SE of the mainshock, oriented NW-SE, was triggered by the largest aftershock (Mw=5.2) that occurred on 17 June. Eastern Kos Basin is bordered by Dikeos Mountain slopes to the north and Tilos Basin to the south. The basin is developed further to the east, north of Datcha peninsula and south of eastern Kos. The orientation of the basin is mainly due to the northern branch of Gökova Fault Zone, which runs parallel to the coast for more than 20 km (Nomikou and Papanikolaou, 2010). The major part of the seismic activity is concentrated along this fault, which is controlled by an E–W trending normal fault system. Intense earthquake activity has occurred in Gulf of Gökova in 2004 and 2005 (Gürer et al., 2013). On July 21, 2017(01:32 GMT), an Mw=6.6 earthquake occurred at a depth of ~10km and epicenter located offshore NE Kos. It was generated by an E-W striking and south dipping (~38°) fault located east of Kos and constitutes the westward prolongation of the northern branch of Gökova fault of the Mugla province in Asia Minor. The activated fault is fairly correlated to major part of the aftershock sequence. A local 1-D velocity model was developed upon a selected dataset revealing a complex hypocentral distribution that may indicate the activation of more than one structure in the area. The recent strong earthquake and intermediate-depth seismicity will be examined due to their vicinity of Nisyros-Kos-Yali volcanic centers (Papadimitriou et al., 2018a).

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ESC2018-S6-843

SYNCHRONOUS N-S AND NW-SE EXTENSION ON THE MAJOR AND SECONDARY NORMAL FAULTS AT THE 2017 BODRUM-KOS SOURCE RUPTURE AREA DEDUCED FROM AFTERSHOCK FOCAL MECHANISMS

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The western part of Gökova Gulf, Kos and Bodrum regions has been shaken on July 20, 2017 by an Mw6.6 earthquake. The main shock is located offshore giving no information on the plunge of the ruptured fault plane The fault plane solution of the mainshock shows nearly E-W striking nodal planes; one dipping southward while the other northward with approximately N-S tentional axis (T-axis). The West-southwestern Anatolia is dominated by N-S extensional tectonic regime that produced several approximately E-W grabens such as Gökova, Büyükmenderes and Gediz. Actually, both the seafloor morphology and the structural data in the northern part of the Gökova Gulf is characterized by south-dipping E–W-oriented normal faults. The Bodrum-Kos earthquake might have ruptured the western part of this fault. The aftershock activity is mostly distributed in NE-SW direction between Bodrum peninsula and Kos Island. In this study, the broadband waveforms of more than 50 aftershocks are analyzed to obtain a CMT solution for each. Almost all the focal mechanism solutions indicate normal faulting. The inversion of the focal mechanisms yield two normal faulting stress regimes: one is characterized with an approximately N-S σ3 axis. The other is characterized by NW-SE σ3 axis. The N-S extension is causative for the Bodrum-Kos mainshock (Mw=6.6) that ruptured the western end of an E-W normal fault extending along the northern part of Gökova Gulf which can be characterized as a significant major fault at a regional scale. The NW-SE extension is taking place on secondary faults which are locally significant causing the earthquakes along the NE-SW normal faults between Kos and Bodrum.

ESC2018-S6-868

THE M6.6 KOS-BODRUM 2017 EARTHQUAKE: SEISMIC AND INSAR EVIDENCE FOR A NORTH-DIPPING, ACTIVE NORMAL FAULT UNDER THE GULF OF GöKOVA, SE AEGEAN SEA

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On July 20, 2017 22:31 UTC, a strong Mw = 6.6 earthquake occurred at 10-km depth offshore Kos

(Greece) and Bodrum (Turkey). We derive a co-seismic fault model from joint inversion of geodetic data (GNSS and InSAR). We assume that the earthquake can be modelled by dip-slip along a rectangular fault buried in an elastic and homogenous half-space. The GNSS observations constrain well most of the model parameters but do not permit to discriminate between south- and north-dipping planes. The interferograms, produced from C-band ESA Sentinel 1 synthetic aperture radar data, give a clear preference to the north-dipping plane. We mapped surface motion away from the satellite (subsidence) along the Turkish coast (from Bodrum towards east) which reached about 20 cm onshore islet Karaada. The orientation of the GNSS vectors and the absence of InSAR fringes onshore Kos constrain the fault's length. The best-fit model was obtained with a 37° north-dipping normal fault, in agreement with the published moment tensor solutions. The slip vector is dominantly normal to a ESE-WNW direction with a component of left-lateral motion (5°). The surface projection of the seismic fault outcrops in the Gökova ridge area, a well-developed bathymetric feature inside the western Gulf of Gökova. Our geodetic model is in agreement with relocated seismicity distribution (about 1160 events) from regional networks, which indicates an aftershock occurrence towards both ends of the rupture. The occurrence of the M6.6 event along a low-angle fault plane implies a need for revision of the structural models for the western Gulf of Gökova rift. Panagiotis Argyrakis acknowledges the Stavros Niarchos Foundation for its support

ESC2018-S6-869

A SOURCE STUDY OF THE FEBRUARY 2017 BIGA PENINSULA (AEGEAN SEA) EARTHQUAKE SWARM INFERRED FROM INSAR AND SEISMIC WAVEFORM MEASUREMENTS

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Aegean sea is an actively deforming environment whose tectonics is related with the subducting slab of the African plate beneath the Eurasian plate. These large-scale tectonic interactions cause the high seismicity rate existing in the area. The Biga peninsula is located at a site where important tectonic structures meet, that is the North Anatolian Fault which is divided to different fault strands. Our study area is located at the immediate proximity of the southern strand which is represented by Edremit Fault Zone. The area is an actively deforming region whose deformation is taken up predominantly by normal faulting, sometimes combined with a strike-slip component. During February 2017 there was a notable tectonic activity in the area. Here, we present surface displacement results from SAR interferometry of the three major events (Mw > 5.0) that have caused severe damages and injuries. Seismic swarms do not always produce a surface displacement footprint. Due to the absence of a specific mainshock and the magnitude of the seismic events of the 2017 swarm, the monitoring using InSAR is challenging. However, we managed to detect a surface displacement signal which was a nice opportunity to demonstrate the use of InSAR in order to study a seismic swarm. We used the retrieved surface deformation fields to estimate seismic source parameters. Comparisons between the InSAR and seismic waveform results indicate a general similarity.

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ESC2018-S7-144

DEVELOPING AND VALIDATING PATH-DEPENDENT UNCERTAINTY ESTIMATES FOR USE WITH THE REGIONAL SEISMIC TRAVEL TIME (RSTT) MODEL

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The Regional Seismic Travel Time (RSTT) tomography model has been developed to improve travel time predictions for regional phases (Pn, Sn, Pg, Lg) in order to increase seismic location accuracy, especially for explosion monitoring. The RSTT model is specifically designed to exploit regional phases for location, especially when combined with teleseismic arrivals. The latest RSTT model (version 201404um) has been released (http://www.sandia.gov/rstt). Travel time uncertainty estimates for RSTT are determined using one-dimensional (1D), distance-dependent error models, that have the benefit of being very fast to use in standard location algorithms, but do not account for path-dependent variations in error. Although global in extent, the RSTT tomography model is only defined in areas where data exist. A simple 1D error model does not accurately model areas where RSTT has not been calibrated. We are developing and validating a new error model for RSTT phase arrivals by mathematically deriving this multivariate model directly from a unified model of RSTT embedded into a statistical random effects model. A goal for any RSTT uncertainty method is to be readily useful for the standard RSTT user. We will demonstrate the method and validation of the error model for Pn and other regional phases.

ESC2018-S7-156

ILOC2.0

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The single event locator iLoc is extensively used together with the RSTT (Regional Seismic Travel Times, a three-dimensional global upper mantle and crust velocity model with rapid raytracing facilities) travel-time predictions to obtain accurate locations in the African continent. We introduce the latest version of iLoc. Among the new features are the continued support for RSTT, with the use of model error predictions from RSTT, the support for the IDC database schema, the use of azimuth measurements from infrasound stations in event locations, and the option to display the results in Google Earth. iLoc is open source, it can be downloaded from the IRIS software depository, https://seiscode.iris.washington.edu/projects/iloc. iLoc is also used in CTBTO training sessions jointly with NDC-in-a-box.

ESC2018-S7-228

REGIONAL SEISMIC TRAVEL TIME (RSTT) TOMOGRAPHIC DATA SET

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The Provisional Technical Secretariat of the Comprehensive Nuclear-Test-Ban Treaty Organization and the United States national laboratories have worked together to conduct a series of workshops and training sessions in Africa. These sessions are focused on use of the Regional Seismic Travel Time (RSTT) model and method, and participants are requested to provide data in their region that may be useful for further development of the RSTT model. Contributed data are evaluated for event location accuracy and arrival time measurement precision. Events meeting the GT5 or better criteria, as established by IASPEI working group on ground truth, are contributed to the International Seismological Centre (ISC) ground truth database for open distribution. We integrate the ISC GT events, other contributed data, and existing bulletin data into a high quality, self-consistent tomographic data set, using the Bayesloc method. Bayesloc simultaneously relocates events, assesses data precision, and corrects travel time prediction biases, which are resolved in part by enforcing prior constraints based on GT data. We find that data integration using the Bayesloc method reduces the standard deviation of regional travel

time residuals by 30% to 50%. Reduced residuals are obtained through identification of outlier data, simple travel time corrections that reduce event location bias, and proper data weighting that is accomplished through simultaneous analysis of the whole data set. The result is a data set with residuals that are predominantly caused by travel time prediction errors with respect to the seismic base model, which is ideal for tomographic imaging. The improved data set results in tomographic models that are smoother and fit the data better than models that are developed using a tomographic data set that is a based on single-event relocation and simple outlier removal. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

ESC2018-S7-288

UPDATES TO THE REGIONAL SEISMIC TRAVEL TIME (RSTT) TOMOGRAPHY MODEL

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The Regional Seismic Travel Time (RSTT) tomography model has been developed to improve travel time predictions for regional phases (Pn, Sn, Pg, Lg) in order to increase seismic location accuracy, especially for explosion monitoring. The RSTT model is specifically designed to exploit regional phases for location, especially when combined with teleseismic arrivals. The latest RSTT model (version 201404um) is located on the Sandia National Laboratories web site (http://www.sandia.gov/rstt). We are in the process of updating the RSTT model to include new features. The original model used CRUST2.0 combined with an a priori model in Eurasia from US National Laboratories. The newest crustal update will use the CRUST1.0 version that includes more detailed and realistic structures. New event data are also being compiled that include global ground-truth (GT) information from local, regional, and teleseismic bulletins as well as data obtained through various RSTT workshops in South America, Latin America, Asia, and Africa. Using the new crust and available data, the tomography will be updated for improved coverage and accuracy. Another new feature is the addition of path-dependent uncertainty estimates for all regional phases in RSTT. For a 2/2.5D model like RSTT, we want to have a path-dependent uncertainty determination with a similar dimension as the model itself. This accounts for spatial variations in empirical data which could lead to bias in the model depending on the specific ray path. The goal for RSTT is to have the general user be able to estimate a path-dependent travel time prediction uncertainty on-the-fly using the available software just like users do for actual travel time itself. We also demonstrate validation of the new model and uncertainty estimates using the International Monitoring System stations and Reviewed Event Bulletin events.

ESC2018-S7-348

SEISMIC GROUND MOTION AND RELATED ACTIVITIES IN GHANA

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Ghana is situated on the West Africa Craton and far away from any plate boundary. However, the southern part of the country is seismically active. Records of damaging earthquakes in Ghana date as far back as 1615. The three major events in the country which registered some casualties occurred in 1636, 1862 and 1939. Twenty people lost their lives and many buildings including fortresses and monuments were destroyed when the 1862 and 1939 earthquakes struck. Some miners were killed in Axim in the Western region in 1636 when a mine they were working in collapsed, burying all of them. The maximum intensity and magnitude of the three events were IX (Modified Mercalli scale) and 6.5 (Richter scale) respectively. Current events registering more than magnitude 4.0 on the Richter scale have been recorded and the frequency at which they occur make the Greater Accra Metropolitan Area more prone to earthquake disaster than expected. The goal of the study was to model the seismic ground motion of the Greater Accra Metropolitan area for land use planning and disaster mitigation. To mitigate the possible disastrous effects that earthquakes could pose, the seismic hazard of the

metropolis was assessed using the deterministic method; a hybrid method based on the modal summation and finite difference method. Using these techniques, the seismic ground motion along six profiles located in the Greater Accra Metropolitan Area was modelled. The 1939 earthquake of magnitude 6.5 (ML) was used as the scenario earthquake. Synthetic seismograms from which parameters for engineering design such as peak ground acceleration, velocity and spectral amplifications were produced along the geological cross sections.

ESC2018-S7-357

BENI ILLMANE EARTHQUAKE OF MAY 14, 2010 - AFTERSHOCK SEQUENCE LOCATION USING A DENSE SEISMIC NETWORK

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Algeria suffered frequently from effect of destructive moderate sized and strong earthquakes because of seismotectonic setting on the boundary of African and Eurasian tectonic plates. On May 14th, 2010 at 13 h 29 m GMT, a moderate earthquake of magnitude Md 5.2 (CRAAG Research Center of Astronomy, Astrophysics and Geophysics – Algeria) struck Beni-Illmane a small village located about 200 km southeast of Algiers (the capital of Algeria). The main shock caused substantial damage and resulted in three fatalities, 86 injured, 1720 out of shelter families and 6431 constructions damaged. The main shock was followed by a significant number of aftershocks for days after the earthquake. The Beni-Illmane earthquake sequence, which started on May 14th, 2010, occurred in a region of low to moderate seismic activities in north Algeria. Following the first main shock, the National Center of Applied Research in Earthquake Engineering (CGS) acted and organized a seismic survey of aftershocks using 13 temporary seismic stations installed close to the epicentral area during 30 days recording period. The data was analyzed by using the Seisan program and the phase picking was performed for 22 days. In this study 741 aftershocks after the May 14th, 2010 Beni Illmane earthquake were analyzed. A subset of 406 aftershocks was used to resolve details of the hypocenter distribution. The VP/VS ratio was calculated by using both Wadati diagram and Chatelain method and was estimated to 1.74. The Chatelain method was also used fordata quality control of the phase picking. We used the velocity model proposed by Yelles et al. [Yelles K, Abacha I, Semmane F and Beldjoudi H, 2013. Pure Appl. Geophys., DOI 10.1007/s00024-013-0709-3]. Using Hypocenter location program under Seisan, the single event localization was performed and used as input for the modified joint hypocenter determination relocalization program. At the beginning 406 events in total were used, but after errors were screened (time residual less than 1s, X error less than 2 km, Y error less than 2 km and the vertical error less than 5 km), we relocated 141 event precisely using the Modified Joint Hypocenter Determination (MJHD) method and calculated composite focal mechanism solution. The results obtained showed a distribution of aftershocks in a small region near the Beni-Illmane village located within a dense seismic network. The result obtained depicted the best fitted location area in the NNE-SSW direction between 35.90o and 36.01o N with 12.5 km length and the foci were distributed in the two clusters on a near-vertical plane, mostly at depths of 0-5 km and 6-15 km. Three composite focal mechanisms calculated, in North, South and the center of the epicenter area, shows same T axis oriented NNE-SSW consistent with the first and the third main shocks. The composite focal mechanism calculated for the 24th most well located aftershocks, shows strike-slip faulting with NW-SE compressional axis, which were consistent with previous studies in the north Algeria.

ESC2018-S7-368

THE IDENTIFICATION OF POSSIBLE GROUND TRUTH EVENTS FROM A REASSESSED DATABASE OF MAJOR SOUTHERN AFRICAN EARTHQUAKES OF MAGNITUDE ML ≥ 5.0

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In recent years, efforts have increased to improve velocity models used in the location of earthquakes and explosions, especially nuclear

explosions. This is being done through the improvement of velocity models used in the calculation of travel time corrections for regional phases as well as by generating correction surfaces for teleseismic P phases. To be able to effectively test and validate models and corrections, it became clear that there was a need for high quality data of earthquakes and explosions referred to as ground truth (GT) event data, which are referred to as events with exactly known locations, depth and origin time. Realising the scarcity of such events, the definition was modified to "epicentres with a known accuracy". New such calibration events were identified in the catalogue of major South African earthquakes by implementing previously defined GT5_95% criteria. The catalogue of South African events was prepared by first reassessing source parameters of earthquakes identified as having magnitude values of ML ≥ 5.0 using available collected phase and macroseismic data. The first step in identifying possible GT events was to preselect events that were going to be further analysed to see if they satisfy the GT595% criteria. A set of eight events recorded by more than five stations located within a distance of 150 km of the event epicenter was identified. Using the ISC location algorithm, iLOC, and a 3D global velocity model made compliant with the Regional Seismic Travel Times (RSTT) parameterization, the eight events were further analysed. Results of this analysis include results of Ground Truth (GT) candidate test according to preset selection criteria. Solutions of two of the eight preselected events were found to satisfy the conditions for GT595% candidacy whilst four events satisfied the criteria for GT2090% candidacy. The P wave path coverage for the two identified GT595% events shows that both events were well recorded by 106 and 542 stations respectively, which were well distributed azimuthally. It is hoped that these GT595% events are going to be useful in the improvement of the RSTT models for our region as well as the improvement of local velocity models used in local analysis software packages.

ESC2018-S7-423

RECENT ADVANCES IN EARTHQUAKES RELOCATION, CRUST-UPPER MANTLE MODELING AND PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR PLANNING IN WEST AFRICA

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This work is aimed at utilizing modern techniques and tools to improve earthquake location, Crust-Upper Mantle imaging, a robust seismic mapping and probabilistic seismic hazard assessment (PSHA) for planning purposes in West Africa. Despite seemingly increasing seismic activities in the region as recently shown in (Meghraoui et al., 2016), West African region is yet to receive desired crustal, seismotectonics, seismicity and PSHA studies due to dearth of data, reliable processing tools, well-defined velocity models, and requisite pool of skilled scientists etc. In this research however, Regional Seismic Travel Times (RSTT) and iloc in Geotool software were used to relocate a number of earthquakes in West Africa. An algorithm in Python which gives distance and travel time as a function of ray parameter was used to carry out Crust-Upper Mantle modeling; and PSHA was done at different levels of earthquake completeness using 1618-2016 historical and instrumental earthquake catalogue. The results showed enhanced events characterization and epicenters, with attendant improved seismicity and manifest seismotectonic scenarios in West Africa. The Moho depths beneath stations covered ranged from 28km to 42km and an average of Vp/Vs of 1.7. The computed Peak Ground Accelerations (PGAs) from this study ranged from 0.002 – 0.02g. These parameters would be useful for engineering design for siting of critical facilities, and could serve as baseline parameters for the establishment of seismic building codes. For the first time, results from PSHA show values of earthquake recurrence parameters that are representative of the seismicity of West Africa. It is believed this work will not only help West Africa in planning, but will also contribute to verification compliance especially with the CTBT regime. Ongoing research involves refining some relocated earthquakes with prospects of identifying Ground Truth events to improve RSTT model in the region.

ESC2018-S7-434

THE AFTERSHOCK SEQUENCE OF THE 22 SEPTEMBER 2016, MOZAMBIQUE EARTHQUAKE (ML 5.2)

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The occurrence of the 22 September 2016 Mozambique earthquake (ML5.2) and its subsequent aftershocks provided data to study the physics of earthquakes along the East African Rift system. The event occurred in the southern parts of Mozambique a few hundreds of kilometers from the M7.2 Machaze earthquake which occurred in 2006 and ruptured about 40 km long fault. About 450 aftershocks were recorded within a period of 6 months from the main shock event. Accurate seismic-event locations of the aftershocks were determined using the Seisan software. The events were then relocated using the double difference method as part of an effort to identify the causative fault. Statistical analysis of the aftershock sequence was performed for the calculation of the b-value and the aftershock decay rate p-value. An attempt was made to test the event as a ground truth event by using regional and global stations that managed to record the event. The b-value and p-value obtained for this sequence are 1.02 and 0.84 respectively.

ESC2018-S7-468

SEISMIC ASPECT IN COMOROS, ESTIMATION OF LOCAL/REGIONAL EVENT LOCATION ACCURACY AND CRITERIA ASSESSMENT

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The identification of fundamental seismic causes is of major importance in a complex geological and geographical area such as Comoro-islands. Events stress regime throughout the time correlate bearably with the direction of the islands (hot spots) apparition motion in a South-East/ North-West orientation. The central part of Gde-Comore-Island hosting Karthala volcano is an asset for seismovolcanic activity records and remains significant source of event investigation in a local scale. Regional seismic activity is concentrated in the North-western part of the Comoro-islands, where the “Kerimbas Graben” offshore northern Mozambique is approximately 150 km long and 30 km wide symmetric rift graben within East African Rift System (interpreted by Franke et al. 2015). We identify multiple cases of local and regional data in order to understand and assess the coherence of the seismicity within the region. A background of local seismovolcanic events generated from volcanic activity in recent past will be associated with the evaluation process based on the identification of parameters such as, time, magnitude, event duration, etc. Source parameters of the regional seismotectonic events like, location, distance, magnitude, azimuth and etc., will support the concept of event direction and regional data accumulation, which can hypothetically have close indication on the crustal deformation studies in the area. In both cases we identify the minimum and maximum magnitude, part of the assessed criteria, in order to be able to evaluate the level of seismicity within the area.

ESC2018-S7-483

BOTSWANA'S EARTHQUAKE OF 3RD APRIL 2017 IS RELOCATED USING NARS DATA

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High quality seismic waveform data obtained from the recent project of the Network of Autonomously Recording Seismographs (NARS) in Botswana is complimented with IMS stations to relocate the 3rd April 2017 event. The waveforms used comprised of vertical components from 9 NARS stations and 32 IMS stations with good arrivals and around the event such that they achieve very good azimuthal coverage and were processed using Geotool software from the CTBTO. The relocation of this event indicates that it occurred at 22.6448 oS and 25.2199 oE with a UTC origin time of 17:40:16 or local time of 19:40:16. The earthquake has a depth range of 22.1 km to 24.1 km. Key words: Botswana, Geotool, earthquake, seismic

ESC2018-S7-504

THE 03 APRIL 2017 BOTSWANA M6.5 EARTHQUAKE: PRELIMINARY RESULTS

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An earthquake of magnitude Mw 6.5 occurred on the evening of 3 April 2017 in Central Botswana, southern Africa. The event was well recorded by the regional seismic networks and the location by the Council for Geoscience (CGS) placed it near the Central Kgalagadi Game Reserve. Its effects were felt widely in southern Africa and were especially pronounced for residents of Gauteng and the North West Province in South Africa. In response to this event, the CGS, together with the Botswana Geoscience Institute (BGI), embarked on two scientific projects. The first project involved a macroseismic survey to study the extent and nature of the effects of the event in southern Africa. This involved CGS and BGI scientists soliciting information from members of the public through questionnaire surveys. More information was collected through questionnaires submitted online by the public. In total 181 questionnaires were obtained through interviews and 151 online from South Africa, Zimbabwe and Namibia in collaboration with the Meteorological Services Department of Zimbabwe and the Geological Survey of Namibia. All collected data were analysed to produce 79 intensity data points located all over the region, with maximum intensity values of VI (according to the Modified Mercalli Intensity scale) observed near the epicentre. These are quite low values of intensity for such a large event, but are to be expected given that the epicentral region is in a national park which is sparsely populated. The second scientific project involved the rapid installation of a temporary network of six seismograph stations in and around the location of the main event with the purpose of detecting and recording its aftershocks over a period of three months. Data recorded in the first month of April 2017 were collected and delivered to both the CGS and BGI for processing. More than 450 aftershock events of magnitude Ml> 0.5 were recorded and analysed for this period. All the events are located at the eastern edge of the Central Kgalagadi Park near the location of the main event in two clear clusters. The observed clusters imply that a segmented fault is the source of these earthquakes and is oriented in a NW-SE direction, similar to the direction inferred from the fault plane solution of the main event.

ESC2018-S7-525

3D CRUSTAL AND LITHOSPHERIC COMPLEXITY BENEATH THE NORTH TANZANIAN DIVERGENCE

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The North Tanzanian Divergence is the locus of a ramification of the Eastern Branch of the East African Rift caused by complex interaction between tectonic and magmatic processes within the mantle and the crust. We present here the compilation of geophysical analyses such as receiver function, seismic tomography, gravity measurements and MT profiles on a recent dataset collected during 2 years (CRAFTI-CoLiBrEA project). The combined images of the crustal and lithospheric structure show a complex interaction between melt, gas, faults and inherited fabrics that guide the deformation in specific areas. In particular, melt and gas are present in the middle and lower crust near the youngest volcanic edifices, south of lake Natron. Beneath Nogorongoro volcanic area, the Moho is clearly affected by underplating and the crust is highly stratified. A clear interface at 70-80~km depth beneath each flank of the rift axial valley seems to be the locus of either melt concentration or grain boundary sliding process. Both Archaean lithosphere and Proterozoic mobile belt prevent from the lateral EW extension of the mantle characterized by low velocity and low density

anomaly related to the Manyara-Natron-Magadi branches. No lithospheric propagation in the Eyasi branch is evidenced, whereas the Pangani rift seems to be associated to an upper mantle anomaly both in velocity and density.

ESC2018-S7-528

ACTIVE INTRABASIN FAULTING IN THE NORTHERN BASIN OF LAKE MALAWI FROM SEISMIC REFLECTION DATA

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Many questions remain about the development and evolution of fault systems in weakly extended rifts, particularly the relative roles of border faults and intrabasin faults in accommodating extension and variations in faulting along strike within and between rift segments and with time. The northern Lake Malawi (Nyasa) rift in the East African Rift System is an early stage rift exhibiting pronounced tectonic segmentation, which is defined by ~100-km-long border faults. The basins also contain a series of intrabasinal faults and associated synrift sediments. The occurrence of the 2009 Karonga Earthquake Sequence on one of these intrabasinal faults indicates that some of them are active. Here we present new multichannel seismic reflection data from the Northern Basin of the Malawi Rift collected in 2015 as a part of the SEGMeNT (Study of Extension and maGmatism in Malawi aNd Tanzania) project that constrain cumulative faulting patterns and recent activity on some intrabasin faults. Keywords: Early stage rifting, Malawi rift, Multi-channel reflection, Northern Lake Malawi

ESC2018-S7-915

RAYLEIGH WAVE GROUP VELOCITY DISPERSION TOMOGRAPHY OF WEST-AFRICA USING REGIONAL EARTHQUAKES AND AMBIENT SEISMIC NOISE

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Most models of the seismic structure of the West African craton come from global-scale studies. Higher-resolution velocity models would improve our understanding of the craton and would enable us to locate seismic events and calculate regional Green's functions more accurately. We present a tomographic inversion that used surface waves from both regional earthquakes and seismic ambient noise cross-correlation. Combining these two types of data improved azimuthal coverage of the region and produced higher resolution models than possible using either type alone. We inverted for Rayleigh-wave group velocity maps for periods between 20 and 120s. The tomographic maps show good correlations between velocity anomalies and tectonic features in the study region and provide the first observations of seismic velocity differences between the Paleoproterozoic basement (Leo Rise) and the Archean basement (Man Shield). The Tindouf basin and the Anti-Atlas present low wave speeds consistent with recent tectonic activity. At longer periods, the roots of the Man-Leo and the Reguibat shields are underlain by cold and thick lithosphere with faster wave speeds, while we found thin, warm and slow lithosphere under the Pan-African mobile belt zones.

ESC2018-S7-1067

MAGMATIC MODIFICATION OF THE CRUST ALONG THE EAST AFRICAN RIFT

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TThe East African rift (EAR) system occurs within the African continent, which underwent orogeny during the Pan-African (800-500 Ma). We interpret geophysical constraints in conjunction

with geological and geochemical results to improve our understanding of the role of magmatism in the development of rifting. In young magmatic rift zones (<3 My), the creation of gas-rich magma reservoirs at the base of the crust due to asthenospheric melt migration impacts both crustal rheology and composition during the initiation of rifting. The southern sector of the Eastern rift (<7 My) hassignificant lower crustal intrusion (underplate), ~20% new magmatic material intruded as sills, and shallower in the crust as both sills and dike intrusions. In the Western rift the Rungwe and Virunga volcanic provinces, in addition to the Tanganyika rift, show evidence for crustal thinning and altered crustal compositions indicative of lower crustal intrusion and melt ponding at the base of the crust. Our synthesis of crustal studies beneath zones of active rifting along the East African rift show that magma and volatiles are migrating from the asthenosphere through the plates, modifying lithospheric rheology and influencing the development of rifting.

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ESC2018-S8-60

THERMAL ORIGIN OF THE VELOCITY ANOMALIES BELOW THE IBERO-WESTERN MAGHREB REGION INFERRED FROM TRAVELTIME P- AND S-WAVE TOMOGRAPHY

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The availability of independent P- and S-wave models may provide constraints on the physical cause of the imaged velocity anomalies and allow to distinguish thermal signatures from those of partial melt, volatiles and compositional variations. Here, we use data which comes from stations that cover the area from Pyrenees to Canaries to obtain new Pand S/SKS relative travel-time tomography models below the Ibero-western Maghreb region. The model provides evidence of (1) three upper-mantle low-velocity structures below the Canaries, the Atlas ranges and the Gibraltar arc which are interpreted as mantle upwellings fed by a common source in the lower mantle below Canaries; (2) two low-velocity anomalies below the eastern Rif and eastern Betics due to the Gibraltar subduction-induced quasi-toroidal mantle flow which drives the sub-slab mantle material around its lateral edges. The performed travel-time residual analysis and the thermal conversion of the velocity anomalies given the seismic sensitivity to temperature, reveal that these features may be solely thermal in nature, with different temperature excess within the range of ~ 50-300 C, consistent with previous geophysical and petrological studies. However, signatures of local partial melting content may be present at shallow depths, in line with additional constraints provided by geochemistry, heat flow measurements and LAB estimates.

ESC2018-S8-63

VELOCITY STRUCTURE OF THE SIBERIAN PLATFORM ON THE BASE OF THE PEACEFUL NUCLEAR EXPLOSION DATA

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During 1976–1987 in the former USSR in the territory of the Eastern Siberia and Sakha republic 10 peaceful nuclear explosions (PNE) were conducted in scientific and commercial applications. PNEs were measured by regional analog seismic stations located in the Baikal rift system and surroundings at epicentral distances from 246 to 1407 km. Regional travel time curves for the both crustal and mantle seismic phases (Pn, Pg, Sn and Sg) were constructed using arrival times of these explosions. Based on these data the regional velocities of seismic waves were determined: VPn = 8.25 km/s, VPg = 6.12 km/s, VSn = 4.57 km/s, VSg = 3.58 km/s. The velocities obtained are well correlated with the data known on the velocity structure of the Baikal rift system. According to the PNEs records obtained on the Yakutia seismic station network (Neva serial), in the earlier works, the P and S wave velocities in the crust and upper mantle of the Siberian Craton were calculated: Pn=8.313 km/s, Pg=6.158 km/s, Sn=4.695 km/s and Sg=3.594 km/s [Mackey et al. 2005] and Pn=8.27 km/s, Pg=6.20 km/s, Sn=4.67 km/s and Sg=3.55 km/s [Burkhard et al. 2016]. It can be seen that the values of the velocities of seismic waves in the upper mantle obtained in this work for the same events at the stations of the Baikal region are much lower: ~0.2–0.8 % for P waves and ~ 0.4–2.7 % for S waves, while in the srust, on the contrary, they are higher – 0.6–1.3 %. Such a spatial distribution of the velocities of seismic waves agrees well with the SibCrust model [Cherepanova et al. 2013]. Low velocities of seismic waves indicate the presence of low-velocity anomalies in the region under the crust. Earlier, the presence of anomalously low velocities of seismic waves under the Moho in the Baikal rift system was noted according to the deep seismic sounding data [Krylov et al. 1981]. Also, the layer of high attenuation of seismic waves under the crust of the northeast flank of the Baikal rift system has been detected by the seismic quality

factor calculations [Dobrynina et al. 2016]. The presence of such a layer was associated with the possible partial melting of matter under the crust of the northeast flank of the Baikal rift system [Pospeev 2012]. The reported study was funded by RFBR and Government of Irkutsk region according to the research project 17-45-388049.

ESC2018-S8-68

THE CRUSTAL TOMOGRAPHY (VP, VS, VP/VS) ACROSS THE OROGENIC LAKE REGIONS OF EASTERN ANATOLIA HIGH PLATEAU (E-TURKEY): KEY CONSTRAINTS FOR THIN-SKINNED TECTONICS

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Crustal tomography can provide fine Poisson's ratio, Vp and Vs structures of the crust and uppermost mantle with proper computation. The tomography of the Poisson ratio structures, which depends on the Vp/Vs ratio, provides much tighter constraints on the crust and uppermost mantle than either Vp or Vs alone. In this study, the high-resolution crustal tomography beneath the lake regions (Lakes Van and Erçek regions) of E-Anatolia (E-Turkey) is used to estimate detailed crustal Poisson's ratio, Vp and Vs structures. The crustal Poisson ratios are estimated from the joint inversion analyses of the travel times of Vp and Vs by analyzing the station records of the permanent KOERI network (Kandilli Observatory and Earthquake Research Institute, Turkey). The velocity anomalies from the inverted P- and S-waves are well recovered down to crustal levels and are considered to be reliable at depths of 10 km up to 30 km. The velocity perturbations in percentage from the initial velocity model at each depth are deduced from the inverted 3-D model. The results of Poisson's ratio anomaly reveal distinct substantial variations in the different tectonic units and show a prominent, continuous and dense high Poisson's ratio anomalies in the range of 0.27–0.30 for the lowermost crust/the uppermost mantle beneath the Lakes Van and Erçek regions and comparably low average Poisson's ratio (~0.23) anomalies for the brittle crust in several local areas. Also, low Vp, Vs anomalies slightly change to high Vp, Vs at focal depths (10-23 km) of the 2011 Van earthquake (Mw 7.1) and are densely concentrated with low-V, low- to high-V within the cluster. These results are in remarkable agreement with the results of the seismic reflection studies that were performed in the lakes. This implies that the estimated Poisson's ratio anomalies can provide new geophysical constraints for tectono-magmatic evolution of the lake regions. High Poisson's ratios (over ~0.29) in the Lakes Van and Erçek Basins and in the vicinity of their boundary faults (e.g., TB, V, LE and variable in BPM) appear to be due to partial melts and, are considered to be consistent with the extensional deformations associated with magmatic intrusions in TB across MS. Low Poisson's ratios (over ~0.23) near major regional seismogenetic faults (e.g., around C, E, ÇF) at ~14 km depth beneath the Lakes Van and Erçek regions suggest presumably even weaker, brittle and more easily deformable crust. The high and low Poisson's ratio structures suggest a strongly fault-controlled and highly heterogeneous crustal architecture beneath the lake regions across BPM. High Poisson's ratios at variable depths suggest that the mafic content beneath the lake regions is higher than ever expected, thus indicating the existence of intrusive materials of possible mantle origin as a thermal source (e.g., mantle?derived magmas) interacting with faulted crustal rocks; the partial melts sourced from the uppermost mantle propagate into the fragmented lowermost crust, intrude through the whole crustal column, and result in local increases in Poisson's ratios in the places where low ratios are expected. This scenario proposes that extensive crustal heating and differentiation produce a decrease/an increase of ? with a decrease (10 km) of depth, respectively. This may explain both low and high average values of ???? at upper and lower depths and also high-V. The regional extent of the high Poisson's ratios (0.27-0.30) of the lowermost crust/the uppermost mantle proposes strong interaction of partial melts with active tectonics in Lakes Van and Erçek Basins and suggests that the processes that formed the deep Lake Van basin may have affected the shallow Lake Erçek basin. Key constraints from the estimated Poisson's ratios and V-anomalies indicate the diverse and interactive nature of crustal deformations beneath tectono-magmatic lake regions where the underplating of the mantle magma scenario proposed serves as a working hypothesis for further studies. The strong underplating of the

uppermost mantle magma and the effects of the partial melts on the deformation processes beneath the lake regions not only caused the high Poisson's ratio anomaly, but also resulted in a local rise of the uppermost mantle and are probably responsible for the rise of the local crust and thus, of lake regions. The underplating appears to exert a key control on tectono-magmatic evolution of Lakes Van and Erçek regions and probably, of intra-plate E-Anatolian orogeny.

ESC2018-S8-74

THE CRUSTAL ATTENUATION TOMOGRAPHY BENEATH THE LAKE VAN REGION (EASTERN ANATOLIA, TURKEY)

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The attenuation of body-wave amplitudes is sensitive to the seismic interfaces and fluid reservoirs in the crust. In this study, we obtained the P- and S-wave attenuation pattern from local earthquakes in the Lake Van region of E-Anatolia. The 3-D P- and S-wave attenuation patterns (1/Qp and 1/Qs) presented by the tomographic images of tectonic structure and fluid pathways starting from surface of earth to 25 km was determined in the Lake Van region. We used the software modified from The MuRAT code that uses a source- and site-independent coda-normalization method based on P-to-coda and S-to-coda energy ratios. The software based on the Matlab inverts the data for the geometrical spreading factor and the spatially-dependent quality factors as Qp and Qs. High-attenuation anomalies are indicative of fluid zone down to 25 km depth. In the Nemrut Volcano (the W-end of Lake Van) between depths of 0 and 15 km and in Lake Van between depths of 0 and 25 km, a low-velocity, high-attenuation is attributed to alteration zone and thick piles of sediments within Lake Van. A laterally extended 3-D scattering contrast at depths of 10 to 15 km is related to the boundary between upper and lower crust in the W-side of the Lake Van, but we didn't determined this type border in the E. We combined the tomographic results of P- and S-wave to the velocity tomography to represent the future of seismic activity and volcanic activity imaging. A total number of 3419 waveforms obtained from a selection of 855 earthquakes recorded from January 2009 to 2016 occurred between latitudes 38.00-39.50 N and longitudes 41.50-44.00 E at 10 stations with three-components (the Seismic Network of Regional Earthquake-Tsunami Monitoring Center operated by Bogaziçi University, Kandilli Observatory and Earthquake Research Institute, KOERI). The dynamic range of stations is 140 and 164–184 dB for the broadband and short-period seismic stations with a sampling frequency of 100 Hz, respectively. We restricted the earthquake magnitude in the range from 2.0 to 7.1. Ray-tracing was calculated using the 3-D velocity model. We used multi-resolution seismic attenuation imaging method (MuRAT) based on the Thurber-modified approach to trace the path of each ray in the 3-D velocity structure of Lake Van and vicinity. This is an extension of the approximate ray-bending method that works well in velocity structures characterized by fairly sharp velocity variations. After dividing the whole structure in three different grids (respectively with 1, 2 and 2 km cubic cell size) we stored in a database the length of each ray, connecting each source to each receiver, and the length of the ray-segments crossing each cell. The single-path attenuation with the coda-normalization (CN) method is widely used to retrieve attenuation parameters independently of the site and instrumental transfer function. We obtained the attenuation structure in Lake Van and vicinity in two frequency band centered at 18 Hz by using the present multi-resolution method. All the depths (negative downward), are calculated respect to the sea level. Using CN technique, an estimate of the variation of the S-wave inverse total-Q respect to their mean was obtained for the frequency 18 Hz. The higher attenuation zone is located in a depth range along the fault zones of the region. Attenuation values are also changed according to the tectonic structures. It was found that the attenuation structure was consistent with the distribution of intensity of 2011 Van earthquake (Mw 7.1). From the estimated Qp anomalies indicate diverse characteristics of crustal deformations in the basin of Lake Van. The regional extent of the low Qs values proposes strong interaction of partial melts with active tectonics in Lakes Van and Erçek Basins. The low Qs values' anomaly of partial melts through the fault zones, at which the largest 2011 Van earthquake occurred. Low Qs anomalies conclude

that one or more active magma chambers are composed of hardened push slopes under Lake Van and that these chambers have distinct morphological representations at the bottom of the lake. The Van and Erçek regions show that the volcanic cover is shaped like a tower and a wedge-like structure where the volcanism is injected into the lake. The sprayed volumes on the surface may represent only a small fraction of the melt produced under the zone. In this study, the implications of the obtained 1/Qp and 1/Qs structures and their relation to the current seismic activity and the present-day tectonics are provided for a better understanding of the seismotectonics of Lake Van region.

ESC2018-S8-75

THE CONTINENTAL MOVEMENT IN THE ISPARTA ANGLE (SW-ANATOLIA, TURKEY) FROM 3D-TOMOGRAPHIC IMAGES OF VP, VS, AND VP/VS

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The Isparta Angle (IA) is located to the N of Antalya Bay in SW-Anatolia, where the Hellenic and Cyprian arcs intersect as reverse V-shaped in the E-Mediterranean region. The convergent plate boundaries between the Anatolian and African plates comprise two separate arcs; the Hellenic and the Cyprian, and these arcs intersect in the E-Mediterranean area. However, plate interaction along the Hellenic and Cyprian arcs is a matter of debate concentrating mainly on subduction or wrench systems. In order to understand the subduction zone and plate interactions in the study area, the 3-D tomographic method to determine subduction geometry of the IA is used and applied within IA. For this purpose, P-wave velocity and Vp/Vs ratio distribution are determined and compared with depths of earthquakes and tectonic structure in study area.
A number of 39,059 events collected between 2007 and 2016 that occurred between latitudes 34 – 38.5°N and longitudes 26 – 31.5°E were used in this study. These events are recorded by 53 seismic stations (the Seismic Network of Regional Earthquake-Tsunami Monitoring Center, operated by Bogaziçi University, Kandilli Observatory and Earthquake Research Institute, KOERI). This network has 50 broadband and 3 short-period seismic stations with a sampling frequency of 50 Hz. The dynamic range is 140 and 164–184 dB for the broadband and short-period seismic stations, respectively. The accuracy of arrival times is estimated to be less than 0.15 s for P wave data. All residuals have been stepwise examined with respect to the assumed initial velocity model, and those beyond the limit ±1 s have been excluded from the tomographic inversion. However, more than 70% of the residuals are within the bounds ±0.3 s. We used the software of tomotools based on tomography to analyze the arrival time data, which has been applied to many parts of the world with different tectonic circumstances. This method is adaptable to a general velocity structure, which includes several complex-shaped velocity discontinuities and allows 3-D velocity variations everywhere in the model. A grid spacing of 0.5° in the horizontal direction was adopted for the present study. In previous studies, the earthquake activities are intense along highly heterogeneities in the IA, which is characterized by low to high P-wave velocity. These regional earthquake profiles indicate various depths of descending slab formed by the interaction between the African and Anatolian plates. It starts dipping behind the Anaximander Mountain and the Florence Rise towards the north-east of the Antalya Bay. While deep-focus earthquakes occur at depths of about 190 km beneath the Gokova Gulf related to Hellenic arc and about 130 km beneath the Antalya Bay. Meanwhile, depths of earthquakes are shallow and are not deeper than 50 km in the continental crust along the IA. The observations from the subduction geometry of IA by using the 3-D tomographic method may suggest that the subduction is undergoing Anatolian-Aegean plate as slabs along the Hellenic and Cyprian arcs. The obtained results of 3-D tomography are compatible with tectonic structures. From the depth of 28 km the slabs are seen as clearly. These two slabs are separated by tear zone around the Fethiye Gulf. These arcs intersect in this region, forming a north pointing cusp which is located approximately in Fethiye Gulf between the Hellenic and Cyprian arcs is likely to have resulted in a lithospheric tear in the downgoing African plate that allowed the asthenospheric mantle to rise beneath SW-Anatolia. Asthenospheric upwelling occurring in the tear zone induces decompressional melting of shallow mantle, leading to linearly distributed alkaline magmatism younging in the direction of

tear propagation. This tear might have also caused a lateral tear, which separates these arcs, coincides with the Pliny-Strabo-Fethiye-Burdur fault zone. Briefly, this study concludes the concrete evidence about the tectonic formation in the study area and confirms the major subduction slabs related to Hellenic and Cyprian arcs. Fethiye-Burdur Fault crosses along to tear zone among the two slabs. The results of P-wave distribution suggests the presence of subduction zones in the IA inclined to the NW beneath the Gokova Gulf in the W-side and to the NE beneath the Antalya Bay in the E-side. The seismic activity is intense along highly heterogeneous zones along the subduction zone in this region.

ESC2018-S8-104

UPDATE ON THE RECONSTRUCTION OF THE ISC-EHB DATASET

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The EHB bulletin, one of the most used dataset for seismological research, was originally developed with procedures described by Engdahl, Van der Hilst & Buland (1998) as a groomed version of the International Seismological Centre (ISC) Bulletin (www.isc.ac.uk). In its original form, the EHB covered the period 1960-2008. Because of its popularity in the seismological and a broad geoscience community, we started reconstructing the EHB exploiting the updated procedures at the ISC to produce the ISC-EHB. We begin with events in the modern period (2000-2013) and apply new and more rigorous procedures for event selection, data preparation, processing, and relocation. The ISC-EHB criteria selects seismic events from the ISC Bulletin which have more than 25 teleseismic (> 28º) time defining stations, with a secondary teleseismic azimuth gap of 3.75 (Di Giacomo & Storchak, 2016). These criteria minimize the location bias produced by unmodeled 3D Earth structure and select many events that are relatively well located in any given region. There are several processing steps; (1) EHB software relocates all the events using ISC starting depths; (2) Near station and secondary phase arrival residuals are reviewed and a depth is adopted or assigned according to best fit, and in some instances depths may be reassigned based on other sources (e.g., USGS broadband depths); (3) All events are relocated with their new depths and plotted in subduction zone cross sections, along with events from the ISC-GEM catalogue for comparison; (4) These plots are used to confirm or modify weakly constrained depths. The new ISC-EHB dataset will be useful for global seismicity studies and high-frequency global tomographic inversions. This will be facilitated by online access to the ISC-EHB Catalogue and Bulletin via the ISC (www.isc.ac.uk/isc-ehb/), where we also include maps and cross sections of the seismicity in subduction zones. Example maps and cross sections for events in years 2000-2013 will be presented.

ESC2018-S8-299

TOMOGRAPHIC IMAGES OF TECTONIC AND VOLCANIC STRUCTURES IN EASTERN SICILY OBTAINED BY ACTIVE AND PASSIVE SEISMIC DATA
INVERSION

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The eastern Sicily and southern Calabria present a complicated geological framework, characterised by collisional, subduction and volcanic processes. Despite the large number of studies, the major tectonic structures of the area and their complex interaction with the magmatism are still elements inadequately constrained and matter of discussion. In this work, we present high resolution tomographic images obtained using both seismic passive data acquired during the TOMO-ETNA experiment and a selected dataset of about 5,900 earthquakes recorded by the local INGV network. This tomography, performed with a dense grid of measure nodes, allows us to investigate in careful detail the crustal structure of Mt. Etna, the Peloritani, the southern Calabria region and the Aeolian Archipelago. In particular, results depict major discontinuities which characterise the Aeolian area, as part of the Southern Tyrrhenian Fault System, and which extend up to the Ionian Sea. In addition, some high velocity anomalies have been found in the southern sector of Mt. Etna. Tomographic images

indicate that these last features could be related to a fissural activity of an ancient volcanic edifice which was located offshore the existing volcano and which has been disrupted and modified by erosive and tectonic processes during the time, since its formation more than 220 ka ago.

ESC2018-S8-306

TRIPLICATED BODY WAVES: A MULTI-FREQUENCY MEASUREMENT APPROACH

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Regional body waves (14-29o) exhibit strong sampling of mantle transition zone depths between 410-690km. They ought to be incorporated into body wave tomography of the upper mantle. Despite marked developments in finite-frequency and full waveform inversion, the true potential of triplications remains unrealised. We improve on prior work that modelled triplicated body waveforms with ray-based synthetics, and instead use full-waveform forward modelling and sensitivity calculations based on the spectral element code, AxiSEM . We present a revised data processing workflow that generically tackles each possible triplicated coda permutation. We deliver ~50,000 multifrequency travel-time measurements

ESC2018-S8-323

WHAT REMAINS OF THE CALABRO-IONIAN SUBDUCTION ZONE: SLAB NARROWING AS IMAGED BY HIGH RESOLUTION SEISMIC TOMOGRAPHY

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Among the geological features in the Mediterranean region that continue to capture Earth scientists' attention are the subduction processes, since they have a great influence on the tectonic evolution and the geologic structure of the area, as well as on its seismicity and magmatism. In particular, the tectonic framework of the western-central Mediterranean is mostly the result of the NW-dipping subduction of the ancient Ionian oceanic lithosphere, which currently is recognized to be confined beneath the Calabro-Peloritan Arc. With the aim of improving the image of such subduction system and surrounding zones, we performed a detailed 3D image by means of a seismic tomography. We exploited a large dataset of about 20,100 local earthquakes, recorded between 1981 and 2014, and computing algorithms which are able to build a dense grid of measure nodes (LOTOS) and to improve the relative position of clustered events (tomoDDPS). Results show that the slab is in-depth continuous below the southern sector of the Calabro-Peloritan Arc but the deformation processes developing at its edges are leading to its progressive narrowing, influencing tectonics and magmatism at the surface. In particular, along the southwestern slab boundary, where the sinking and the retrograde movement of the slab have caused its segmentation, the deformation is expressed by a combination of a lithospheric vertical tear and a horizontal slab breakoff. The vertical lithospheric tear propagates in the upper plate along a NW-SE fault system (Aeolian-Tindari-Letojanni) up to its tip zone, which has been identified in the Ionian Sea, about 30-40 km off the Sicilian coast; further southeast, lithosphere appears flexed and not broken yet. On the northern side, the slab has been progressively broken parallel to the trench and the horizontal tear may still propagate southwards. Horizontal tearing affecting both the sides of the slab results into a narrowing of the subduction system with consequent stress concentration at the tip zones and enhanced subsidence due to the gravitational pull along the intact segment of the slab. Finally, northwest of Mt. Etna, tomography highlights low VP which can be related to an upwelling of deep mantle material likely flowing laterally through the window opened by the complete slab detachment in the western Tyrrhenian Sea.

ESC2018-S8-327

A NEW 3D SHEAR VELOCITY MODEL OF THE WIDER VIENNA BASIN REGION FROM AMBIENT NOISE TOMOGRAPHY

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Accurate velocity models of the Earth are a prime result of seismological study, which are useful on one hand for understanding the tectonic evolution of an area, and on the other hand for improving the evaluation of natural resources, and for better locating seismic events. The Vienna Basin (VB) is generally thought to be an area of low seismicity and low to moderate seismic hazard, but some authors argue that the seismic hazard in the region is underestimated. In this study, we retrieve a shear velocity model of the crust in and around the VB. We use continuous seismic records of 63 broadband stations (47 temporary stations of the temporary AlpArray network (http://www.alparray.ethz.ch) and 16 permanent stations, operated by national services) to retrieve inter-station Green's Functions from ambient noise cross correlations in the period range of 5s - 25s. From these Green's Functions we measure Rayleigh wave group travel times and invert them to retrieve a 3D shear velocity model of the study area in the top 30km. The resulting model provides previously unachieved resolution in this area, and matches well with the few known crystalline basement depths from boreholes. For depths, larger than those reached by boreholes, the new model allows new insight into the complex structure of the VB and surrounding areas, including deep low velocity zones. The new model will also open new possibilities for improving earthquake locations, and for better predicting ground motions associated with potential earthquakes in the area.

ESC2018-S8-346

3D LITHOSPHERIC STRUCTURE OF THE PANNONIAN BASIN FROM BODY-WAVE TRAVELTIME TOMOGRAPHY

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We used body-wave tomography to investigate the crust and uppermost mantle structure of the Pannonian basin. The Pannonian basin is a back-arc basin characterized by a thinned lower crust and an updoming mantle. Benath the basin both the crust and the lithosphere have smaller thickness than the continental average. Over 19 thousand traveltime picks have been derived from the ISC bulletin and the local Hungarian National Seismological Bulletin, and altogether we used more than 5000 seismic events (local, near-regional and regional) and more than 150 seismic stations from the time period between 2004 and 2014. Our 3D P-wave tomographic model provides a relatively high-resolution view of the litospheric structure of the Pannonian basin. For tomographic inversion we used the FMTOMO software package which applies the Fast Marching Method (FMM) for calculating the forward step, and the subspace inversion method to recover the model parameters. Also we performed numerous synthetic tests both to help the appropriate interpretation of the resulting velocity model and to select the optimal inversion parameters. The main features of the retrieved 3D velocity image highly resemble the known geologic and tectonic structure of the area (Moho topography, orogenic belts and the deep basins) and are comperable to recent tomographic models published in the literature.

ESC2018-S8-369

INTRA-SLAB SEISMICITY IN THE INDO-BURMA SUBDUCTION ZONE: INSIGHT FROM HYPOCENTER RELOCATION AND SEISMIC TOMOGRAPHY

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The Indo-Burma subduction zone is an active tectonic region where the Indian plate dives beneath the Burma plate. This region is situated between the ocean-continent subduction zone of Sumatra-Andaman, and the continent-continent collision of the Eastern Himalaya syntaxis. In recent years, several significant intra-slab earthquakes (M ≥ 6) occurred at intermediate-depth (60 km ≤ depth ≤ 150 km) within the Indian slab below Myanmar. It is thus important to understand the subduction tectonics in this region for both seismic risk assessment and for improved geodynamic models of the collision zones. In this study, we aim to constrain the geometry of the Indian slab from the 3D seismic velocity structure and relocated seismicity, and to understand the nature of intermediate-depth seismicity in this region. Due to the installation of new stations in

Myanmar, we are able to extend earthquake catalogs with unprecedented local station coverage. We combine new picks on stations of the Department of Meteorology and Hydrology of Myanmar (DMH) with picks from the International Seismological Centre from January 2013 to February 2018. We obtain ~500 earthquakes with good location quality recorded by over 40 stations located in Myanmar and the surrounding regions. We employ SIMULR16 which inverts the 3D Vp and Vp/Vs-ratio and relocates the earthquake hypocenters iteratively. We discuss the velocity models and the hypocenter distribution in conjunction with the Global Centroid Moment Tensor catalog. The hypocenter distribution shows that the Wadati-Benioff Zone (WBZ) appears in a single plane and steepens around 80 to 100 km. The WBZ in the northern part continues down to 200 km, and reaches at most 150 km in the central part, while in the southern part intermediate depth earthquakes rarely occur. Another notable feature lined out by the WBZ is an along-strike bending of the slab from north to south. Most of the focal mechanisms of the intraslab earthquakes in northern Myanmar are oblique mechanisms with arc parallel P-axes and down-dip T-axes. However, the intraslab earthquakes in the central part of Myanmar show a different pattern, with thrust mechanisms, and slab normal P-axis directions, while the T-axes point down-dip.

ESC2018-S8-376

UPPER CRUSTAL VELOCITY STRUCTURE OF SARONIKOS GULF (CENTRAL GREECE) FROM BODY-WAVE TRAVEL-TIME TOMOGRAPHY

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The broader South Aegean area is characterized by the convergence of the African and Eurasian lithospheric tectonic plates at a rate of approximately 30 mm/yr, resulting in a complex and intense deformation of the Aegean (McClusky et al. 2000). Saronikos Gulf is a feature of special interest due to the variety of origins (tectonic and volcanic) and focal depths of the recorded seismicity. It is a well-known neotectonic basin, divided into two major and further smaller parts, mainly bounded by WNW-ESE trending fault zones. The islands that are situated in the Gulf intersect those basins forming a platform. The presence of several Plio-Quaternary volcanic centers makes the overall image of the distributed seismicity more complex and the exploration of the geophysical background more necessary. The study area has been characterized by low earthquake activity during the instrumental era (Makropoulos et al., 2012). In the present study, more than 3,000 earthquakes that occurred between 2012 and 2017, recorded by stations of the Hellenic Unified Seismological Network (HUSN) (Papanastassiou 2011) and the Hellenic Strong Motion Network (HSMN) (Theodulidis et al. 2004) were used and located using a local 1-D layered velocity model. The greatest part of the seismicity is concentrated along Leuces islands (north), near Aegina and Methana (south) E-W striking neotectonic fault zones and ENE of Poros, related to the Poros Fault System (PFS). It is worth noting that 613 events belong to the Poros swarm (03/2016-09/2016), with magnitudes ranging mainly between 1.8 and 2.6 (ML). Their frequency gradually decreased during late 2016 and 2017 (132 events). The largest events of this group occurred on 30 April 2016 (ML=3.7) and 26 July 2016 (ML=3.6). A Local Earthquake Tomography (LET) was performed, using body-wave (P and S) travel-time data from the above mentioned catalogue of the Seismological Laboratory of the National and Kapodistrian University of Athens (SL-NKUA), in order to investigate small to medium scale anomalies related to the local neotectonic and volcanic pattern. In the present study, the analysis was based on the LOcal TOmographic Software (LOTOS) by Koulakov (2009). A dataset comprising of 54,351 P and 34,852 S arrival-times was selected, with at least 14 phases and ratio of S to P residual smaller than 1.8. Inversion was performed for Vp, Vs and Vp–Vp/Vs to obtain additional constraints concerning the Vp and Vs anomalies. The checkerboard method (Humphreys and Clayton, 1988) was applied as an indicator of the resolution and uncertainties associated with the inversion to determine the well-resolved area. This method uses alternating anomalies of high and low velocity, evenly spaced throughout the model in a checkerboard pattern. The adopted procedure included four different sets of anomaly dimensions for the horizontal tests (5x5 km2¬, 10x10 km2 15x15 km2 and 20x20 km2) to define

the limitations of our model. All models were successfully reconstructed throughout the major part of the study area at shallow depths (5-10 km), especially within the region between the southern shores of Attica and the northeastern ones of Peloponnese (37.4º-38.0ºN, 23.1º-23.8ºE). Interesting features of major anomalies are identified North and South of Aigina island, mainly related to the principal local stress orientation and recently activated fault zones in the area, such as the ones of Moni, Anghistri and Leuces Islands. In the area of Methana peninsula, a low velocity (Vp, Vs) anomaly coincides to an area of high Vp/Vs ratio that can be related to the local Plio-quaternary volcanic center of Methana-Pausanias. The high Vp and Vp/Vs in PFS (~5-20 km depth) may be a result of increase in superficial water content and/or hydrothermal fluid circulation, upward and outward from a non-molten Pliocene magmatic intrusion, resulting in hydrothermal alteration of the country rock. Consequently, the existence of pore fluids rich in CO2, H2S and H2O in highly fractured wall rock, caused a redistribution of fluid pressure that could be related to the occurrence of the 2016-2017 Poros earthquake swarm.

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ESC2018-S8-377

ON THE 3-D VELOCITY STRUCTURE OF W. GREECE

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Western Greece is characterized by the highest seismicity rates of the Hellenic peninsula and is a source of interest since it is related to complexities mainly related to distributed continental deformation. The ~SW-NE convergence between the African and the Aegean plates results in intense deformation of the crust and the release of stored elastic energy by seismic slip along large faults. Deformation across the area is mainly accommodated within the accretionary sediments of the External Carbonate Platform of the Hellenides (H1) escarped from the subducted Ionian plate and collided against Pindos (e.g. Royden and Papanikolaou, 2011). This region has been frequently activated during the last decade, providing a large amount of enhanced quality recordings from the Hellenic Unified Seismological Network (HUSN), the Corinth Rift Laboratory Network (CRLN) and the Mediterranean Very Broadband Seismographic Network (MedNet), which were exploited for the purposes of this work. The first step was the development of a local 1D velocity model capable of yielding optimized hypocentral solutions with reduced residuals. This was obtained by the mean travel-time residuals and location uncertainties minimization method (Kissling et al., 1994). Tomographic inversion was performed by applying the Local TOmography Scheme (Koulakov, 2009). A dataset consisting of more than 170,000 P- and S-wave manual picks corresponding to 6,880 events was employed. The checkerboard method was applied as an indicator of the tolerance range of the solutions due to the available data configuration. Several checkerboard tests were performed in order to obtain the optimum cell size representing the horizontal and vertical dimensions of the velocity structures that could be resolved with confidence for both amplitude and shape. This procedure showed that an initial 40x40x40 km³ synthetic checkerboard was the most suitable since this pattern was sufficiently reconstructed by employing the dataset of real raypaths and imposing an amount of traveltime noise. The

dataset enabled good horizontal resolution between 10 and 40 km depth. Deeper than 40 km, the resolution is reduced, whereas for depths greater than 80 km, the results are found not to be reliable. Inversion of real data was performed considering the above grid configuration and the hypocentral locations resulted from the optimized 1D regional velocity model. The tomography outcome in terms of % longitudinal (VP) and shear (VS) velocity perturbations with respect to the 1D velocity model indicates gross structures, with the following characteristics:

• The shape and amplitude pattern (15%) of the retrieved velocity anomalies is found quite similar down to 40 km depth.

• Anomalies are found to be arranged in a NE-SW and NNW-SSE direction at the shallow and the deeper part of the crust, respectively.

• The Ionian slab is highlighted by a strong velocity contrast (8%).

• Segmentation of CTF between Cephalonia and Lefkas is inferred by contrast velocity perturbations.

• A predominant NE-SW oriented low velocity zone observed in central Peloponnesus, related with dextral strike-slip faulting, marks a 90° rotation of the extensional stress direction that is found to occur at both sides.

• The resolved velocity anomalies support the scenario of a rigid microplate that includes the regions of Cephalonia, Lefkas, Aitoloakarnania and NW Peloponnese, consistently with seismological (Kassaras et al., 2016) and geodetic observations (Chousianitis et al., 2015).

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ESC2018-S8-392

ON THE CORRELATION BETWEEN THE CRUSTAL DEFORMATION AND THE UPPER MANTLE STRUCTURE OF THE HELLENIC LITHOSPHERIC PLATE DEDUCED FROM SEISMOLOGICAL AND GPS OBSERVATIONS. PRELIMINARY RESULTS.

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The tectonic regime in the broader area of Greece is complex, involving the subduction along the Hellenic Arc, the collision between Adria and northwestern continental Greece, and the westward intrusion of the Turkish plate in North Aegean. As a result, the Aegean region has been shaped by compression, extension and rotation of different lithospheric blocks. As it is well established, the kinematics at a specific location on the Earth's surface is controlled by plate-scale tectonic processes as well as by stresses acting at local scales (Zoback, 1992). In other words, strain-rates not only represent plate interaction with mantle dynamics, but are also due to second and third order stress sources, related to crustal structure, faults and topography (Petricca et al., 2013). However, very few observations sample the deformation of the Hellenic lithosphere as a whole (Hatzfeld et al., 2001) with most of them based on input regarding the deformation of the shallow crust. Whether the whole continental lithosphere deforms in the same manner as the crust remains a challenging question. The issue of the relation of contemporary and/or inherited shallow tectonics with mantle dynamics is investigated in the present study by exploiting available geophysical data. These observations consist of: Seismicity; GPS strain-rates; directions of maximum horizontal compression, SHmax, deduced from the inversion of a massive dataset of over 2000 focal mechanisms of Mw>=3.5

earthquakes at crustal depths (Kassaras and Kapetanidis, 2018); Fast polarization directions from local shear-wave splitting analysis; Regional and teleseismic fundamental mode Rayleigh-wave recordings from the Hellenic Unified Seismological Network; SKS-wave fast polarization directions. Path average group- and two-station phase-velocity dispersion curves were derived using a waveform multiple filtering and a slant stacking technique, respectively. The multiple filtering technique was also applied to extract Rayleigh wave attenuation coefficients over pairs of stations. The Rayleigh-wave dispersion measurements were then inverted using a least-squares algorithm and 1D path-average models of shear velocity and Qs factor, were obtained for depths down to 200 km. In addition to this, data from a teleseismic survey (Kassaras et al., 2009) were employed. All 1D models were then combined in a continuous regionalization scheme, producing elastic-anelastic tomograms of the upper mantle of the Greek region for various depths. Thereafter, seismicity, GPS strain-rates, SHmax orientations and axes of fast shear-wave polarization directions are superimposed on the inferred upper mantle structure and common features at shallow and larger depths are examined. The most predominant characteristic of the upper mantle, resolved with sufficient resolution, is the velocity and attenuation contrast between North and South Aegean, with low velocities/high attenuation, and high velocities/low attenuation, respectively. This transition occurs roughly along the South Aegean Active Volcanic Arc (SAAVA) that overlies the northernmost part of the Hellenic Subduction Zone. The SAAVA also marks a transition of SHmax and eH1 maximum compressional strain-rate directions from roughly E-W in the north to almost N-S in the south, a pattern consistent with fast SKS-wave polarization directions, while a strong contrast of the stress-shape from uniaxial extension to uniaxial compression along SAAVA is also evidenced. The above imply a linkage between the deep mantle dynamics and the deformation within the continental crust of the Hellenic lithosphere, while inferred inherited structures, possibly related to past processes, need to be further investigated since they can significantly affect the seismic hazard of the Greek region. We acknowledge support of this study by the project “HELPOS - Hellenic Plate Observing System” (MIS 5002697) which is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

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ESC2018-S8-474

ANOTHER LOOK AT THE TREATMENT OF DATA UNCERTAINTY IN MARKOV CHAIN MONTE CARLO AND OTHER PROBABILISTIC METHODS

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The data uncertainty in many geophysical inference problems is poorly quantified. In probabilistic Bayesian inversions, the data uncertainty is a crucial parameter for quantifying the nonlinear uncertainties and correlations of the model parameters. Therefore, it is common practice to allow the data uncertainty itself to be a parameter to be determined. In a Markov chain monte Carlo approach, some uncertainty

parameter is varied probabilistically in the same way as the physical model parameters through subsequent steps. Although in principle any arbitrary uncertainty distribution can be assumed, in the vast majority of published studies Gaussian distributions are assumed for the data error, whose standard deviation is the unknown parameter to be estimated. I will present a simple approach to make this procedure more efficient for the case of Gaussian data uncertainty, including the case of mixing different data classes in joint inversions, and correlated errors. On the other hand, it is well known that the distribution of geophysical measurement errors, although superficially similar to a Gaussian distribution, contain far more frequent samples along the tail of the distribution, commonly described as outliers. In linearised inversions these are often removed in subsequent iterations based on some threshold criterion, but in Markov chain Monte Carlo inversions, this is not possible and introduces ad-hoc parameters, whose effect on the model uncertainty is not easily quantified. Therefore, I will discuss ways to deal with outliers in a Bayesian context. The techniques will be illustrated with observed and synthetic case studies of two-dimensional tomographic problems.

ESC2018-S8-496

RELIEF INFLUENCE DURING MICROSEISMIC SOUNDING

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Geophysical methods of lithosphere investigation, based on the use of surface waves, are currently actively developing. Among such methods, we note the method of microseismic sounding, developed at the IPE RAS [1-4]. This method consists in determining the distribution of the normalized intensity of microseismic noise at various points in the study area. After that, the deep structure of the investigated object is determined: zones with increased microseismic intensity are associat-ed with decompressed inclusions, and zones with a reduced microseismic intensity - with dense inclusions. The corresponding depth is defined as half the length of the sounding wave. It should be recognized that the task of restoring the structure of a geophysical medium from the results of measurements of the spectral amplitudes of the microseisms of its surface still remains unresolved. At the same time, it should be noted that the best results of the microseismic sounding method can be obtained for geophysical media with extended subvertical inhomogeneities having a high contrast in impedance in comparison with the host rocks. These may be vertical elements of magmatic feeding systems of active volcanoes, concentrated zones of unloading of deep fluids, including the channels of mud volcanoes, intrusive bodies, active fault zones, and impact structures [5, 6]. However, consideration of the relief influence in this method has not yet been given due attention [7, 8]. In this paper we investigate the propagation of surface waves in a half-space with vertical contrast inclusion and geometric inhomogeneity of the boundary modeling the relief. Studies were carried out using numerical modeling in a software package Comsol Multiphysics 5.3a [9]. The result of the scattering of the surface Rayleigh wave as a function of various parameters of the contrast inclusion: form and size of inclusion, density, Young's modulus, Poisson's ratio. Comparison of the results of the numerical experiment shows that the relief leads not only to significant distortions in the results of microseismic sounding in the shape and size of the inhomogeneity, but also to fundamental errors in determining the type of inclusion (instead of tight inclusion, the decompressed one is diagnosed). In addition, er-rors can also occur in determining the contrast values of deep structures by impedance. So, for example, if the contrast is about 15%, then if there is a relief, it is diagnosed as 70%. The proposed modification of the method of microseismic sound-ing makes it possible to eliminate all the fundamental errors associated with the influence of the relief. Nevertheless, due to the nonlinear nature of the scattering, when using the developed correction, minor artifacts may appear in the results of reconstructing the structure of the geo-physical medium. The research was carried out with the support of the Russian Science Foundation, the project 17-77-10162.

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ESC2018-S8-534

TOMOGRAPHIC INVERSION OF THE LITHOSPHERIC STRUCTURE OF SOUTHERN ITALY BY INTEGRATION OF DIFFERENT SEISMOLOGICAL DATA

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We present a new 3D P- and S-wave velocity model of lithosphere of South Italy and the peripheral offshore areas. The model results from integration of different types of seismic velocity data available in the literature (Deep Seismic Sounding, Local Earthquake Tomography, surface wave inversion, and others) used as a-priori constraints for our inversion or as parameters of the inversion starting model. Seismic wave arrival times from local earthquakes and DSS sources are inverted for characterization of the velocity structure. The obtained model evidences the main structural features of the area mostly known from previous investigations. Also, the obtained velocity pattern furnishes new information on the relationships between deep dynamics related to the Ionian subduction system and the processes occurring at shallow depths. In addition, we analyse the advantages of using different data types to solve a problem that is usually approached by use of a unique type of data in each individual study.

ESC2018-S8-591

HIGH-RESOLUTION TOMOGRAPHIC MODELS OF THE UPPER MANTLE IN VARIOUS TECTONIC PROVINCES - THE STANDARD ISOTROPIC APPROACH AND A NOVEL ANISOTROPIC ADVANCEMENT

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Teleseismic body waves recorded during passive seismic experiments allow us to investigate isotropic velocities of the Earth's upper mantle in a great detail, on scales of tens of kilometres, by means of the standard high-resolution travel-time tomography. Nowadays, tomographic exploration of anisotropic properties of the mantle becomes realistic as well. Novel code AniTomo enables a simultaneous inversion of travel-time residuals of teleseismic P waves for 3D distribution of isotropic-velocity perturbations and anisotropy in the upper mantle (Munzarová et al., Geophys. J. Int., under review). We assume a weak anisotropy with hexagonal symmetry and axes oriented generally in 3D. The code represents a step further from modelling the upper mantle either under the assumption of purely isotropic seismic-wave velocities (e.g., Sandoval et al., Geophys. J. Int. 2004; Karousová et al., Geophys. J. Int. 2013; Silvennoinen et al., Solid Earth 2016) or from modelling the mantle lithosphere as homogeneously anisotropic blocks (e.g., Babuška

et al., Phys. Earth Planet. Int. 1993; Šílený and Plomerová, Phys. Earth Planet. Int. 1996; Vecsey et al., Tectonophysics 2007). The novel code was successfully tested on a large series of synthetic datasets and synthetic structures. We compare tomographic models of anisotropic velocities of the upper mantle with results from independent studies, particularly SKS-wave splitting and directional analysis of P-wave travel-time residuals, as well as with models of purely isotropic-velocity perturbations in different tectonic provinces. The first application of the new code was carried out with data recorded during passive seismic experiment LAPNET (2007 - 2009) in Precambrian northern Fennoscandia (Munzarová et al., Geophys. J. Int., under review). The isotropic-velocity components from the anisotropic tomography are close to the results from the purely isotropic inversion and the anisotropic part of the model is compatible with inferences from independent modelling of seismic anisotropy in the mantle lithosphere. Next application of the anisotropic tomography is in the Variscan Bohemian Massif in the Phanerozoic part of Europe, exploiting data from series of passive experiments in the region.

ESC2018-S8-648

IMAGING THE MUDURNU SEGMENT OF THE NORTH ANATOLIAN FAULT ZONE FROM WAVEFORMS OF SMALL EARTHQUAKES

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An identification of down-dip extension of faults and detailed structure of the upper crust is key issue in imaging locations and geometries of future earthquake ruptures. Active wide aperture and multichannel seismic profiling can provide such information but require substantial budgets for data acquisition. However, both cannot image near-vertical fault planes. These difficulties can be overcome by studying local seismicity. Local earthquakes generate high frequency seismic waves, which can be reflected and/or converted at structural horizontal or inclined interfaces or faults representing a first-order discontinuity with a velocity contrast. In this study, we analyze waveforms of local earthquakes occurring before, between, and after the two consecutive 1999 Mw > 7 Izmit and Düzce earthquakes in NW Turkey. The waveforms were recorded at three seismic stations located around the Mudurnu segment of the North Anatolian Fault Zone. We focus on the interpretation of a distinct secondary phase contained in the P-wave coda that is well separated from the direct P wave. The phase is visible in many waveforms of most seismicity clusters and has a specific constant time delay after the direct P-wave arrivals at each station, irrespective of epicentral distance, hypocentral depth, or back-azimuth. Based on a polarization analysis of records at one of the stations, this secondary phase is interpreted as a PS wave converted at an interface near the stations. Its particle motion is consistent with the direct S wave and displays S-wave splitting produced by the anisotropic upper crust. Synthetic modeling indicates that this PS phase can be either converted at a horizontal interface or at a steeply inclined interface. The steep Mudurnu fault zone with the near-surface setting indicating a juvenile pull-apart structure fits well into these interpretations, which are in agreement with the eastward progressing transtensional tectonics known for the region.

ESC2018-S8-691

RESEARCH OF ADVANTAGES AND APPLICABILITY LIMITS OF THE "REVERSE WAVE" METHOD BASED ON 3D NUMERICAL MODELLING

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Velocity properties of the heterogeneous crust are required for solving a wide range of geophysical problems, including earthquakes hypocenters location and deep structure investigation for delineating geological anomalies of different nature. In this work, we considered an unusual approach of subsurface characterization on the basis of P- and S- waves travel times – so-called "reverse wave" method, proposed earlier [Slavina L.B., Pivovarova N.B. Three-dimensional velocity models of focal zones and refinement of hypocenter parameters // Physics of the Earth and Planetary Interiors. 1992. V. 75, No. 1, P. 77 – 88] for areas of dense seismicity. Considered method is based on the principle of wave reversibility with

is that the travel time of the seismic wave propagating from the source to the receiver is equal to the travel time of wave propagating from the receiver to the source. This principle allows us to consider quite a bit of travel times of seismic waves running from sufficiently weak local earthquakes to some seismic station as the reversal waves travel times, propagating from this seismic station to the hypocenters of the corresponding earthquakes. Thus, the initial parameters for velocity distribution reconstruction includes coordinates of the earthquake hypocenters and seismic wave travel times corresponding to the particular seismic station. The novel algorithm to find the solution of the inverse problem is developed which incorporates the iteration procedure to improve the reconstruction results and imposes additional smoothness conditions on the reconstructed values. Several numerical experiments based on forward problem solution were performed. Waves travel times in 3D heterogeneous medium have been calculated in the ray approximation. It made it possible to estimate the effect of various parameters including earthquakes density, size and shape of the velocity anomalies on the residual of the reconstructed velocity distribution. Obtained results allow us to choose optimal parameters for calculation of the velocity distribution depending on the set of initial data and make a comparison with tomographic methods. The work was carried out with the financial support of the grant of the President of the Russian Federation to support scientific schools No. SS-5545.2018.5.

ESC2018-S8-736

HADES UNDERWORLD EXPLORER - AN ONLINE TOOL FOR THE GENERATION OF SEISMIC TOMOGRAPHIC PROFILES

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This contribution promotes HADES, an online tool that generates tomographic sections of the deep mantle between two freely chosen points on Earth. The tool is readily available under the Atlas of the Underworld (van der Meer et al., 2018) at http://www.atlas-of-the-underworld.org/hades-underworld-explorer/. Cross sections are requested by dragging two markers on an interactive map. Between the selected endpoints, a linear spacing of points on the connecting geodesic line is taken. From this array a tomographic model is sampled at regular depth intervals. The server applies a binary search on an indexed grid to find the eight nearest grid points. The velocity deviation is then interpolated using a trilinear interpolation. The amount of points used for the sampling is a function of the resolution requested by the user. The UUP07 tomographic model is used by default. We anticipate to add alternative global full mantle models in the future. This contribution facilitates students and researchers interested in deep mantle tomography to freely create high-quality exportable tomographic profiles. Because HADES is fast and easy to operate, it is an excellent tool to satisfy both simple curiosity and a deeper scientific interest.

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ESC2018-S8-754

A MULTI-PARAMETRIC ANALYSIS TO IMAGE WITH HIGH RESOLUTION THE SHALLOW SOLFATARA CRATER IN CAMPI FLEGREI(ITALY)

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Fluids play a key role in controlling and governing the evolution of magmatic processes and eruptions. A reliable imaging of fluid storages and accurate tracking of their movements within the crust is therefore crucial to evaluate the evolution of the volcanic activity and to assess the related hazard. The seismic tomography method can be used to obtain a reliable image of the elastic and anelastic properties of complex geological media. However, because of the hydrothermal system

complexity, a multi-parametric analysis is required for an effective and robust tracking of fluids. Solfatara volcano is located within the Campi Flegrei, a still active caldera, which is characterized by periodic episodes of extended, low-rate ground subsidence and uplift episodes (bradyseisms), accompanied by intense seismic and geochemical activities. In particular, Solfatara is characterized by an impressive magnitude diffuse degassing [1], which underlines the relevance of fluid and heat transport at the crater and prompts for further research to improve the understanding of the hydrothermal feeding system. In this framework, an active seismic experiment, Repeated Induced Earthquake and Noise (RICEN, EU Project MEDSUV), was carried out between September 2013 and November 2014 to provide time-varying high-resolution images of the structure of Solfatara [2]. For this study we used the datasets provided by two different acquisition geometries: a) A 2D array covering an area of 90 x 115 m2 sampled by a regular grid of 240 vertical sensors deployed on the crater floor; b) two 1D orthogonal seismic arrays deployed along NNE-SSW and WNW-ESE directions and crossing the 400 m crater surface. The goal of this work is to present a high resolution multi-parametric image of the shallow Solfatara crater analyzing P-wave velocity and attenuation tomographic models. In particular, we present 1) a 3D velocity model [4]; 2) two bi-dimensional velocity sections multi-2D interpreted [5]; 3) a 3D attenuation model. We compare the obtained 3D images with an electrical resistivity section [3] and temperature and CO2 flux measurements. The 3D elastic and anelastic images of the shallow (30-35 m) central part of Solfatara crater are obtained through an iterative, linearized, tomographic inversion of picked P-wave arrival times and of the measured t* values using a multiscale strategy. 2D velocity sections (60-70 m) are obtained using a non-linear travel-time tomography method based on the evaluation of a posteriori probability density with a Bayesian approach. The 3D retrieved images integrated with resistivity section and temperature and CO2 flux measurements, define the following characteristics: 1. A depth dependent P-wave velocity layer down to 14 m, with Vp<700m/s typical of poorly-consolidated tephra affected by CO2 degassing; 2. An intermediate layer, deepening towards the mineralized liquid-saturated area (Fangaia), interpreted as permeable deposits saturated with condensed and meteoric water; 3. A deep, confined high velocity anomaly associated with a CO2 reservoir. 2D profiles image the shallow sub-surface down to about 60 m depth: the upper 30 m are characterized by velocities comparable to those of the 3D elastic images. Between 40-60 m depth, two low-velocity anomalies were found, probably indicating a preferential way for fluid degassing. These features are expression of a volume located between the Fangaia, which is water-saturated and replenished from meteoric and condensed water, and the main fumaroles that are the superficial relief of deep rising CO2. So, the changes in the outgassing rate greatly affects the shallow hydrothermal system, which can be used as a near-surface proxy of fluid migration processes occurring at greater depths.

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ESC2018-S8-755

LOCAL EARTHQUAKE TOMOGRAPHY OF THE LARDERELLO-TRAVALE GEOTHERMAL FIELD

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Located in central Tuscany (Italy), the Larderello-Travale Geothermal Field (LTGF) is one of the major vapor-based geothermal fields in the world. Currently, its running capacity amounts to about 10% of the global geothermal electric energy production, and it contributes to almost 2% of the Italian power needs in Italy. LTGF is among the most studied and well-known geothermal systems, for what concerns both its geological features and sustainability and efficiency of the whole exploitation cycle. This local earthquake tomography (LET) study provides a new 3D velocity model of the upper crust beneath the geothermal field based on inversion of P-wave travel-times from micro-seismicity (M less than 3) observations. The dataset was obtained in the frame of a specific experiment (Geothermal Area Passive Seismic Sources - GAPSS) carried out by Istituto Nazionale di Geofisica e Vulcanologia (INGV) during May 2012 and November 2013. The experiment consisted in the deployment of about 23 temporary stations complemented by 2 permanent stations belonging to the Italian national seismic monitoring array. The initial dataset consisted of about 2600 earthquakes, whose waveforms were repicked using a semiautomated procedure in order to obtain a highly precise and consistent dataset of traveltimes observations. A representative subsets of events (reference dataset) was then selected considering the quality of the observations, source magnitude and hypocentral distribution. This reference dataset was manually re-picked and used for the subsequent tuning of an automatic picker in terms of timing and quality estimation of the time pickings. We adopted an innovative, iterative picking procedure whose results were subsequently used as input for the advanced MannekenPix (MPX) algorithm. The final, repicked high-quality dataset was then used to find a minimum 1D model for the study area. After numerous resolution tests, we found that the best resolution was achieved with a model parameterized by a grid whose nodes are spaced by 5 km and 2.5 km along the horizontal and vertical directions, respectively. Using the SimulPS_14q inversion procedure, a final model is achieved after 5 iterations with an 80% variance reduction and a solution RMS on the order of 70 ms with an average input error uncertainties of 60 ms. The inversion's results are compared with some available cross-sections from active seismic profiles in literature and measurement of the main wells in the region. Correlation with the main LTGF seismic features has been found in the velocity model: in particular, the 5.2 km/s P-wave velocity isoline correlates well with a regional high-reflectivity horizon (the so called H-horizon). Our results clearly outline the main dome-shaped, Pliocene granitic intrusion as well as the abundant presence of fluids, imaged as low-velocity anomalies beneath the most active wells. Overall, these data open new perspectives on application of LET imaging techniques for the exploration of the geothermal resource at crustal depths.

ESC2018-S8-1060

A REGIONAL DURATION MODEL FOR ISTANBUL

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The total duration (DT) used in stochastic simulation of strong ground motion is defined as the sum of source duration (DS) and path duration (DP). DS is inversely proportional to the corner frequency, which can be estimated via spectral analysis. DP, on the other hand, is calculated as the difference of DT and DS. This study develops a regional duration model by drawing on over 4000 strong motion recordings of the Istanbul Earthquake Rapid Response System (IERRS) operated by the Department of Earthquake Engineering at Bogaziçi University's Kandilli Observatory and Earthquake Research Institute. We use events of local magnitudes occurring within the range of 4.04.0<ML<6.5 and having epicentral distances ranging from 6-444 km. Our aim is to develop a regional, distance-dependent path duration model for Istanbul that can be used in stochastic point-source and finite-fault simulations. Total duration can be found from recorded data based on several definitions. We estimate source durationvia shear-wave spectral analysis of recorded data. Total durations are estimated following a series of definitions. These are the RMS duration (McCann and Shah, 1979), the RVT duration (Boore 1983, 2003), the significant duration -which is defined by the time interval between 5 % - 75 % and 5 % - 95 % of the integral of the square of the acceleration (Arias, 1970)-, and bracketed duration (Kawashima and Aizawa, 1989). We discuss these models' regional compatibility in terms of their drawbacks, and concluded by comparing the proposed duration

model with similar regional studies in the literature.

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ESC2018-S9-263

SEISMIC STRUCTURE BENEATH THE REYKJANES PENINSULA, SOUTHWEST ICELAND, INFERRED FROM ARRAY-DERIVED RAYLEIGH WAVE DISPERSION

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The aim is to obtain a site-specific S-wave structure beneath the Reykjanes Peninsula, southwest Iceland. Nine broadband stations of the Reykjanet network are used to find Rayleigh-wave phase velocity dispersion in a relatively wide range of periods (from 3 to 50 s). The records analyzed were made in the years 2013 to 2015 and concern fourteen selected earthquakes whose epicentral distances range from tens of kilometers to almost ten thousand kilometers. Our approach to retrieving Rayleigh phase velocity dispersion involves two partly independent methods allowing for array apertures larger than a wavelength: 1) the zero-crossing point method, and 2) the phase-plane method. The two methods used here work with seismograms decomposed into quasi-harmonic components and implicitly assume a single plane wave propagation. The good match between the dispersion curves obtained by means of the two methods indicates that the assumption has been reasonably fulfilled. The Rayleigh wave phase velocity dispersion data are inverted into a horizontally layered isotropic S-wave velocity model of the Earth's crust and uppermost mantle by a modified method of the singleparameter variation. At shallow depths, the derived model is rather similar to some previous models that were derived predominantly from the arrival times of body waves. At depths exceeding about 20 km, the dispersion data require low S-wave velocities, indicating a noticeable low-velocity zone.

ESC2018-S9-303

SURFACE-WAVE IMAGING OF CAPE VERDE CRUST AND UPPER MANTLE

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The Cape Verde archipelago is located in the Atlantic Ocean, approximately 500 km from the African Continent. The 9 main islands and a few islets of volcanic origin that form the archipelago are on top of the Cape Verde Rise, a mid-plate topographic swell suggested to be formed at ~22 Ma. The origin of Cape Verde Rise has been generating some controversy and debate but it is widely accepted that this feature is associated with Cape Verde hotspot volcanism. Dating of volcanic rocks showed that the volcanism in the archipelago was first originated on the east (Sal, Boavista and Maio islands) during the middle Miocene (~15 Ma). The western segment evinces younger volcanic activity (~5 Ma years later) and the remaining islands, Fogo and Brava, are much younger yet (6 Ma to presently active). Despite recent progress yielded by seismological and geochemical studies, the physical properties of Cape Verde crust and lithosphere remain largely undetermined. We used the two-station method in order to measure phase-velocities of the fundamental mode of Rayleigh waves and investigate the Earth's lithosphere and sublithospheric mantle beneath Cape Verde. Two different temporary broadband deployments (YW and CVPLUME consisting of 7 and 38 stations, respectively) were used in this study. We determined the phase-velocity curves of the fundamental Rayleigh mode in the period band between 10 to 100 s, sampling from the crust to the sub-lithospheric mantle. The majority of measurements are between 13 - 35 s. A large number of inversions were performed in order to determine the optimal regularization parameters - norm damping, smoothing and gradient damping - and produce optimal-resolution velocity maps. Our tests also confirmed that Rayleigh-wave azimuthal was required by the data. The phase-velocity maps evince, between 16 to 20 s, a positive (high velocity) anomaly on the older islands (Sal, Boavista and Maio) and a negative (low velocity) one on the younger islands (Santiago, São Nicolau and Santo Antão, Fogo and Brava). Above 20s (at 20-30 km depths) this pattern changes but the low phase-velocity anomaly remains the (youngest) Brava and Fogo islands. At the same time, the northern islands present a positive anomaly increasing with

increasing period. We will present our results relating to the volcanism and subsequent cooling of the lithosphere, to the possible existence of a hot plume beneath the lithosphere, and also to the character of the sea-floor spreading. The authors thank to the European COST action TIDES (ES1401) for discussions.

ESC2018-S9-334

WHOLE-MANTLE STRUCTURE UNDER THE REUNION HOTSPOT IN THE WESTERN INDIAN OCEAN FROM MULTIPLE-FREQUENCY P-WAVE TOMOGRAPHY

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We present a high-resolution body-wave tomography of the whole mantle column beneath the western Indian Ocean, with a focus on the volcanic hotspot of La Reunion, the presumed location of a deep mantle plume. From 2011 to 2016, the RHUM-RUM (Reunion Hotspot and Upper Mantle & Reunions Unterer Mantel) project instrumented a 2000 km x 2000 km area of the seafloor and islands surrounding the hotspot with broadband seismometers. The central component was a 13-month deployment of 57 German and French ocean bottom seismometers (OBS) at 2300-5600 m depth. This was supplemented by 37 island stations on Reunion, Mauritius, Rodrigues, the southern Seychelles, the Iles Eparses and southern Madagascar, which ran for 2-3 years. Two partner projects contributed 30 more stations on Madagascar. This large deployment vastly improved the seismological illumination of a previously sparsely instrumented oceanic region. More than 200 teleseismic events during the 13-month long OBS deployment yielded usable measurements, supplemented by another 400 events recorded by the land stations before and after the OBS deployment. Multiple-frequency traveltime measurements are obtained by cross-correlation of observed with predicted waveforms, which are computed by full waveform propagation and careful deconvolution of source time functions. We obtained ~50,000 cross-correlations measurements for our multiple-frequency tomography, in passbands between 30 and 2.7 seconds dominant period. For the final inversion, we combined regional multifrequency measurements with ISC data (1970-2013) in order to regularize the tomography on the margins of the region of interest. The new P-wave model shows a lowermost mantle source for the plume beneath La Reunion, rooted in the African LLSVP. The model is consistent previous studies in terms of 'fat' plumes in the lower mantle but reveals much more detail and considerable complexity in the transition zone and upper mantle beneath the Reunion hotspot. Rather than being near-vertical, the upwelling shows considerable tilt in the lower mantle (which is consistent with geodynamic predictions) and splits into several branches closer to the surface.

ESC2018-S9-415

IMAGING THE CRUSTAL STRUCTURE OF AN OCEANIC PLATEAU: INSIGHTS FROM THE AZORES ISLANDS (PORTUGAL)

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The Azores Plateau, located at the tectonic triple junction between the American and the Eurasian-Africa (Nubia) Plate Boundaries, is the morphologic expression of the intersection of the Mid-Atlantic Ridge (MAR) with the complex western sector of the Eurasian-Africa Boundary. This plateau is considered the surface expression of the interaction between the Azores hot-spot and the MAR, the observed thicker crust and volcanism explained by the associated higher magma budget. The region is under right lateral transtension due to higher rates of seafloor spreading north of the triple junction and to the obliquity of the Azorean segment of the Eurasian-African plate boundary relatively to the spreading direction and associated ultra-slow spreading rates. The volcanism that built the islands and the submarine volcanoes is tectonically controlled and is result of this transtensile tectonic regime on that portion of oceanic lithosphere. The deformation is represented by widespread active faulting of the islands and surrounding seafloor, and is expressed by intense seismic activity, with mostly low to moderate magnitudes, occasionally reaching M~7. To image the seismic structure of the crust beneath the islands, we used the data collected since 1998 by the permanent network of IPMA, complemented by data from the network of

the University of Azores. The irregular spatial distribution of the seismicity, together with the geometry of the network, resulted in a very heterogeneous distribution of seismic ray-paths. Therefore, we've concentrated in the central group of islands, which was subdivided in three crustal volumes, each with a specific density information and imaging capability. The most densely sampled volume corresponds to the Faial-Pico islands ridge. The tomograms show a thicker crust, around 14 km consistent with previous studies. A low-Vp anomaly is located roughly beneath the "caldeira", the main vulcanic structure of Faial island, and extending at least to depths of 10km, which is coherent with the presence of a magmatic chamber. Beneath Pico mountain, a stratovolcano dominating the island of Pico, a low-Vp anomaly is also observed but unlike in Faial, mainly limited to the shallow layers of the model and weaker than the one beneath Faial; this may be due to poorer imaging, consequence of less rays sampling the volume, or the signal of a magma chamber located deeper in the lithosphere. Beneath the East Graciosa Basin area, an area offshore the island, the models show a thinner crust consistent with the presence of a crust more akin to oceanic, the Vp-isolines pointing to values around 10 km. The main seismicity cluster separate to two clear Vp domains, faster to the west, slower to the east; this is probably the signature of crustal-scale fault system, undoubtedly the one responsible for the devastating January 1st, 1980 earthquake. The third, smaller, modeled volume correspond to the structure beneath Terceira island. Unlike the other two, the seismicity distribution allowed only to image the crustal structure up to about 8 km depth. The results point to a subdivision of the islands into two main blocks; a western bloc, presenting low-Vp anomalies coincident with the still active Santa Barbara volcanic complex and an eastern, faster block, coincident with the extinct volcanic structures of Serra do Cume.

ESC2018-S9-689

THIN MANTLE TRANSITION ZONE BENEATH HAWAII AND THE EQUATORIAL MID-ATLANTIC RIDGE: UPWELLING FROM THE LOWER MANTLE

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The roots of hotspot ocean islands and ocean ridges likely originate from the deep mantle. Seismic evidence, however, remains limited because these places are located in remotes areas on the planet away from seismic stations found on the mainland. Despite the increasing number of elaborate experiments involving ocean-bottom seismographs (OBS), the restricted station coverage sometimes still makes it difficult to image deep below the stations. Thus, we look at a specific seismic signature, the P-to-S phase conversions at the Mantle Transition Zone (MTZ), and use the inferred thickness as a proxy for temperature and dynamics. We analyse the seismic data of the recently deployed Passive Imaging of the Lithosphere-Asthenosphere Boundary experiment (PI-LAB) at the equatorial Mid-Atlantic Ridge, and the data from the Hawaiian Plume-Lithosphere Undersea Mantle Experiment (PLUME). We find significantly thin mantle transition zone beneath both locations. In the case of Hawaii, the MTZ is characterised by an inner thin zone indicative of a hot mantle upwelling plume, and a thicker outer zone probably the result of cold downwelling uppermost mantle material. Beneath the equatorial Mid-Atlantic Ocean, the MTZ has an average thickness between the African continent and the ridge, and a thin transition zone just offset from the ridge axis. Our mapping for the MTZ thickness and the topography of the 410- and 660-km depth discontinuities compares well with seismic tomography. Interestingly the discontinuities at the two locations have distinct topographies, probably reflecting the different mantle dynamics involved at the two locations: Hawaii as result of a narrow upwelling mantle plume, and the Mid-Atlantic Ridge as a result of an upwelling mantle convection cell, both of which originating from the lower mantle.

ESC2018-S9-928

SHALLOW CRUSTAL STRUCTURE OF FOGO ISLAND (CAPE VERDE) FROM AMBIENT SEISMIC NOISE

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Fogo, one of the most active oceanic island volcanoes in the world, is located in the SW of the Cape Verde Archipelago. Since its settlement, in the 15th Century, it has erupted approximately every 20 years. The most recent eruption of Fogo volcano started on Nov 23, 2014, and lasted for almost three months. Several models have been proposed for the structure of Fogo volcano. However, its seismic structure has not been investigated with seismic tomography so far. Constraints such as source-receiver geometry, uneven seismicity distribution or, for some methods, infrequent seismicity hindered to obtain high-resolution models of the Fogo crustal structure by traditional passive seismology. Seismic interferometry/seismic ambient noise tomography allows imaging regions with a resolution that mainly depends on the seismic network coverage. We applied ambient seismic noise tomography to data recorded by three different temporary deployments, to illuminate the shallowest crustal structure underlying the Fogo Volcano edifice. To compute Rayleigh wave empirical Green's functions between all station pairs, we phase cross-correlate one-hour-length data segments. Application of a phase-weighted stack to the entire recording period allowed enhancing the signal-to-noise ratio. Dispersion analysis enables to extract inter-station group velocities. The short inter-station distance limited our measurements to a period range of 0.5–5 s. Our preliminary results show group velocities of the fundamental mode Rayleigh waves between 1.8 and 2.8 km/s, with the smallest values being observed for the in the inter-station paths crossing the volcanic structure. Such relatively small velocities are tentatively interpreted as the result of the existence at shallow depths (< 3 km bsl) of magma reservoir(s) that fed the two last eruptions (1995 and 2014-15) for which the volcanic vents were almost coincident. The presence of these shallow reservoirs, where magma stalled before the eruption, has been also recognized by petrological studies. Group velocity measurements will be regionalized to obtain 2D tomographic images in central Fogo. The models will be compared with models for the crust gathered from Ps and Sp receiver functions (Lodge and Helffrich, 2006; Vinnik et al., 2012) and interpreted within a geodynamic framework.

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ESC2018-S10-198

INVERSION OF VSP P-WAVE TRAVELTIMES IN HOMOGENEOUS AND INHOMOGENEOUS ANISOTROPIC MEDIA

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Determination of seismic anisotropy plays an important role, both in structural and exploration seismology. We test possibilities to determine seismic anisotropy from P-wave traveltimes recorded in a vertical seismic profiling (VSP) experiment. We use synthetic traveltimes generated in homogeneous and inhomogeneous anisotropic media. The inversion scheme is based on the so-called weak-anisotropy approximation, in which the relation between traveltimes and parameters specifying anisotropy is given by relatively simple formulae. Instead of stiffness tensor or elastic parameters in the Voigt notation, we use the so-called anisotropy parameters. Their use has many advantages one of them being the fact that P-wave propagation in a generally anisotropic medium is specified by only 15 anisotropy parameters instead of commonly required 21 parameters. As observed data, synthetic P-wave traveltimes generated by program package ANRAY with added Gaussian noise are used. First tests are made with P-wave traveltimes obtained from a VSP experiment in a homogeneous model of arbitrary anisotropy. In this case, the inverse problem is linear. The following tests concentrate on P-wave traveltime data generated in inhomogeneous media of arbitrary anisotropy. In this case, the inverse problem is strongly nonlinear. In both cases, results of the inversion are estimates of anisotropy parameters, their resolution and accuracy. Inversion schemes are tested for various types of anisotropy, varying inhomogeneity, varying source-receiver configurations or varying noise levels

ESC2018-S10-201

SHEAR-WAVE SPLITTING RESULTS FROM THE RECENT JANUARY 2018 SEISMIC SEQUENCE IN MARATHON (ATTICA, GREECE)

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The area of Marathon is located 25 km NE of Athens, the capital of Greece. It is a region of low activity, as only three Mw > 4.0 earthquakes have occurred since 1900. In addition, annual seismicity is characterized by a small number of events. On January 15th 2018 20:24:14 (GMT) a Mw = 4.2 earthquake occurred in the area. The mainshock was preceded a week earlier by a significant, for the region, foreshock sequence consisting of 36 earthquakes. The activity didn't cease until the end of the month, with a total of 73 earthquakes which were located from manually determined P- and S-wave arrivals. Shear-waves are known to split when entering anisotropic media, into two components, i.e. the Sfast and the Sslow. Shear-wave splitting (SWS) studies utilize the polarization direction of the Sfast and the time-delay between the arrivals of the two components (td). In the present study, we used all 73 located earthquakes of the January 2018 sequence to explore the anisotropy features of the Marathon area. Stations PTL and DION, of the Hellenic Unified Seismological Network, were used, being the only ones that presented recordings that fit the initial selection criteria, i.e. rays with an angle of incidence up to 45°. Waveforms were visually inspected to reject recordings with shear-wave amplitudes greater in the vertical component than in the horizontal ones. To determine the Sfast polarization direction, we utilized both polarigrams and hodograms, after filtering the initial recordings to the 1 -20 Hz band. Horizontal components were then rotated according to the Sfast polarization direction and td was defined by temporally shifting the waveforms to match the arrivals of Sfast and Sslow. Results for DION indicate a mean anisotropy direction of N113°E, in agreement with the regional maximum horizontal stress inferred from the focal mechanism of the mainshock, indicating the existence of fluid-filled microcracks controlling the anisotropy in the upper crust. PTL exhibited a similar mean anisotropy direction of N82°E. Nevertheless, PTL is characterized by a much smaller mean td (23 ms) compared to DION (87 ms). Given that both stations are in close proximity, these observations point to a complex interpretation model to

properly explain the differences. Further investigation would require the installation of additional stations.

Acknowledgements: We acknowledge support of this study by the project “HELPOS - Hellenic Plate Observing System” (MIS 5002697) which is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

ESC2018-S10-239

MASSIVE SHEAR-WAVE SPLITTING MEASUREMENTS TOWARDS AN UPPER CRUST SEISMIC ANISOTROPY STUDY IN THE WESTERN GULF OF CORINTH (GREECE)

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The Gulf of Corinth (GoC) is a highly active neotectonic structure located in Central Greece. The majority of the seismicity is located in the Western part (WGoC). A two–year seismic anisotropy study (from 2013 to 2014) is presented, yielding more than 2,100 measurements of shear-wave splitting parameters, i.e. the fast shear-wave polarization direction, the time – delay (td) between the fast (Sfast) and slow (Sslow) components, as well as the source polarization direction. The WGoC is monitored by two dense seismological networks; the Hellenic Unified Seismological Network (HUSN) and the Corinth Rift Laboratory Network (CRLN). Strict selection criteria were applied to the initial dataset. Each event – station pair must be located within the shear-wave window (i.e. angle of incidence smaller than 45°). In addition, converted and scattered phases were avoided by rejecting recordings with greater shear-wave amplitudes in the vertical component. We employed the visual inspection of polarigrams and hodograms to analyze waveforms from local events and determine the splitting parameters. The obtained results for all stations, both surficial and two borehole (ALIK and MALA), are presented individually using rose diagrams and equal-area projections. The predominant Sfast direction, for most stations, is aligned with the maximum horizontal compressive stress component (i.e. WNW – ESE) in the area. Considering that this direction seems to be independent of the event’s azimuth, the source of anisotropy is interpreted according to the Anisotropic Poro-Elasticity (APE) model, where fluid saturated microcracks control the splitting of shear-waves. For PYRG and SERG stations, presenting NE-SW anisotropy direction, the influence of microcracks aligned according to local active faults, is proposed. The wide variability of results in the DSF station may be explained by the possible existence of two anisotropic layers with different properties. Temporal variations of normalized time-delays (tn) are thoroughly studied. The tn increase and drop is considered to be an indicator of stress changes in the propagation medium and is associated, in the present study, with the occurrence of significant events in the WGoC. Acknowledgements: The present study is co-funded by the Special Account for Research Grants of the National and Kapodistrian University of Athens.

ESC2018-S10-250

IMPLICATIONS FOR MANTLE FLOW BENEATH GREECE FROM SKS AND PKS SHEAR-WAVE SPLITTING ANALYSIS

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Shear-wave splitting, being an undoubted indicator of seismic anisotropy, allows the investigation of mantle dynamics to a great extent. The thorough examination and detailed interpretation of the orientation of the fast quasi-S phase and the time-delay between the fast and slow components (dt), determined by the analysis of PKS and SKS phases, is a key factor in order to correlate seismic anisotropy with the geodynamic framework. The main purpose of the present study is the enrichment of the already existing shear-wave splitting measurements database for the Greek region, regarding the upper mantle. It is worth noting that it is the first time that PKS phases are utilized in the framework of a seismic anisotropy study in Greece. Shear-wave splitting parameters (fast quasi-S phase orientation and dt) were determined in the Greek territory using

teleseismic events recorded by stations of the Hellenic Unified Seismological Network (HUSN) between 2010 and 2017. The selected event-station pairs have epicentral distances in the range of 90°- 130° for the SKS and 120°- 180° for the PKS phases, respectively. In addition, all events have moment magnitudes Mw greater than or equal to 6. More than 800 high-quality splitting measurements have been acquired by analyzing more than 17.000 records of SKS and PKS phases. Processing of seismic data was performed using the rotation-correlation, eigenvalue and minimum energy methods. The measurements determined by the minimum energy method provided more reliable results. Mean anisotropy directions in most stations are in good agreement with the plate motion directions, deduced by GPS studies, possibly related to coupling of the crustal and upper mantle deformation. In addition, exclusively null measurements were also determined in certain regions, such as Kozani (NW Greece), implying complex behavior of the propagating medium in the vicinity of the recording station. Acknowledgements: We acknowledge support of this study by the project “HELPOS - Hellenic Plate Observing System” (MIS 5002697) which is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

ESC2018-S10-312

COMPLEX LABORATORY STUDY OF ROCK ELASTIC ANISOTROPY

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We present a combined study of a classical rock sample from Val Malenco, Italy, by investigating the microstructure and texture with state-of-the art synchrotron X-ray, neutron diffraction methods and measuring ultrasonic velocities both with a multi anvil apparatus and a novel instrument to measure P and S velocities on spheres. Petrological properties were studied by thin section analysis. Both, synchrotron and neutron diffraction data were analyzed for preferred orientation with the Rietveld method. The program MAUD was used for texture analysis. Velocity measurements were done by classical measurements of P- and S-wave velocities using the pulse transmission technique at room temperature and pressures up to 600 MPa with a triaxial apparatus. There was also measured 3D velocity distribution of spherical samples by P- and S-wave ultrasonic sounding. Determination of P, S1 (fast) and S2 (slow) wave velocities enables to calculate a full stiffness tensor. The crack distribution from non-linear approximation of P-wave measurements on sphere was determined. From quantitative texture measurements, elastic properties are modelled by self-consistent averaging. Comparison of experimental and model Cij parameters is done based on microstructures. Both, results from diffraction methods and velocity measurements are compared. Good agreement between the velocity and microstructural models is observed.

ESC2018-S10-333

CRUSTAL THICKNESS AND ANISOTROPY INFERRED FROM A MULTIPLE PHASE SPLITTING ANALYSIS OF RECEIVER FUNCTIONS - A TOOL FOR TEMPORARY SEISMIC STATIONS

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Previously proposed methods to infer crustal anisotropy from receiver functions require a more-or-less complete azimuthal coverage of the teleseismic events, as they are based on periodical variations of amplitudes and arrival times of the crustal Ps-phases (e.g., Rümpker et al., 2014). In temporary deployments of seismic stations, the necessary azimuthal coverage, often, cannot be acquired. Our new approach is based on an extension of the well-known H-κ-stacking algorithm of Zhu and Kanamori (2000) to anisotropic media. In the inversion we use the polarizations and arrival times of the two crustal Psand PpPs-phases to simultaneously constrain the thickness of the crust, H, the average P to S velocity ratio, κ, the fast-axis orientation of the crust, ϕ, and the percentage of anisotropy, a. The calculations are based on solving the eigenvalue

problem of the anisotropic system matrix defined by Woodhouse (1974). In the algorithm we first rotate the receiver functions into the polarization directions of the fast and slow crustal phases using variable (trial) fast-axis orientations. We then correct for the time shift between the fast and slow phases. If the anisotropy is chosen correctly, the transverse energy is minimized when rotating back to the radial/transverse coordinate system maximizing the radial energy at the same time. Therefore in the stacking procedure we sum up the radial minus the (absolute) transverse amplitudes of the corrected receiver functions by systematically varying the corresponding parameters for simple models of the crust. The maximum of the stacking function is obtained for the model parameters (H,κ,ϕ,a), that best explain the observed receiver functions. We apply the method to synthetic waveforms as well as to data from the Swiss seismic network and test for different (limited) event distributions. We show that it is possible to obtain all parameters from one receiver function only, if the backazimuth of the event is different from the fast or slow axis direction (thus excluding "null" measurements).

ESC2018-S10-370

OBSERVATIONS OF SKS SPLITTING BENEATH THE NORTHERN EXTERNAL DINARIDES

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The area of study is located in the broad Africa-Eurasia convergent plate boundary zone and it covers Northern Croatian Littoral, including its hinterland, where tectonics are characterized by complex interaction between the Adriatic microplate and the Dinarides. Number of global and regional tomographic studies indicate apparent slab-gap in the northern and possibly central parts of the Dinarides (especially at the upper mantle depth), probably due to a recent slab break-off. However, tomographic results are far from unique and the mantle structural models in this region are less certain than they are in the surrounding areas. In order to provide more data needed to help resolve the ambiguities, we estimate seismic anisotropy from observations of SKS splitting. Here we present the results of SKS splitting analysis performed on the available data recorded on broadband seismological stations in the studied area (permanent stations operated by Croatian Seismological Survey and temporary stations recently installed within the VELEBIT multidisciplinary research project financed by the Croatian Science Foundation (IP-09-2014)). Since it is the first SKS splitting study of anisotropic properties for this studied area, these new results should provide constrains for modelling geodynamical processes occurring in the region. Moreover, this results together with the SKS splitting results in the surrounding areas (in the Central and Southern External Dinarides, the Alps and the Apennines) will support the mapping of the seismic deformation pattern and enhance understanding of Earth's crust and upper mantle structure.

ESC2018-S10-430

EXPERIMENTAL AND THEORETICAL STUDY OF THE SEISMIC ANISOTROPY OF BIOTITE GNEISS ROCKS

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We present the results of experimental and theoretical investigations on highly anisotropic sample of plagioclase-biotite gneiss with structure of compositional layering and biotite gneiss sample of weak anisotropy. Two acoustic methods are used for measuring seismic anisotropy: measurements of P-wave ray velocities on a sphere and comprehensive measurements of P- and S-wave phase velocities on a cube under different confining pressures. The complete 3D P-wave distributions at confining pressures ranging from 0.1 to
400 MPa were measured at the Institute of Geology AS CR (Prague, Czech Republic). The geometry of the
piston–sample arrangement in the multianvil pressure apparatus of the Institute of Earth Sciences at Kiel
allows simultaneous measurements of compressional and two orthogonally polarized shear wave velocities in

the three perpendicular directions of a sample cube at pressure (up to 600 MPa). The combination of P-wave
velocity spatial distribution with S-wave velocities in three orthogonal directions was used to calculate the bulk elastic moduli of anisotropic rock samples. The crystallographic textures of biotite gneisses were obtained using neutron diffraction. Crystallographic preferred orientations (CPO's) of major rock-forming minerals (biotite, muscovite, plagioclase and quartz) were measured at the neutron texture diffractometer SKAT at the pulsed reactor IBR-2 in Dubna, Russia. On the basis of texture data the theoretical modeling of elastic properties was performed using different averaging methods and theories of effective properties of microheterogeneous media. In this work, for the first time the authors implemented a nonlinear approximation of the P-wave velocity pressure relation for estimation of mineral matrix properties and orientation distribution of microcracks. From the theoretical modeling, it was found that the bulk elastic anisotropy of the sample is caused by the preferred orientations of micas grains and microcracks. On the example of studied samples it is shown the importance of determining the elastic properties of the mineral skeleton in solving problems of crack-porous space in rocks on the basis of seismo acoustic methods and theoretical modeling.

ESC2018-S10-593

EUROPEAN-ADRIATIC PLATE COLLISION IMAGED BY SEISMIC ANISOTROPY

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Convergent movements of the European and African plates, closing several microplates in between, formed the Alps and several neighbouring mountain belts – the Carpathians, Apennines and Dinarides in the south. To the west and north, the large Variscan massifs – the French Massif Central and Bohemian Massif – adjoin the Alps. Besides high-velocity tomography images of the subducted lithospheric plates in the collisional zone, analyses of seismic anisotropy represent a powerful tool to improve our understanding of the orogenic process and mantle dynamics of the region. We present a detailed seismic anisotropy study of the mantle lithosphere along a broad north-south transect crossing the East-Alpine root and the adjacent Bohemian Massif based on body-wave data from the AlpArray-EASI complementary experiment (2014-2015) and nearby permanent stations. Relief of the European and Adriatic plates as well as a change of mantle lithosphere fabrics, modelled in 3D, supports the northward, down to 200-250km depth dip of the Adria. The fabrics exhibit distinct regional variations, implying complex domain-like architecture of the south-central part of the European plate, particularly in the Alps and their surroundings. Ongoing cooperative studies focusing on the 3D mantle fabrics, with the use of the AlpArray Seismic Network data, will substantially improve our knowledge of the structure and tectonic development of the complex Alpine region and its surroundings.

ESC2018-S10-594

FROM 3-D OBSERVATIONS OF SEISMIC ANISOTROPY OF MANTLE LITHOSPHERE TOWARDS BETTER UNDERSTANDING OF CONTINENTS FORMATION

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How the first continents formed belongs to fundamental questions regarding the evolution of the Earth. Role of the mantle lithosphere that forms the biggest volume of continents is often overlooked due to its difficulty to image and uncertainty in its rheology. Seismic anisotropy investigated in 3D provides a unique constraint on tectonic fabrics and character of past and present deformations of the continental lithosphere. We examine seismic anisotropy of Archean, Proterozoic and Phanerozoic provinces of Europe and model fabrics of the mantle lithosphere by inverting jointly P-wave travel-time deviations and shear-wave splitting parameters from teleseismic recordings of portable and permanent stations. Changes in orientation of the large-scale anisotropy, caused mainly by systematic preferred

orientation of olivine, identify boundaries of domains of mantle lithosphere. Individual domains are characterized by a consistent large-scale orientation of anisotropy approximated by hexagonal symmetry with generally inclined symmetry axes (inclined foliation and/or lineation). Model of systematically dipping mantle fabrics, supported by other seismological findings, suggests that the continental lithosphere could be built from successive subductions of plates of ancient oceanic lithosphere. Field observations and laboratory experiments indicate the oceanic olivine fabric should be preserved in the subducting lithosphere to a depth of at least 200-300 km. We thus interpret the dipping anisotropic fabrics in domains of the European mantle lithosphere as systems of "frozen" paleosubductions.

ESC2018-S10-619

PRELIMINARY SEISMIC ANISOTROPY RESULTS FROM "CENTRAL ADRIATIC SEISMIC EXPERIMENT" (CASE) PROJECT: A DEPTH WINDOW BETWEEN APENNINIC AND DINARIC SLABS

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In the framework of the AlpArray project (AlpArray Seismic Network, 2015), the complementary "Central Adriatic Seismic Experiment" (CASE; AlpArray Seismic Network, 2016) was established as collaboration between ETH Zürich, University of Zagreb, INGV and Republic Hydrometeorological Service of Republic of Srpska. The CASE project consists of 10 temporary stations, installed in October 2016 (and still working), and located in Bosnia and Herzegovina, Croatia and Italy. Temporary broadband seismic stations, together with the permanent stations present in the region shared by the Croatian Seismological Service, INGV and MedNet networks, make an almost continuous transect cutting the Central-Southern Apennines, the central Adriatic region, External and Internal Dinarides. The presence of the Apenninic and the Dinarides slabs, verging in opposite directions and plunging along the opposite sides of the Adriatic plate, makes this area a peculiar spot to understand the complexities of the region. Various tomographic images (e.g. Bijwaard and Spakman, 2000; Piromallo and Morelli, 2003) do not indicate continuous slabs under the Apennines and the Dinarides, suggesting the presence of slab-gaps right beneath the region covered by the CASE experiment. The preliminary results of SKS splitting analysis performed up to now are summarized in this work. Using the classical shear wave splitting techniques on data recorded by temporary and permanent stations shared in the project, a clear change in anisotropic properties occur moving from Italian to the Dinarides regions. From this preliminary dataset, a clear dependence of the measurements with the back-azimuth of the analysed events seems to be present, confirming the complexity of the deformational mechanisms acted at the upper mantle depth between opposite slabs verging. Even if still preliminary, these results in combination with previous interpretations, could provide clues about the depth connection between Northern and Southern Apennines and could give more information about how the slab rollback of the Apennines and Dinaric thrust belt acted. Together with the measurements from previous studies and from those coming by the AlpArray project, our new data will support the mapping of the seismic anisotropy deformation pattern from the Western Alps to the Pannonian region.

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ESC2018-S10-632

THE INFLUENCE OF NEAR-VERTICAL SK(K)S RAY PATH INCIDENCE ON THE BACKAZIMUTHAL VARIATION OF SHEAR-WAVE SPLITTING PARAMETERS: A CASE STUDY IN THE PACIFIC NORTHWEST

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The occurrence of seismic anisotropy, e.g. the spatial behavior of shear-wave splitting (SWS) parameters (phi, delta t), has been studied widely in various regions. While lattice-preferred orientation (LPO) of upper mantle minerals, such as orthorhombic olivine and orthopyroxene, is known as the main source of SWS in SK(K)S observations, it is still to be determined, to which degree the nature of azimuthal anisotropy is due to frozen-in-deformation in the lithosphere or to recent geodynamic activities in the asthenosphere. In this study, we use the approach by Davis (2003), to address this key problem. A Taylor-series expansion of the angular eigenvector dependence in the Christoffel equation allows analyzing the backazimuthal (baz) variation of phi in the case when the incidence angle of SK(K)S phases is not vertical. phi then has a baz variation of 180° periodicity and a polarity depending on the d1 parameter, which is related to the foliation orientation. We distinguish between olivine having a vertical b-axis (“b-up”), as may be associated with the Simple Asthenospheric Flow (SAF) model, or c-axis (“c-up”) as may be expected for a Vertical Coherent Deformaton (VCD) in the lithosphere. Applying the Mainprice (1990) code, implemented in MSAT, enables us to compare the baz behavior of phi and delta t, obtained from the near-vertical SWS approach, with the results from numerical modeling. Based on the SWS dataset of IRIS DMC (2012) for North America, mostly from USArray stations but also from other networks (Liu et al., 2014), we explain our procedure to select, group and cluster suitable stations. This leads us to an investigation of the Pacific Northwest region. The d1 parameters are calculated from the SWS-baz dependence first. To explain polarity changes, we further compute d1 for upper mantle particles in a geodynamic model of the Cascadia Subduction Zone fabric, generated by an updated version of the D-Rex code of Kaminski et al. (2004). Comparing these findings with the foliation orientation, determined from the modeled fabric, we relate the resolved variation in d1 polarity to changes in the mantle flow field.

ESC2018-S10-828

MANTLE FLOWS IN THE WESTERN ALPINE REGION UNRAVELLED BY SEISMIC ANISOTROPY ANALYSIS AND HIGH-RESOLUTION P WAVE TOMOGRAPHY

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The anisotropy of seismic velocities in the mantle, integrated with high-resolution tomographic models, can be used to detect active mantle flows in complex plate boundary areas. In this work, we use a densely spaced array of temporary broadband seismic stations — CIFALPS — to analyse the seismic anisotropy pattern of the western Alpine region, at the boundary between the Alpine and Apenninic slabs. Our results are supportive of a development of anisotropic mantle fabrics, possibly starting from the Jurassic to present. Geophysical data presented here, together with geologic evidences taken from the literature, indicate that: (i) mantle deformation during Apenninic slab rollback is not compensated by a complete toroidal flow around the northern tip of the retreating slab; (ii) the previously observed continuous trend of anisotropy fast axes near-parallel to the western Alpine arc is confirmed; (iii) fossil fabrics formed during Tethyan rifting may be still preserved within the Alpine and Apenninic slabs. We observe the arc-parallel trend of fast axes is located in correspondence to a low velocity anomaly in the European upper mantle, beneath regions of the

Western and Ligurian Alps with the highest uplift rates. Probably, the progressive rollback of the Apenninic slab, in the absence of a counterclockwise toroidal flow at its northern tip, induced a suction effect at the scale of the supraslab mantle. The resulting mantle flow pattern was characterised by an asthenospheric counterflow at the rear of the unbroken Western Alps slab and around its southern tip, and by an asthenospheric upwelling, mirrored by low P wave velocities, that would have favoured the topographic uplift of the Alpine belt from the Mont Blanc to the Mediterranean sea.

ESC2018-S10-893

EVALUATION OF THE PARAMETERS OF ANISOTROPY OF THE CENTRAL PART OF EAST EUROPEAN CRATON

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Central part of the East-European craton, so called the Russian platform, consists of three different segments –Fennoscandia, Sarmatia and Volgo-Uralia. For this research we use SKS/SKKS data acquired by OBN seismic station and MHV small aperture array, that are located right in between of these blocks, VSR seismic station located closer to the central part of the Sarmatian segment and"Monakovo"temporary small aperture array located on Volgo-Uralia. In addition, we estimate anisotropy for the ARU seismic station near the Ural mountains. We analyze shear wave splitting parameters such as fast direction and lag time working in the assumption of a single layer of anisotropy material. For the given research we obtained data since 2000 year and take events with magnitudes more than 5.5 from different azimuths and epicentral distances more than 80 degrees with isolated SKS/SKKS phases. Working with the dataset we selected events with individual delay time less than 3 seconds that could be seen in tectonic stable regions. Commonly, anisotropy is related to the layers with unusual elastic parameters and higher or lower velocities in the upper mantle. Keeping that in mind, we obtain the velocity structure for each seismic station used for the given research for the depth up to 300 km. We applied receiver function technique that is wide spread for the tasks of the deep velocity structure evaluations. We inverted P and S receiver functions along with the dispersion curves of surface waves to get accurate results. Based on the velocity models we have done numerical modeling to estimate depths of the anisotropic medium in the upper mantle.

This publication is based on work supported by the Russian Foundation for Basic Research (RFBR), project 17-05-01099 and by the program of the presidium of RAS 56.

ESC2018-S10-903

SHEAR WAVE SPLITTING BENEATH THE WESTERN ALPS HIGHLIGHTED BY ANOMALOUSLY DEEP EARTHQUAKES

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The Western Alps formed as a result of the oblique subduction of the European plate under the Adriatic microplate, which started from Late Cretaceous and continued as continental collision between the Adriatic and European plates during the Cenozoic. Albeit the overall structure and geometry of the Alpine belt is well known at different scales and the geometry of the European lithospheres is drawn by local and teleseismic tomography, the structure of the region beneath the Western Alps need to be further investigated. In this work, we explore the seismic anisotropic properties beneath the Western Alps by using, for the first time, the earthquakes that occurred within the lithospheric mantle down to 75 km. We benefit from the catalogue of accurate location of the deep earthquakes recorded since 1990 by several permanent seismic stations operating in the area. We then compare the obtained results to geological and seismological information, such as the high-resolution tomographic images as well as SKS shear wave splitting, to derive a regional tectonic model that takes into account the complex interaction between subducted slab, asthenospheric flow and overriding plate. We applied the classical cross-correlation method to the S wave to obtain the splitting parameters, fast

polarization direction and delay time. The S splitting measurements reveal strong anisotropy into the lithosphere beneath the eastern sector of the Western Alps. Fast directions of deep earthquakes show variable orientation, from E-W to ENE-WSW and NNE-SSW with delay time value ranging between 0.01 sec and 0.3 sec. Comparison of preliminary S splitting results with SKS fast directions and local tomographic images reveals a similarity, suggesting that in this region seismic deformation is probably coherent at different scales.

ESC2018-S10-927

SEISMIC ANISOTROPY OF NORTH ALGERIA FROM SHEAR-WAVE SPLITTING ANALYSIS

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There are only few studies of internal deformation under Northern Africa; here we present such a study. We analyse teleseismic shear-wave splitting for the north part of Algeria, which improves our knowledge of lithospheric and asthenospheric deformation mechanisms in this region. The data are from several broadband (BB) stations that have recently been installed in this part of Algeria. This allows us to study waveform data generated by many tens of teleseismic events that were recorded at seventeen broadband stations. These stations cover thus a large area from the Tellian geological units in the North to the Saharian Atlas units in the South. Analysis of SKS-wave splitting results in signi cant spatial variations in fast polarization orientation, over scale length of 100 km and possibly less. The seismic anisotropy shows three clear spatial patterns observed at the stations. One pattern is a general ENE-WSW orientation observed for the subsurface under the stations in the North. This polarization orientation follows the direction of the Tell Atlas mountain chain, which is perpendicular to the convergence direction between Africa and Eurasia. Delay times vary signifcantly across the region, between 0.6 and 2 sec. At several stations there is an indication of a WNW-ESE polarization orientation, which is apparently related with a later geodynamic evolution phase of this region. A third pattern of seismic anisotropy emerges in the South, with roughly N-S orientation. We discuss the observations in light of geodynamic models and present-day geodetic motion.

ESC2018-S10-993

HOW LIKELY DOES SHEAR WAVE SPLITTING AND MOMENT TENSOR PARAMETERS INTERACT FOR THE "2016 -2018 CENTRAL ITALY SEISMIC SEQUENCE" ?

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The "2016-2018 Central-Italy seismic sequence" is characterized by a Mw 6.0 mainshock that occured close to the towns of Accumoli and Amatrice at 1:36 a.m. (UTC) of August 24th 2016 and it is still ongoing. In 20 months activity, 63905 recorded earthquakes are spatially elongated NW-SE, the aftershocks are mainly concentrated between 2 and 25 km of depth with minimum and maximum magnitude ranging from Mw 0.1 to 6.5, respectively. This study area is characterized by a complex geological and structural setting derived by multi-phased contractional and extensional deformation began in the Early Tertiary. In detail, the epicentral area is located in the central sector of Apennine chain characterized by several NW-SE oriented Quaternary fault systems and compressional fronts. Nowadays stress indicators (such as borehole breakouts, anisotropic parameters, earthquake focal mechanisms and active faults) point out that the axial part of the Apennine belt is characterized by a general extension about NE-SW oriented. Slip data from Amatrice fault structures show that roughly N–S trending leftlateral strike–slip and transtensional/normal faults are all kinematically consistent with the existence of a Late Quaternary. The remote stress field is characterized by a NE–SW-oriented minimum horizontal stress (Shmin, sigma3 or maximum extension) and by a NW–SE trending maximum horizontal stress (SHmax, sigma1 or maximum compression). In this preliminary study we define the possible correlations between shear wave splitting and moment tensor parameters during the "2016-2018 Central-Italy seismic sequence". Shear Wave Splitting phenomenon is described by 2 parameters: fast polarization direction and delay time. Generally, fast component strikes as the orientation of the anisotropic symmetry axes, and delay time measures the anisotropic strength. In

this geo-structural context, for sedimentary rocks, according to the Extensive Dilatancy Anisotropy (EDA) model and its evolution in Anisotropic Poro Elasticity (APE) the local variations of the anisotropic parameters are both time and space dependent. As a consequence the fast direction will be parallel to the SHmax direction and the delay time will measure the intensity and/or thickness of the fracture field. Moreover, SHmax corresponds to sigma1 (thrust and strike-slip faulting regime) or sigma2 (normal faulting regime) and can be related to P, T and B axes orientations of seismic moment tensors. In this assumption, we analyze the spatial variations of local stress-field in term of SHmax which is strictly related to sigma, and fast polarization direction. After computing the parameters above described, we compare them with the stress field and geologic structures of the crust to explain the tectonic processes.

ESC2018-S10-1002

THE POLLINO SEISMIC SEQUENCE: SHEAR WAVE SPLITTING, FRACTURE FIELD AND ACTIVE STRESS

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In the years between 2010 and 2015 in the Apennines-Calabrian arc boundary, in the Pollino massif, a long seismic sequence took place. The area is subject to Northeast- Southwest extension, which results in a complex system of normal faults striking Northwest-Southeast, nearly parallel to the Apenninic mountain range. The seismic sequence includes more than 6000 earthquakes in the Pollino region, the maximum magnitude recorded is Ml=5.0 and it happened in October 25th 2012 after about two years of ongoing activity, the peculiar temporal evolution of the seismic sequence allows to catalogue it as a swarm. Here we describe the main seismological characteristics of this seismic sequence and characterize the fracture field of the region. We analyse thousands of seismograms, deriving anisotropic parameters in the crust. These parameters yield clues and insights that may help understanding the physical mechanisms behind the seismic swarm. Since the late the late ’60s-early ’70s era seismologists started developed theories that included variations of the elastic properties of the Earth crust and the state of stress and its evolution prior to the occurrence of a large earthquake. Among the others the theory of the dilatancy: when a rock is subject to stress, the rock grains are shifted generating micro-cracks, thus the rock itself increases its volume. Inside the fractured rock, fluid saturation and pore pressure play an important role in earthquake nucleation, by modulating the effective stress. Thus, measuring the variations of wave speed and of anisotropic parameter in time can be highly informative on how the stress leading to a major fault failure builds up. We systematically look at seismic-wave propagation properties to possibly reveal short-term variations in the elastic properties of the Earth crust. In active fault areas, tectonic stress variation influences fracture field orientation and fluid migration processes, whose evolution with time can be monitored through the measurement of the anisotropic parameters. Through the study of S waves anisotropy, it is therefore potentially possible to measure the presence, migration and state of the fluid in the rock, thus providing a valuable route to understanding the seismogenic phenomena and their precursors. Shear wave splitting is the clearest evidence of seismic anisotropy; in fact, when a seismic shear wave travels into an anisotropic medium, its energy is split into two components with orthogonal polarization direction that travel at different velocities. The polarization direction of the fastest wave is defined as fast direction and the lag of the slower wave is the delay time. In the crust, preferentially aligned joints or microcracks, layered bedding in sedimentary formations, or highly foliated metamorphic rocks cause anisotropy. To understand how the anisotropic parameters vary, spatially and temporally, we analyzed waveforms recorded at permanent and temporary stations hold by Istituto Nazionale di Geofisica e Vulcanologia. Four stations (MMN, T0721, T0722 and T0723) have the correct position with respect to the hypocenters of the seismicity to evaluate shear wave splitting parameters: the incidence angle of the seismic rays should be smaller than 35°. Three out of these four were installed after the occurrence of the Ml=5.0 event at the end of October 2012; MMN station instead has a very large number of measurement of shear wave splitting for the whole analyzed period (October 2011-March 2013). The prevalent fast direction is coherent with the stress field in the area being

parallel to the NE-SW SHmax but is also parallel to the main fault structure of the area leaving the ambiguity on the possible source of seismic anisotropy. The delay time values are higher in the crust volume to south of T0722 station in the hanging wall of the fault where the Ml=5.0 event was generated.

ESC2018-S10-1079

SHEAR-WAVE SPLITTING IN THE CRUST BY A PORTABLE SEISMIC ARRAY ACROSS HAIYUAN FAULT (SAHY) IN THE EASTERN MARGIN OF TIBETAN PLATEAU

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Tibetan Plateau intensely lifts, related to collision between the Indian plate and the Eurasian plate, draw the attention of Geologists and Geophysicists in the mass-flux style and deformation pattern in the crust and in the upper mantle. Surface movement or deformation could be extracted by geological investigation and GPS measurement. However the information in the interior of the Earth depends on only seismic observation or other geophysical explorations. We set up a portable seismic array SACHY (Seismic Array Across the HaiYuan fault) in the eastern margin of Tibetan Plateau. The SACHY consists of 40 seismic stations, ran up to 22 months. The array was across the Haiyuan fault, where occurred a big earthquake of Magnitude 8.5 in 1920. Having collected seismic records of local earthquakes, this study analyzes shear-wave splitting (SWS) of seismic waves to detect the crustal seismic anisotropy around the Haiyuan fault in the eastern margin of Tibetan Plateau. The SACHY includes the linear arrays about 300km long and the areal array about 60km×10km along the Haiyuan fault. There is a good chance to detect the spatial distribution of SWS parameters around the Haiyuan fault by dense observations. By the SWS analysis, this study obtains SWS parameters in the crust, polarization of fast shear-wave (PF) and time delay of slow shear-wave (TD). The predominant PF orientation to north of fault is nearly perpendicular to the fault strike, consistent to direction of regional principal compressive stress. But the predominant PF orientation to south of the fault is nearly parallel to the fault strike. It seems a clear boundary just along the fault which divides anisotropy into two patterns. It indicates the strong influence of Haiyuan fault. The TD shows spatial distribution seemingly related to the tectonics, however it needs further study. Comparing with tomography (Wang et al. 2018, Xiao et al. 2017), the crustal structure shows the obvious difference at two sides of Haiyuan fault. As a result, we consider that the Haiyuan fault strongly changes crustal physical features, including stress, deformation and velocity [Grateful to the support by NSFC Project 41474032].

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SESSION 11

ESC2018-S11-67

AMBIENT SEISMIC NOISE IMAGE OF THE STRUCTURALLY-CONTROLLED HEAT AND FLUID FEEDER PATHWAY AT CAMPI FLEGREI CALDERA

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Earthquakes at Campi Flegrei have been low-magnitude and sparse for more than thirty years, denying onshore monitoring observations of their usual source for structural constraint: seismic tomography. Here, we used ambient seismic noise recorded between 2011 and 2013 to reconstruct period-dependent Rayleigh-wave velocity maps of caldera-wide structures and volcanic reservoirs. The lowest velocities have been aseismic since 1985 and correspond to a fluid-storage zone that was fractured during the 1983-1984 volcanic unrest. Earthquake locations show that fluids migrate from the reservoir towards the Solfatara and Pisciarelli fumaroles along shallower low-velocity fractures. The Neapolitan Yellow Tuff rim faults bound high-velocity intra-crater domes, a product of historical eruptions, which act as a barrier for deep fluid migrations. The structurally-controlled reservoir is likely the shallowest product of a deep-seated offshore source SE of it, causing bradyseism and heating the caldera. The spatial correlations with regional ongoing dynamics and observations from historical unrests mark the reservoir as the most likely feeder pathway for fluid and magmatic inputs from this source.

ESC2018-S11-85

TIME-DOMAIN MULTI-ARRAY ANALYSIS OF VOLCANO-RELATED SEISMICITY AROUND FOGO AND BRAVA, CAPE VERDE

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The Cape Verde archipelago is believed to originate from a mantle plume beneath an almost stationary tectonic plate. Fogo and Brava are located in the south-western part of the archipelago, about 18 km apart from each other and belong to the younger islands of the Cape Verde. Only Fogo experienced historic eruptions at intervals of about 20-25 years, with the last eruption from November 2014 to February 2015. It is known from several previous studies that most of the seismic activity occurs in the vicinity of Brava. Based on these findings, a possible link of the plumbing system of Fogo to a magmatic source near Brava was proposed. However this could not be confirmed by our more recent studies. Here, we aim to investigate the magmatic system of Fogo and to characterize the seismic activity of the region in greater detail. As the majority of the events are located offshore, we employ multi-array techniques to study the seismic activity. Furthermore, as many volcano-related seismic signals lack a clear onset of phases, array methods may be better suited for their localization. In January 2017 we installed three seismic arrays on the islands - two on Fogo and one on Brava. Each array consisted of 3 broad-band and 7 short-period stations distributed over a circular shaped area with an aperture of approximately 700 m. The arrays were complemented by seven single short-period stations, five on Fogo and two on Brava. The complete network of 37 stations was in operation until January 2018. To locate earthquakes, we perform the array analysis in the time-domain. While computationally more expensive than traditional f-k analysis, the time-domain approach allows for more flexibility regarding the selection of relevant time windows to calculate the beam energy. Traces are first shifted and then cut to select suitable time windows for the energy stack as function of horizontal slowness. For a single array, epicentral distances can be estimated from arrival-time differences between S- and P-waves, by assuming a suitable velocity structure. However, with two or more arrays, earthquake epicenters can be obtained directly from the intersecting beams. In addition, using S-P arrival-time differences, depth estimates are also possible. As the three intersecting beams, generally, lead to three different solutions, we determine the epicenter by combining individual probability functions for the arrays. These are derived from the energy stack and its variation as function of slowness (backazimuth) close to the maximum. The technique can be applied to earthquakes as well as to volcanic signals lacking a clear onset of P- and S-phases, e.g. hybrid events. We test our approach by comparison with results

from a classical earthquake localization applied to events located between Fogo and Brava and using the 7 single stations of the network.

ESC2018-S11-87

GEODYNAMICS OF THE INTRAPLATE VOLCANOES IN THE EAST ASIA

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Earthquakes and volcanoes are important aspects of mantle dynamics. Many intraplate volcanoes exist in the East Asia, such as the Wudalianchi, Jingbo, Changbai, Sikhote-Alin, Ulreung, etc. Global tomographic studies have revealed the largescale mantle structure under the East Asia and provide important insights into the origin of the active volcanoes in these areas. A continuous high-velocity anomaly is clearly visible in the lower portion of the mantle transition zone, and deep earthquakes occurred within the high-velocity zone in the depth range of 480-600 km. The high-velocity zone is proposed to represent the stagnant Pacific slab in the transition zone. Deep stagnation and dehydration of the subducted Pacific slab in the mantle transition zone might result in wet upper mantle, and the lowering of density of the transition zone minerals by water is likely to trigger wet plumes at the top of a stagnant slab. The active volcanoes in East Asia are thus suggested to be caused by wet plumes induced by water related to the stagnant slab. Age and thermal state of a slab plays an important role on the water transport capacity of slab. It is usually thought that young and hot slabs can carry little water into the deep mantle, while old and cold slabs may transport significant amounts of water into the deep mantle. In order to better understand the transportation of water and its implications for intraplate volcano and deep earthquakes, a thermochemical mantle convection model is constructed to simulate numerically the thermal evolution of slab and the transportation of water in the process of slab downgoing, flattening and stagnation. Model results indicate the water transport behavior depends greatly on the viscosity contrast between the hydrous layer above slab and the surrounding mantle. Since warming of slab by surrounding mantle is rather slow, the effective viscosity of slab can be much large due to low temperature. Water could be successfully dragged into the transition zone if the reference viscosity of the hydrous layer (with initial water of 2 wt%) is higher than 1017 Pa s and that of mantle is 1021 Pa s. Wet plumes could then originate in the flat-lying part of the slab, relatively far from the trench. Wet plume from the flattening Pacific Plate arrives at the lithospheric base and induces melting, which can explain the intraplate Cenozoic volcanoes in the East Asia.

ESC2018-S11-101

UNREST AT MASAYA AND MOMOTOMBO VOLCANO, NICARAGUA, INVESTIGATED WITH A TEMPORARY SEISMIC NETWORK

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Since the end of 2013, the region around the volcanoes Masaya and Momotombo, which includes Nicaraguans capital Managua, has shown an unusually high seismic and volcanic activity. On April 10, 2014, a M6.3 earthquake occurred near Momotombo volcano followed by intense aftershock activity and a migration of seismicity towards Managua. In the following 2 years, the seismic activity remained considerably higher than in the previous network operation time (1975-2013). In December 2015 and January 2016, Momotombo volcano erupted after 110 years of quiescence. Since Mid December 2015, Masaya volcano has a lava lake in its main crater with gradually increasing activity. With 30 broadband stations, we temporarily (Dec16-March17) densified the permanent Nicaraguan seismic network around these volcanoes. With this network, we obtain a first image of the depth of the magma chambers of the volcanoes using ambient seismic noise tomography. A detailed analysis of the present seismicity provides us with a better understanding of the underlying tectonic processes and possible interactions between seismic and volcanic activity.

This work is supported by the government of Nicaragua on behalf of the Instituto Nicaraguense de Estudios Territoriales (INETER). GeoForschungsZentrum/Potsdam (GFZ-Potsdam) provided the 30 mobile seismic broad band

stations from its geophysical instruments pool. The cooperation between SED/ETHZ and INETER is promoted and supported by the Swiss Agency for Development and Cooperation DEZA.

ESC2018-S11-281

LOCATING DRUMBEAT SIGNALS GENERATED AT THE NIRANO MUD VOLCANO, ITALY

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Mud volcanoes are dynamic systems with elevated fluid pressures at depth that only recently started to be investigated with passive seismic methods. We deployed a temporary seismic network composed of 7 stations within the Nirano Mud Volcano (NMV), Italy, which were continuously acquiring for a period of three months. The stations were deployed in vicinity of the mud vents to detect possible seismic signals generated by this shallow active system. Over the night of 17th-18th of March 2016, we temporarily densified the network with 4 additional broadband stations on the edge of the NMV inferred caldera. During the acquisition period we detected, identified and characterized high frequency drumbeat signals. We consider a drumbeat signal as a seismic pulse that occurs rhythmically and constantly through the continuous data. We could distinguish two types of drumbeats: Drumbeat 1 (D1), with a duration of about 50s, a frequency range of about 10-45 Hz and only visible in one station; and Drumbeat 2 (D2), with a duration of 4s, a frequency range of 5-45 Hz, and visible in up to three stations. The amplitude decay observed in D2 suggest a marked attenuation in the area. We determined the source location of D2 using a back-projection method based on the cross-correlation envelope of the drumbeat signal recorded at different station pairs. The location result points out the generating source of this signal on two of the major mud cones. D1 is only visible in a station neighboring a recently appeared mud vent. Both drumbeats are situated at the NE-most part of the NMV. The presence and amplitude of the identified drumbeats is different in each station, depending on the source of the signal and suggesting that the most active part of the system is located nearby the new mud vents. Therefore, we propose that the drumbeat signals are generated by mud and gas gushing at the surface through the conduits and/or changes in pressure in the mud system. Overall, they seem to be related with a shallow source (in the order of tens of meters).

ESC2018-S11-402

THE LOGISTICAL CHALLENGE OF ESTABLISHING A REAL-TIME SEISMIC NETWORK ON HEKLA VOLCANO, ICELAND

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Hekla is one of the most active and dangerous volcanoes in Iceland. It is seismically surprisingly quiet, resulting so far in a short pre-eruption warning time of only around one hour. The last eruptions occurred in 1947, 1970, 1980, 1991 and 2000. Recent strain and deformation measurements and increasing seismic activity suggest that the next eruption is overdue. A temporary seismic network deployed by us on Hekla in 2012 recorded unexpected micro-seismicity. However the stations in that deployment did not transmit data in real-time. The HERSK project (HEkla Real-time Seimic networK) presented here involves the installation of six broadband seismometers directly on top of Hekla with real-time data connectivity. This will lower the detection threshold of seismic events significantly. The result will be a better scientific understanding of the processes driving the evolution of pre-eruptive seismicity at Hekla and a substantial improvement in early warning times. The transmission of real-time seismic data from the top of Hekla is a logistical challenge not yet achieved due to harsh winter conditions. We describe how we address this challenge using specialized wind generator installations and the transmission of power and data over up to 1km long cables. By accepting to sacrifice the installed

equipment should an eruption occur we create the possibility of observing a fissure eruption close up. This would contribute to a better understanding of how such eruptions initiate in detail.

ESC2018-S11-444

MONITORING NYIRAGONGO'S LAVA LAKE ACTIVITY (D.R. CONGO) USING SEISMIC, INFRASOUND AND SAR MEASUREMENTS

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Nyiragongo volcano, in North Kivu (D.R. Congo) is among the most active volcanoes in Africa and on Earth, with the presence of a persistent lava lake from at least 1928 to 1977 and since 2002. After its drainage during the last eruption in 2002, the crater filled up on ~400 m thickness until 2008 and resumed rising in 2016. The persistent lava lake at Nyiragongo gives a unique opportunity to study the dynamics of the upper magmatic system of the volcano over long time scales. Its monitoring also offers a chance to detect pressure change in the magmatic activity. A continuous background, shallow tremor source has been identified since the deployment of a local seismic network (October 2015) and has been related to short-term cyclic meter-scale variations attributed to gas-piston activity. Since late 2016, the increased number of highly similar, discrete long-period events accompanies several decameter-scale level rises or falls, which convey major pressure changes in the upper magmatic system. The source region of this cluster at shallow depth is confirmed by the observation of associated infrasound transients. Additionally, high-resolution satellite SAR images allow to infer the lava lake level fluctuations by measuring the length of the SAR shadow casted by the edge of the bottom of crater on the lava lake surface. Up to 70 estimations of the lava lake level are obtained with this technique between August 2016 and November 2017. These isolated measurements allow to constrain continuous co-located infrasound and seismic observations at the closest station (~6km to the crater). We show here that slight changes in the spectral properties of the seismo-acoustic signals are related to successive drop and increase of the lava lake level, thus highlighting the potential to monitor continuously Nyiragongo's lava lake activity at several kilometers away to the crater using a single station with infrasound and seismic records.

ESC2018-S11-445

THE BROADBAND SEISMIC NETWORK KIVUSNET IN THE VIRUNGA VOLCANIC PROVINCE (DEMOCRATIC REPUBLIC OF THE CONGO): SEISMICITY CATALOGUES AND FUNDAMENTAL SEISMOLOGICAL MODELS AFTER MORE THAN 2 YEARS OF CONTINUOUS OPERATION

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Over the course of the past 5 years, the first dense real-time telemetered broadband seismic network in the Kivu Rift region (KivuSNet) was gradually deployed in the frame of several Belgo-Luxembourgish research projects (the most recent one being RESIST: "Remote Sensing and In Situ Tracking of geohazards", funded by the Belgian Science Policy and Luxembourg National Research Fund). The Kivu Rift is located in the bordering region of the Democratic Republic of Congo and Rwanda, in the Western branch of the East African Rift. Here the active volcanoes Nyamulagira and Nyiragongo threaten the city of Goma and neighbouring agglomerations. For many years already, urbanisation in that region undergoes sustained rapid growth, and the region counts 1 million inhabitants today. In 1977 and 2002, eruptions of Nyiragongo caused major disasters. Destructive earthquakes can also affect the region, as was the case in 2002 in Kalehe (Mw 6.2) along the western shore of Lake Kivu, or in 2008 in Bukavu (Mw 5.9), south of Lake Kivu. While the

first stations were already installed in 2012/2013, KivuSNet is fully operational with a sufficient station coverage only since October 2015. Today, KivuSNet is composed of 17 stations delivering continuous real-time data, many of these installed under difficult conditions in a hostile environment. Many KivuSNet stations are co-located with GNSS KivuGNet stations, and three KivuSNet sites are in addition equipped with infrasound arrays. This contribution will present the lessons learned from these more than 2 years of continuous KivuSNet operation as well as the current status of seismological information as deduced from these data, including a robust 1D seismic velocity model and calibrated local magnitude scale for the Kivu Rift region. The complete seismicity catalogue (volcanic and tectonic events) has been relocated, and a spectral inversion carried out on a subset of the data to characterize source, path and site effects.

ESC2018-S11-543

RESULTS OF VIBRO- AND MICROSEISMIC STUDIES OF DEEP SUBSURFACE STRUCTURE OF MUD VOLCANOES

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The results of multidisciplinary geological and geophysical studies of mud volcanism in the Taman mud-volcanic province are presented. Comparative analysis of results of geophysical data interpretaion on the deep subsurface structure of several mud volcanoes obtained by means of vibroseismic methods on one hand and by microseismic sounding approach with respect to previous studies has demonstrated advantages of the ambient noise seismic prospecting. It has been shown that subvertical pathways of fluid migration and so feeding systems of mud volcanoes represent nearly-ideal case of local geological heterogeneities affecting the amplitudes of low-frequency microseismic noise. The analysis of the results was performed with respect to available geological as well as geomorphological data. On the other hand, active seismic experiments with controlled vibroseismic sources followed by mathematical simulation provides more detail on velocity structure of layered medium and may be also used for theoretical modelling of the processes of hydrodynamic outflow under various mechanisms of mud volcanic eruptions. For several mud volcanoes there were outlined subvertical feeding structures in sedimentary layers and deeper in the crust, responsible for fluid migration and eruptive activity. Specific features of volcanic products (gas components and mineral inclusions in breccia) were analyzed with respect to the new geophysical data obtained.

ESC2018-S11-567

EVALUATION AND REFLECTION OF THE STATE OF VOLCANIC ACTIVITY AND MAGMATIC SUBSTANCE OF THE NORTH GROUP OF KAMCHATKA VOLCANOES BY KINEMATICAL PARAMETER VP/VS

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The dynamics of volcanic activity, the magmatic feeding system, the accumulation and migration of magmas, the structure of the roots of volcanoes are the main problems of volcano research. The Northern Group of Volcanoes (NGV) is the most powerful active group located in the north of Kamchatka and includes such active volcanoes as Klyuchevskoy, Krestovsky, Ushkovsky, Bezemyanniy and Ploskii Tolbachik. In the north, Shiveluch also belongs to this group. Studies of the structure of the Klyuchevskaya group were carried out by various geophysical methods, including the methods of the DSS. The main boundaries in the crust and mantle were obtained. The "inverted wave" method, developed by Slavina, Pivovarova, made it possible to follow the change in velocity over time in depth, to restore velocities in the concentration region of volcanic earthquake foci. Earthquakes occurring in the volcanically active region bear information about the path of magmas moving, the state of matter in the geological environment, reflect the spatio-temporal changes in the environment, and its stress-strain state. Seismic activity at the level of weak regional earthquakes carries information about the activation of a particular area of the volcanic region, the preparation of the eruption. Tracking the travel times of P- and S-waves recorded at stations and the ratio of the velocities of these waves, the parameter Vp/Vs gives

information on the state and composition of matter in the geological medium, on the ways of moving magmas, and on the tectonic structure of the medium, and state of the medium of intermediate and peripheral volcanic foci. This work was carried out with the financial support of the grant of the President of the Russian Federation for the support of scientific schools No. SS 5545.2018.5.

ESC2018-S11-595

FORCING MECHANISMS OF ROCKFALLS IN A VOLCANIC ENVIRONMENT: TEN YEARS OF SEISMIC DATA ON THE PITON DE LA FOURNAISE VOLCANO, LA RéUNION.

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The seismic network of the Piton de la Fournaise volcano (La Réunion Island) is very well appropriate to study seismic signals generated by rockfalls in the Dolomieu crater. In particular, seismic data make it possible to precisely locate the rockfalls and recover the volume of each rockfall. In April 2007, an eruption caused the collapse of the crater floor. We processed ten years of data, from after the collapse to June 2017, ending up with a catalog of precise time, location and volume of rockfalls. These ten years show three different periods, in term of volcanic activity. From April 2007 to December 2010, four eruptions occurred. They are followed by a quiet period, with four years with no eruption. Then, the eruptive activity started again in June 2014, with eight eruptions in three years. It allows us to study three regimes of rockfall activity. First, the activity linked to the rearrangement of the crater slopes following the collapse. Then, the activity during a quiet period, with only climatic excitation. Finally, the activity linked to the recovery of the eruptive activity, on stable slopes. Comparing the spatio-temporal evolution of rockfalls during these three periods enables us to have an insight into the influence of the seismicity and the deformation associated to the eruptive activity on the slope stability. We observe that the slopes respond differently to excitation, depending on their stability. Around eruption times, stable slopes will exhibit a change in rockfall volumes, but not in their frequency, whereas unstable slopes will show a change in both volume and frequency. This study also suggests that pre-eruptive seismicity is the main triggering factor for the largest volumes, with a delay of one to several days. We infer that repetitive vibrations from the many seismic events induce crack (or slip) growth in highly fractured (or granular) materials, leading to the collapse of large volumes. Rain seems to act as a final straw in the slope destabilization.

ESC2018-S11-658

THE PRELIMINARY RESULT OF AUGUST 2017 BAYAN SWARMS IN THE TATUN VOLCANO GROUP AREA

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The Tatun Volcano Group (hereafter called TVG) is located at the northern tip of Taiwan. In recent years, its magma reservoir has been confirmed beneath the Jinshan area close to the TVG, with a depth of approximately 20km. The last eruption was about 6,000 years ago determined by the volcanoclastic deposits and the morphology of lava flows. As a result, volcanic activities are usually in the TVG area, such as hot springs, fumaroles, and several types of small earthquakes. The impact of eruption in the TVG is devastating for Taiwan, because of the location of the TVG is between two major cities, Taipei City and New Taipei City. In particular, the total population of both metropolises is close to 7 million, almost one-third of the population of Taiwan. A local seismic network was established in 2003 in order to monitor the seismic activity of the TVG area. It recorded a variety of events including common volcano-tectonic earthquakes and volcano-seismic signals like tornillos, short duration monochromatic events (10–15 s) and long duration spasmodic bursts (15 min). Over the past few years, the spatial distribution of earthquake epicenter is mainly located in Mt.

Qixing and Dayoukeng area in the TVG. Focal depth is distributed within 5 km, and magnitude (Md) is almost less than 2.0. We also detected some swarms in several small areas, such as Xiaoyoukeng, Dayoukeng, and Bayan area. In this study, the seismic waveform data of several swarms in Bayan area are processed and analyzed by SEISAN - EARTHQUAKE ANALYSIS SOFTWARE. The swarms occur within 3 km but each swarm shows a different pattern of hypocenter distribution. We will not only try to determine the spatial-temporal distribution but also identify the fault plane solution. Further, the shallow structure and the recurrence swarms around the Bayan area will be discussed in detail.

ESC2018-S11-859

TOWARDS A MONITORING NETWORK DEPLOYMENT AT METHANA VOLCANO: AN EFFORT TO MONITOR SEISMICITY, SEISMIC VELOCITY CHANGES AND DEFORMATION.

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An effort to monitor seismicity and deformation across the Methana volcanic complex is under implementation. Our target is to monitor continuously any potential volcanic activity and deformation across the volcano using pilot applications of innovative seismic and geodetic methods. Aim of the project "GEORISK – Developing Infrastructure and Provision of Services through Actions of Excellence to Reduce the Impact of Geodynamic Hazards" is to assess the volcanic risk in the broader area that may affect maritime and air transport, in order to determine preventive measures. Even in the case of volcanic quiescence, seismological and geodetic data, derived from a permanent and temporary infrastructure, will define the level of volcanic status, hence the continuous (background) seismic-volcanic activity. We are deploying a network of permanent broadband seismic stations at the volcano and the neighboring islands. These stations will be incorporated in the Hellenic Unified Seismic Network (HUSN). A complementary dense deployment of temporary seismic stations will cover the entire volcanic complex aiming at the microseismicity monitoring and its association with tectonic or volcanic processes. In recent years, ambient noise interferometry (ANI) methods have been successfully used to detect temporal seismic velocity changes in volcanoes. Travel times between neighboring seismic stations are constantly obtained from their cross-correlation function (CCF) of ambient seismic noise. Moreover, the temporal evolution of each station autocorrelation function (ACF) is interpreted as the source–receiver collocated elastic wave Green's function. Thus, relative velocity changes in the Earth crust are likely to be caused by the change of stress and/or volume within the volcano and are accounted as precursors to volcanic events. The ground motions in the Methana volcanic complex will be also investigated geodetically by means of a non-permanent GNSS network, comprising 5 stations, along with one continuously recording GNSS station. Strict criteria will be set while selecting the location of the stations to ensure stable installations, unobstructed horizon view and avoidance of the multipath effect. An extensive experience on similar studies and network deployments in Santorini, Milos and Nisyros volcanic complexes in the Aegean will assist on the optimal design of seismic and geodetic network able to monitor, in a cost effective way, temporal changes across Methana volcano. We acknowledge support of this abstract by the project "GEORISK – Developing Infrastructure and Provision of Services through Actions of Excellence to Reduce the Impact of Geodynamic Hazards" (MIS 5002541) which is implemented under the "Action for the Strategic Development of Research and Technology Organizations", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

ESC2018-S11-966

SEISMIC EVIDENCE FOR SIGNIFICANT MELT BENEATH THE LONG VALLEY 1 CALDERA, CALIFORNIA

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In the late 1970s, and throughout the 1990s, Long Valley Caldera (California) experienced intense periods of unrest characterized by uplift of the resurgent dome, earthquake swarms, and CO2 emissions around Mammoth Mountain. While modeling of the uplift and gravity changes support the possibility of new magmatic intrusions beneath the caldera, geologic interpretations conclude that the magmatic system underlying the caldera is moribund. Geophysical studies yield diverse versions of a sizable but poorly resolved low-velocity zone at depth (> 6km), yet whether this zone is indicative of a significant volume of crystal mush, smaller isolated pockets of partial melt, or magmatic fluids, is inconclusive. The nature of this low-velocity zone, and the state of volcano's magmatic system, carry important implications for the significance of resurgent-dome inflation and the nature of associated hazards. To better characterize this low-velocity zone we present preliminary results from a 3D full-waveform ambient-noise seismic tomography model derived from the past 25 years of vertical component broadband and short-period seismic data. This new study uses fully numerical solutions of the wave equation to account for the complex wave propagation in a heterogeneous, 3D earth model, including wave interaction with topography. The method ensures that wave propagation is modeled accurately in 3D, enabling the full use of seismic records. By using empirical Green's functions, derived from ambient noise and modeled as Rayleigh surface waves, we are able to extend model resolution to depths beyond the limits of previous local earthquake studies. The model encompasses not only the Long Valley Caldera, but the entire Long Valley Volcanic Region, including Mammoth Mountain and the Mono Crater/Inyo Domes volcanic chain.

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SESSION 12

ESC2018-S12-43

CRYOSEISMIC SIGNALS AND THEIR RELATION TO SURFACE DYNAMICS AROUND THE LüTZOW-HOLM BAY, EAST ANTARCTICA

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"Cryoseismology" is a new branch of inter-disciplinary sciences which treats glacial related seismic events and their dynamics associating the variable phenomenon of the Earth's surface in particular in polar region. Characteristic seismic tremors with harmonic overtones were clearly observed in the Lützow-Holm Bay, East Antarctica during the period in 2014-2015. More than 120 tremors were recognized by both short-period and broadband seismographs at Syowa Station in the Bay during seven months. Many of the remors had characteristics of strong harmonic overtones, in their frequency content over 1 Hz, representing nonlinear features with duration times from few minutes till few hours. The harmonic overtones could be explained by a repetitive source, suggesting existence of several inter-glacial asperities which generate the characteristic tremors. It implies that the tremors might be involved in the local origins, presumably the cryosphere dynamics. In this regard, the cryoseismic origins recorded as the tremors were classified into several categories (i.e., the collision, calving, crevassing, crashing, etc.); the "crevassing events" which are occurring in a line along with large cracks inside the fast sea-ices in the Bay, "discharge events" of the fast sea-ices from the Bay to the Southern Ocean, "collision events" between icebergs and the edge of fast sea-ices, "crashing movement" of fragmentation between the fast sea-ices and packed sea-ices, and other origins rela

ESC2018-S12-57

WHAT DOES AMBIENT SEISMIC NOISE TELL US ABOUT GLACIAL CREVASSING?

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Ambient seismic noise on glaciers is mostly composed of surface waves, which carry information about elastic properties of the ice body through which they pass. Here, we apply this concept to study the ice structure in the uppermost part of a glacier, i.e. the density, depth and orientation of near-surface crevasses. We first analyze data from two temporary seismic arrays of Alpine avalanching glaciers in Switzerland: Bisgletscher, with 5 seismometers (corner frequencies: 1 Hz, array aperture: ~500m, installed for 2 months), and the hanging glacier in the Eiger-Westflanke, with 3 seismometers (corner frequencies: 1 Hz, array aperture: ~30m, installed for 5 months). There exists a prominent influence of near-surface crevasses on the orientation of the seismic wavefield polarization, and specific resonance frequencies depend on crevasse depths. In a designated experiment on a small lake-calving glacier near Klausenpass, Switzerland, we apply our results using seismometers operational for a few hours at increasing distances from the calving front. Additionally, we install a reference seismometer on rock for the duration of our field work. We analyze this dataset with two methods established in seismic site characterization: site-to-reference spectral ratios and wavefield polarization analysis. Using independent measurements from the "plumb-line system" (Mottram and Benn, 2009), we assess the accuracy of our seismic crevasse-depth measurement method. Our method aims to monitor glacial crevasses as they grow and become deeper before calving events. Such a monitoring tool would not only improve calving models, but also prove useful for hazard assessment of avalanching glaciers.

Mottram, R. H., & Benn, D. I. (2009). Testing crevasse-depth models: a field study at Breiðamerkurjökull, Iceland. Journal of Glaciology, 55(192), 746–752. https://doi.org/10.3189/002214309789470905

ESC2018-S12-83

MONITORING GLACIER CHANGES WITH DISCRETE SEISMIC ACTIVITY INTERFEROMETRY AND GREEN'S FUNCTION ESTIMATION FROM ICEQUAKE CODA WAVES

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Basal sliding is a fundamental control on ice stream and glacier dynamics that remains poorly

understood or constrained by traditional glaciological measurements (Morlighem et al., 2010; Ritz et al., 2015). In order to justify and incorporate different treatments of deformable subglacial beds, original observations of basal rheologies are needed. To date, measurements of bed properties and sub-/englacial hydrology are deduced from labor-extensive active source geophysics or deep drilling. Using ambient noise to characterize subsurface structures and any changes thereof has revolutionized solid earth seismology. Seismic interferometry techniques have yet to be harnessed to glacial environments. Using high-frequency englacial noise, Preiswerk and Walter (2018) successfully retrieved Green's functions from cross-correlations of on-ice seismic records in several Alpine glaciers. However, given the changing nature of the glacier noise, the estimation of Green's functions is not always possible especially in the presence of moulins and preferred water conduit channels. Here we use discrete icequake activity rather than continuous noise for correlation function computation. Glacier surface crevassing generates hundreds of icequakes per day with dominant 1-100 Hz surface waves. Glacier ice is commonly treated as a weak scattering and homogeneous medium. However, focusing on strongest icequakes, we still observe long-lasting coda waves which exhibit scattered energy. Cross-correlating icequake coda waves between pairs of on-ice seismic stations enable to retrieve accurate and stable Green's functions with symmetrical parts and this independently on the source position, which ensure us that the equipartioned wavefield condition has been reached. From Green's functions it is then possible to access the glacier subsurface and monitor any change thereof, with minimum efforts based on glacier naturally occurring seismicity records from only two seismic stations deployed on the ice for several hours to days.

ESC2018-S12-132

NON-TECTONIC TREMORS IN GREENLAND

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Greenland is the origin of a wealth of seismic signals. More than a thousand small to moderate magnitude tectonic earthquakes, most of them ranging between ML 1.0 and 3.0 are located along the coasts of Greenland every year. This is largely possible thanks to the data collected and distributed by the Greenland Ice Sheet Monitoring Network (GLISN) federation and its members (glisn.info). The data are routine processed for tectonic events on a daily basis at GEUS. In addition to the regular earthquakes, a class of non-tectonic signals have become apparent. The signals are emergent in nature, and many of them lack both clear P- and S-onsets. The S-energy dominates and the duration of the signals can be up to a few minutes. ML measured on the wave train, typically yield values ranging from 1.0 to 3.0, similar to the local tectonic events. For the larger tremors the frequencies peak in the 1-5 Hz range, the smaller tremors are more pronounced at slightly higher frequencies. The GLISN seismographs are located several hundred kilometers apart and constitute a regional network. Fortunately, the geology and noise conditions in Greenland are very favorably for seismographs, allowing the signals from the slow tremors to be registered 5-600 km away. Lacking a dense seismograph network and clear onsets, the events are hard to locate precisely, but using the trained eye strategy it is possible to build consistent solutions. The origin of the events is in many cases close to major glaciers and ice streams, especially the Jakobshavn Isbrae in west Greenland. The tremors show similar characteristics as glacier-related earthquakes in other parts of the world. Some of the emergent events are located away from large glaciers and the cause is of now unknown. This presentation will give an overview of the current state of analysis of the non-tectonic tremors in Greenland.

ESC2018-S12-160

DEEP VELOCITY SRTUCTURE OF THE ARCTIC REGION FROM SURFACE WAVE DATA

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We study deep velocity structure of the poorly investigated Arctic region (>60° N) on the basis of surface wave data. A representative dataset of Rayleigh (1555 seismic paths) and Love (1265 seismic paths) wave group velocity dispersion curves in the period range from 10 to 250 s was

collected using a frequency-time analysis procedure. A 2D tomography technique developed for spherical surface without the sphere-to-plane transformation was implemented to image the distributions of the group velocities at different periods. Totally, we calculated 18 maps for each wave type and estimated their lateral resolution. Then, we constructed local dispersion curves of Rayleigh waves and inverted them to SV-wave velocity sections up to the depth of 500 km. The obtained SV-wave velocity model of the upper mantle was imaged in the form of horizontal distributions of velocity variations at different depths and 2D velocity sections along the profiles crossing the main tectonic units of the study area. Our results show some general trends in distribution of large-scale lateral inhomogeneities which appear as zones of high velocity gradients at the boundaries of tectonic units and local velocity minimums and maximums. The highest group and SV-wave velocities (variations up to +5%) are observed under the Canadian and Baltic Shields. The Siberian and East European Platforms are also characterized by high velocities (+1…+3%). The lowest velocities (variations up to –10%) are observed under the fold belts at the north-east of Eurasia and Alaska and under the Bering Sea basin. We found evidences of the mantle plumes under Iceland and Jan Mayen Islands represented by velocity minimums. The spreading Gakkel Ridge is manifested as low velocity zone which widens at the Laptev Sea shelf. Thus, the revealed velocity anomalies are correlated with the positions of the main tectonic structures of the study area. The results obtained are of great value for further development of reliable geodynamical models of the Arctic region. This work was supported by the grant of the Russian Science Foundation, project No 17–77–10037.

ESC2018-S12-161

EARTHQUAKE FOCAL MECANISMS AND STRESS REGIMES OF THE CRUST IN THE EASTERN SEGMENT OF THE ARCTIC-ASIAN SEISMIC BELT

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To trace the changes in dominating stress-strain state of the crust we consider 75 earthquakes with mb > 4.3 occurred in 1990–2017 within the territory (60°–83° N, 105°–165° E) including the spreading Gakkel Ridge, Laptev Sea Shelf, Taimyr Peninsula, Verkhoyansk and Cherskiy Ranges and Moma 'Rift' system. Focal mechanisms, scalar seismic moments, moment magnitudes and hypocentral depths of the seismic events have been calculated from the data on amplitude spectra of surface waves. On the basis of the obtained solutions supplemented with the data from Global CMT catalogue, we have calculated the stress-strain field of the crust throughout the study region. The results of this study sufficiently implement the existing dataset on reliable earthquake source parameters and prove the change of the stress regime of the crust from extension in the Gakkel Ridge and on the Laptev Sea shelf to compression on the continent providing finer spatial details in the transition zones such as Buor-Khaya Bay and the Lena River Delta. On the western (Taymir Peninsula) and eastern (the New Siberian Islands) boundaries of the inferred earlier from seismological data Laptev Sea microplate we observe predominance of compression. The results obtained are of great value to further statistical analysis of modern deformation field of the crust and various geodynamical reconstructions including verification of location of the pole of rotation between the Eurasian and North American lithospheric plates. This work was supported by the grant of the Russian Science Foundation, project No 17–77–10037.

ESC2018-S12-166

DECENNIAL OF THE 21 FEBRUARY 2008, STORFJORDEN EARTHQUAKE: CONTRIBUTIONS TO SVALBARD SEISMOTECTONICS

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On 21 February 2008, an earthquake of M 5.9 occurred in the offshore area of Storfjorden, between Spitsbergen and Edgeøya, Svalbard Archipelago. This main event, that ruptured a previously unknown NE-SW trending fault, initiated a long earthquake series that subsided four years later, to be followed by episodic bursts

of seismicity, concentrated around larger events (M > 4). This still persisting activity pattern delineates a more than 150 km long zone, the result of epicenter migration already during the first 2 years of the original aftershock sequence. In March 2016, a new focus of activity emerged at the NE of the 2008-2012 seismicity volume, with a M 5.3 mainshock near the western shore of Edgeøya and its short-lived aftershock sequence. Although resolution for a detailed seismotectonic analysis is lacking, these 10 years of seismic activity have offered us unprecedented insight into the neotectonics of Svalbard. We will present newly derived knowledge along the following main topics: i. Epicenter distributions and focal mechanism solutions have disproven the idea that tectonic seismicity on Spitsbergen mainly occurs along major Paleozoic, N-S fault zones. Seen jointly with the emergence of previously unmapped, active structures they provide significant input for a reappraisal of seismic hazard in the region. ii. The activity in Storfjorden laid additionally the foundation for an enhanced assessment of background levels of tectonic seismicity in the Archipelago. Until 2008, related knowledge was based on the recordings of a very sparse permanent network, as well as temporary, local-scale deployments of seismic stations that achieved resolution for limited source regions over short intervals. The long observation interval gave us the possibility to evaluate the performance of the network in time and derive conclusions on the fidelity of past observations. iii. Finally, the occurrence of moderate magnitude events associated with the series led to the availability of double-couple solutions obtained through moment tensor inversion that were included in the latest update of the World Stress Map. Results describe a regional stress field that is greatly affected by the nearest spreading plate boundary, and not a typical stable continental region setting.

ESC2018-S12-240

STUDYING AND QUANTIFYING GLACIER DYNAMICS IN SVALBARD USING CRYO-SEISMOLOGY

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Cryo-seismology has become a popular tool to study glacier dynamics on different spatial scales. We employed seismic records of glacier seismicity in Svalbard from the past two decades to study and quantify different glacier processes such as calving, surging, and local ice dynamics. Global glaciers and ice caps lose mass through calving, while existing models are currently not equipped to realistically predict dynamic ice loss. This is mainly because long-term continuous calving records with high temporal resolution do not exist. Combined passive seismic/hydro-acoustic monitoring is the only method able to capture rapid calving events continuously, independent of daylight or meteorological conditions. We have produced such a continuous calving record for Kronebreen, a tidewater glacier in Svalbard, using data from permanent seismic stations between 2001 and 2017. We used this record calibrated with glacier frontal ablation independently measured from satellite images to quantify ice loss directly from seismic data. We derived a statistical model that allows to model frontal ablation from the cumulative duration of seismic calving signals and an indicator of the completeness of the seismic record. This allowed to estimate a time series of ice loss more than one decade back in time with weekly resolution. To improve our models, we incorporated more precise, high-resolution measurements of calving volumes from terrestrial laser scanning and time-lapse camera images and related them to seismic and underwater-acoustic signal properties of individual calving events. This allowed to estimate the dynamic ice loss component at the calving front in addition to the total frontal ablation which also includes frontal melting. Frontal ablation and dynamic ice loss estimated form seismic calving observations can be analyzed jointly to improve our understanding of the processes at the glacier terminus. On a local scale, we also studied glacier seismicity generated by other processes than calving such as crevassing and glacier sliding. We identified different classes of seismic signals recorded on an on-ice instrument and implemented detection methods for each class. Furthermore, we used ambient seismic noise to

invert a sub-surface velocity model for the glacier using the Horizontal-to-Vertical Spectral Ratio method. Interpretation of the temporal event distribution and modeling of synthetic seismograms based on the inverted 1D velocity model allowed us to relate the event classes to different glacier processes, a first step towards an improved understanding of local ice dynamics.

ESC2018-S12-268

EARTHQUAKE MONITORING IN THE ARCTIC REGION - THE SEISMOLOGICAL COMPONENT OF INTAROS

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By DEC 1st 2016 the five year INTAROS project was launched with Horizon 2020 funding from the European Commission. The overall objective of INTAROS is to develop an integrated Arctic Observation System (iAOS) by extending, improving and unifying existing systems in the different regions of the Arctic. INTAROS will have a strong multidisciplinary focus, with tools for integration of data from atmosphere, ocean, cryosphere and
terrestrial sciences, provided by institutions in Europe, North America and Asia. Here we present the status of the ongoing work to map the data completeness of the earthquake monitoring in the Arctic region. The work include estimated earthquake magnitude detection threshold for different time intervals and modelling of ways to improve detection threshold. This seismological component of INTAROS is based on existing earthquake catalogues for the Arctic, and it provides knowledge on which areas that are poorly monitored. This knowledge is key for the next seismological component of INTAROS to perform a yearlong deployment of broadband OBS'es in the Arctic using ROV technology. The aim using OBS'es is to show how to fill the earthquake/seismic monitoring gap in the Arctic region. We will give an overall presentation of INTAROS and outline the status of the seismological contributions.

ESC2018-S12-286

SEISMICITY OF THE CANADIAN ARCTIC: ADVANCES IN SOURCE CHARACTERIZATION AND THE POSSIBLE RELATION BETWEEN EARTHQUAKES AND GLACIAL ISOSTATIC ADJUSTMENT

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Although several of Canada's active seismic zones, among them Baffin Bay and Island, Boothia-Ungava, and the Queen Elizabeth Islands, lie within the Arctic regions considerably less is known about earthquakes in the Arctic in comparison to those occurring in southern Canada. Poor knowledge about pre-instrumental earthquakes stems from a low population density combined with a lack of a long-term written history. The instrumental era led to a slowly improving knowledge of Arctic seismicity. There were no seismograph stations in the Canadian Arctic until the 1950s although larger events from the 1930s onward were recorded at distant stations. Although the number of northern stations has increased, the Canadian National Seismograph Network is still relatively sparse in the north because of difficult access and lack of infrastructure stemming from the remoteness of much of the region and the low population density. For example, the territory of Nunavut covers more than two million square km but has a population of less than 40 000. Nevertheless, as instrumentation improves and analysis techniques advance, our understanding of northern earthquakes has increased. About a decade ago, regional moment tensor inversion was implemented for focal mechanisms determination replacing the first motion analysis that had been used in the past and which rarely resulted in well-constrained solutions for northern earthquakes of less than magnitude 5.0. With this change, focal mechanisms and depths can now be determined for the majority of magnitude 4.0 and greater earthquakes occurring the north allowing for a better characterization of earthquake sources and regional seismotectonics. Both thrust and strike-slip faulting are observed in and around Baffin Bay where earthquake depths are generally less than ~15 km. The Arctic Islands also show a blend of strike-slip and thrust faulting. Depths in excess of 30 km have been determined for some events in the Barrow Strait between Somerset and

Cornwallis islands. The possible connection between glacial isostatic adjustment (GIA) and seismicity in the Canadian Arctic is not a new concept. It has long been known that the overall GIA strain rate is more than adequate to explain the overall seismic strain rate. Recent improvements to GIA models allow for more detailed and regional comparisons of GIA and seismic strain rates with equivocal results. High horizontal compression is observed in Baffin Bay where seismicity is also high, but even higher horizontal strain rates in southern Greenland coincide with an area of very low seismicity. Regions of high crustal extension, such as Foxe Basin and southern Hudson Bay, have very low seismicity rates. Further investigation into the correlation between GIA and seismicity is needed. Modeling and comparison of stress rates is considered a key future activity.

ESC2018-S12-289

ON THE USE OF SEISMIC INTERFEROMETRY IN GREENLAND

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Ambient seismic noise methods, also called seismic interferometry, have been around for more than a decade now, but they have not run out of applications yet. Both imaging and temporal monitoring of seismic velocities techniques bring invaluable information on the structure and dynamic of the Earth crust and some environnemental phenomena affecting it. This is particularly true for remote and seismically quiet areas such as Greenland. I will present two studies of the Greenland crust using ambient noise correlation methods. In the first one, I monitored the Greenland ice-sheet seasonal mass variations by measuring the loading-induced pore-pressure variations in the crust as seen through the prism of shear-wave speed temporal fluctuations. We will see that these variations are quite sensitive to the glacier bed properties. In the second study, I used the Rayleigh waves contained in the noise correlations computed between each pair of sensors from the GLISN seismic network to image the crustal and uppermost mantle structures of the Greenland landmass. The shear-wave velocity model shows structures associated with the Iceland hotspot track beneath Greenland. In the upper mantle, a pronounced low-velocity anomaly below the East coast might be due to the remnant effect of the Iceland hotspot when it was at its maximum intensity. Thermo-mechanical modeling suggests that this area has higher temperature and lower viscosity than the surrounding cratonic areas and experiences a higher than average surface heat flow. This new detailed picture of the Greenland lithosphere will drive more accurate geodynamic reconstructions of tectonic plate motions and help to better understand the North Atlantic tectonic history. Models of Greenland glacial isostatic adjustment will benefit from the 3D upper mantle viscosity model, which in turn will enable more precise estimations of the Greenland ice-sheet mass balance.

ESC2018-S12-300

EVALUATING PERFORMANCE OF BULGARIAN ANTARCTIC SEISMIC STATION LIVV

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Bulgarian Antarctic seismic station LIVV is installed on 19.12.2015 on Livingston Island, South Shetland Archipelago , Antarctica and is situated close to Bulgarian Antarctic Base “St. Kliment Ohridski”. LIVV station is established as seasonal station with deployment period during the astral summer in the frame of the project DFNI I02/11/2014 “Creating an information base for exploration of seismicity and Earth structure of Livingston Island and surroundings by complex research in the Bulgarian Antarctic Base area” supported by the Science Research Fund to Bulgarian Ministry of Education and Science. The seismological equipment of the station consists of one broad band seismometer Guralp CMG 40T with flat response from 30s to 50Hz, one 3 component geophone with 4.5 Hz natural frequency and a 6 channel digital acquisition system Reftek DAS 130. Both seismometers are

installed on a concrete pillar previously constructed on the bedrock. Isolation cover is mounted over the sensors which ensures stable environment during the deployment period. Here we evaluate the overall performance of the station LIVV for the three seasons of its operation. The influence of diurnal variations of ambient seismic noise, tidal variations, weather changes and site characteristics on data quality and capacity of the seismic station is investigated. The results are important for the future deployment of Bulgarian seismic station LIVV as permanent Antarctic station. To ensure good quality of seismic data registered by station LIVV is very important both for the purposes of the project and for the future research of the tectonics and Earth structure in the region of Livingston and surroundings. When the project completes the data will be freely accessible for international seismological community.

ESC2018-S12-366

SEISMICITY OF PERUNIKA GLACIER, LIVINGSTON ISLAND, ANTARCTICA

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Bulgarian temporal Antarctic Station LIVV was installed during astral summer of 2015/2016 on Livingston Island, South Shetland Islands as part of the project DFNI I02/11/2014 “Creating an information base for study of seismicity and Earth’s structure on Livingston Island and surroundings through complex research in the Bulgarian Antarctic Base area” supported by the Science Research Fund to Bulgarian Ministry of Education and Science. The station is situated about 100 m from the glacier Perunika and about 1 km air distance from Bulgarian Antarctic Base St. Kliment Ohridski. For all nine months (three astral summers) operational time of the station LIVV more than 8000 seismic events with different origin were registered. We have identified 2/3 from the events as icequakes generated mostly due to movement of the closest glacier Perunika. A set of different data within the operational period were collected to study the glacier seismic sources. Icequake data were distinguished from the seismic data recorded by the LIVV station and were divided in five groups according to waveform, duration and spectral characteristics. Set of GNSS measurements was carried out on the glacier Perunika. Weather condition data for the period of interest were acquired from the data archive of permanent meteorological station installed in close vicinity of Bulgarian Antarctic Base. Tide information for South Bay of Livingston Island was also used for correlation with number of icequakes. In this study we propose an approach to study seismic activity and surface motion of the glacier Perunica by complex processing of the collected data.

ESC2018-S12-373

FEASIBILITY OF 3-SEASON LONG GLACIER MONITORING BY TEMPORAL SEISMIC NETWORKS AT HANS GLACIER, SVALBARD

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Glaciers' seismic activity investigations focus on more and more detailed analysis in order to link seismic response to physical mechanisms. Therefore, local seismic networks located in the vicinity of a glacier body became a must in order to provide enough details. Those networks are predominantly deployed temporarily for short time and in summer seasons only, because of challenging environment and remoteness of studied areas. We have deployed a pilot 3-season long-term seismic network to monitor the dynamic activity of Hans glacier in Hornsund, Svalbard. The network was aimed to continuously gather seismic data from September 2017 to May 2018, hence from the late summer throughout whole winter until the spring season. It consisted of 11 recorders commonly used in controlled-source seismology (DATA CUBES) equipped with 4.5 Hz three-component geophones and powered by battery packages. The stations were placed either directly on ice or rocky basement in the close vicinity of Hans glacier terminus, with some of them only a couple hundreds of meters from it. Moreover, we took an advantage of the permanent HSPB broad-band seismological station located nearby, treating it as a 12th station within the network, knowing that it already

proved to be useful in Hans glacier seismic monitoring. Our experiment was intended to test the possibility of installing and maintaining a local seismic network for a period much longer than usual and especially during the winter conditions. For the network upkeep a minimum of one maintenance visit to each station was necessary to keep it running. Despite the loss of some of the stations mainly due to the power shortages the acquired data coverage is still satisfactory. Recorded data reveal a reach and complex wavefield consisting of events of different characteristics. We can observe short-lasting events present in a broad range of high frequencies (above 20 Hz), short-lasting spiky events, and monochromatic low-frequency events. Most of them is strong enough to be registered on all stations. We are able to locate registered events and study the correlation between their location and character. We analyse this very unique dataset in order to understand the differences between glacier system seismic behaviour in summer and winter seasons. Also we test if maintenance of the network for such a long time is feasible in order to supplement broad range of research taking place on Hans glacier with detailed and continuous seismic monitoring. The research was funded by the Institute of Geophysics PAS Young Scientist grant no. 500-10-36. We thank employees of the Polish Polar Station in Hornsund for their help in network upkeep. The HSPB seismological station is operated by the Institute of Geophysics PAS in cooperation with NORSAR research foundation and is part of Polish Seismological Network. We also thank to Mariusz Majdanski for support from Grant UMO-2016/21/B/ST10/02509 funded by National Science Centre, Poland (NCN).

ESC2018-S12-374

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Glaciers' seismic activity investigations focus on more and more detailed analysis in order to link seismic response to physical mechanisms. Therefore, local seismic networks located in the vicinity of a glacier body became a must in order to provide enough details. Those networks are predominantly deployed temporarily for short time and in summer seasons only, because of challenging environment and remoteness of studied areas. We have deployed a pilot 3-season long-term seismic network to monitor the dynamic activity of Hans glacier in Hornsund, Svalbard. The network was aimed to continuously gather seismic data from September 2017 to May 2018, hence from the late summer throughout whole winter until the spring season. It consisted of 11 recorders commonly used in controlled-source seismology (DATA CUBES) equipped with 4.5 Hz three-component geophones and powered by battery packages. The stations were placed either directly on ice or rocky basement in the close vicinity of Hans glacier terminus, with some of them only a couple hundreds of meters from it. Moreover, we took an advantage of the permanent HSPB broad-band seismological station located nearby, treating it as a 12th station within the network, knowing that it already proved to be useful in Hans glacier seismic monitoring. Our experiment was intended to test the possibility of installing and maintaining a local seismic network for a period much longer than usual and especially during the winter conditions. For the network upkeep a minimum of one maintenance visit to each station was necessary to keep it running. Despite the loss of some of the stations mainly due to the power shortages the acquired data coverage is still satisfactory. Recorded data reveal a reach and complex wavefield consisting of events of different characteristics. We can observe short-lasting events present in a broad range of high frequencies (above 20 Hz), short-lasting spiky events, and monochromatic low-frequency events. Most of them is strong enough to be registered on all stations. We are able to locate registered events and study the correlation between their location and character. We analyse this very unique dataset in order to understand the differences between glacier system seismic behaviour in summer and winter seasons. Also we test if maintenance of the network for such a long time is feasible in order to supplement broad range of research taking place on Hans glacier with detailed and continuous seismic monitoring. The research was funded by the Institute of Geophysics PAS Young Scientist grant no. 500-10-36. We thank employees of the Polish Polar Station in Hornsund for their help in network

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ESC2018-S12-502

SURFACE WAVES IN THE LAYERED GEOPHYSICAL STRUCTURE LITHOSPHERE - HYDROSPHERE - ICE COVER - ATMOSPHERE

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The Arctic region is actively exploring. First of all, this region is interesting for deposits of hydrocarbons on the shelf. Therefore, among the new scientific approaches to solving the problem of performing year-round monitoring of the environment in extremely difficult ice conditions, theoretical development of methods based on the experimental measurement of natural geo-hydro-acoustic noises comes to the fore. Unfortunately, the ice cover makes it impossible to study the seabed by means of towed hydroacoustic antennas and significantly complicates the installation of bottom seismic stations. Therefore, the main task of the project was to investigate the propagation of various types of surface waves in the system "lithosphere - hydrosphere - ice cover - atmosphere" in order to develop a basis for modifying deep-sounding methods to ice conditions. The most important result of this project was the theoretical substantiation [1] and experimental confirmation (both with the help of field observations [1-5] and numerical modeling [6]) of the possibility of obtaining information on the heterogeneous structure of the seabed from the data of seismic receivers that are installed only on the surface of the ice cover, both in active and passive modes. This is possible due to the fact that the fundamental mode of the surface wave propagating in the "lithosphere-hydrosphere-ice-atmosphere" environment bears information about the seabed structure, while having a local maximum amplitude near the ice cover. Recommendations are formulated for adapting to ice conditions as dispersion methods for deep sounding (surface-wave tomography) and for amplitude probes (the method of microseismic sounding). To achieve this result, an analytical study was carried out of the propagation of various types of surface waves in the layered medium under study. The investigation of the dispersion and amplitude properties of the fundamental and flexural mode showed that the first carries information about the structure of the seabed and spreads much faster than the second, which carries information on the characteristics of the ice cover. Thus, to determine the characteristics of the bottom, primarily of interest for the search for hydrocarbons on the shelf, it is possible to use the fundamental mode. To determine the state of the ice cover, which is important for the organization of winter roads in many regions of our country, it is possible to use flexural fashion. In addition, a large-scale numerical simulation of the propagation of surface waves in the investigated medium was carried out. It is shown that, if the proposed recommendations are complied with, it is possible to reconstruct the structure of the seabed from the data of seismometers located only on the ice surface, for example, using the method of microseismic sounding. Processed data from field experiments performed on the ice of Lake Umbozero and Ladoga Lake confirmed the theoretical studies obtained. The research was carried out with the support of the Russian Foundation for Basic Research, the project No. 16-35-60109. This project was supported by the Russian Foundation for Basic Research (project 16-29-02046), as well as by a grant from the President of the Russian Federation to support scientific schools 5545.2018.5

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ESC2018-S12-505

COMBINED BOREHOLE AND PASSIVE SEISMIC INVESTIGATIONS OF THE SUBGLACIAL ENVIRONMENT

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It is difficult to overemphasize the extent to which subglacial processes control glacier and ice sheet flow. Depending on whether meltwater is routed efficiently in large channels or inefficiently in networks of small channels at the ice-bed interface, ice bodies react differently to increased melt water production at the surface. Accordingly, changes in subglacial hydraulics can provoke different types of changes in ice sliding, such as spring speed up events, glacier surges or long-term ice sheet slowdown. On a global scale, this interplay between subglacial hydraulics and ice flow controls large scale dynamics of polar ice sheets and ultimately affects eustatic sea level rise. Traditional theories in glaciology describe the evolution of subglacial water pressure and glacier sliding over the underlying bed as stable and smooth processes. However, in recent years, theoretical and experimental work has revealed sudden fracture events or stick-slip sliding episodes, which suddenly perturb subglacial water pressures with effects on ice flow and glacier erosion that have yet to be fully understood. To date, our observational capacity of such short-term and sudden processes has been limited as we either rely on monitoring seismic stick-slip sources from the glacier surface or on rare observations at the bottom of boreholes, which are associated with great effort and nevertheless constitute point measurements, only. The causes and effects of sudden fracturing, stick-slip sliding and water pressure perturbations are therefore not yet fully understood and it is unclear how widespread they are and which subglacial environments favor or suppress them. Here we propose a new approach to studying the subglacial environment: We combine passive seismic monitoring of basal stick-slip motion and fracturing with borehole geophysical techniques. Much like drilling into seismogenic strike-slip faults in crustal studies, we propose to target borehole experiments to specific glacier bed regions, where short episodes of fracturing or spatially limited microseismic stick-slip sliding happens. This provides information on subglacial water pressure evolution, material properties of the ice-bed interface at these distinct patches, and potentially the amount of aseismic and co-seismic sliding, which cannot be obtained remotely from the ice surface. We describe the challenges of monitoring basal seismicity in near-real time necessary for guided glacier drilling and report on first observations and results from a campaign on an Alpine glacier in Switzerland.

ESC2018-S12-545

LONG-PERIOD SEISMIC EVENTS AND TREMOR AT A TIDEWATER GLACIER IN GREENLAND

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Recent seismic observations from the most remote and hostile environments on Earth, like Antarctica and Arctic, have generated a surprising number of discoveries, which are reshaping our understanding of glacier dynamics. Among some newly reported phenomena were: tele-seismically observable earthquakes due to iceberg detachment, Mw7-stick-slip motion of an ice stream, and various types of tremors produced by water flow through subglacial drainage system or

by multiple time-overlapping micro-shear-slips. Compared to subduction zones, glaciers remain an easier target to reach for comprehensive, near-source observations. Yet, we are still lacking a good understanding of glacial basal motion and its dependence on water pressure, both of which are difficult to monitor. Moreover, since fast glacier sliding can be seen as a model of shear dislocation, glaciers constitute a natural laboratory to study seismogenic phenomena. During three field campaigns of 2015–2017, seismic and GPS arrays, as well as other instruments, were temporary installed on ice and near Bowdoin Glacier in Northwest Greenland. The analysis revealed a wide range of co-seismic processes, including tide-modulated seismicity, Long-Period (LP) events similar to those caused by fluid motion or slow rupture below volcanoes, and tremor-like behaviour. Here, we present a localized glacier source of repeating LP-events (re-occurring every ~5 mins), and a continuous seismic tremor correlated to an ice speed. And, also discuss what do these two phenomena represent, and if they are related to shear falling and could be considered members of the slow-earthquake family.

ESC2018-S12-623

MONITORING GREENLAND ICE-SHEET CALVING VOLUMES WITH GLACIAL EARTHQUAKES

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Iceberg calving is responsible for one third up to one half of the Greenland ice-sheet mass loss and discharge in the oceans. High rates of calving recorded in Greenland may be responsible for (1) rapid glacier thinning, acceleration and retreat and (2) freshwater discharge in the ocean that could potentially affect the Atlantic overturning circulation. Thus, accurate estimations of iceberg geometries (volumes, shape, waterline length) and their distributions over time and space are needed to (1) study the impact of calving on the dynamics of tidewater glaciers and the ice-sheet stability, and (2) estimate discharged icebergs' impact on seawater properties for initiation and validation of ocean and atmospheric circulation models. In Greenland, increased rates of calving have been synchronized with an increase of glacial earthquakes (GEs) which have expanded to previously unactive tidewater glaciers since 2005. GEs are magnitude 5 events whose seismic signals are recorded globally at long periods (20-150 s). They are caused by specific calving styles when the glacier terminus is near-grounded and produce km-scale icebergs of the full-glacier thickness which slowly capsize in the proglacial fjord. During their buoyancy-driven rotation, icebergs apply contact forces on the calving front, responsible for GEs. This source force can be inverted from recorded long-period surface waves and its time history shows different levels of complexity given the earthquake. Furthermore, observations and mechanical modelling of iceberg capsize show no correlation between the GE force amplitudes and calving volumes. The forces of 160 GEs located at different glaciers in Greenland were inverted using broadband data from the Greenland seismic network GLISN. Half of the investigated events were clustered into a dozens of family based on the similarity of their force history. Each GE family clusters events originating from various glaciers and no specific trend in the timing of the events was observed. Using an iceberg calving model, a catalog of 10000 contact forces was computed with various iceberg dimensions. The comparison between the contact force catalog and the forces inverted from two GEs which produced well-documented capsized icebergs gives correct iceberg dimensions and calving volumes. This analysis is expanded to every event constituting a GE family. It appears that one GE family is characterized by one specific iceberg aspect ratio (the ratio between the iceberg longitudinal width and its height) as this primarily controls the iceberg capsize dynamics and the contact force history. Whereas individual dimensions of icebergs are difficult to predict, the aspect ratio and iceberg volumes are well constrained from the force history. This study reveals the potential of GEs for quantifying and monitoring the endured mass loss at the Greeland ice-sheet and the dynamics of Greenland fast-moving outlet glaciers, from the analysis of seismic signals recorded globally.

ESC2018-S12-695

THE CRUST AND UPPER MANTLE OF THE EURASIA BASIN REVEALED BY GEOPHYSICAL DATA AND MANTLE TOMOGRAPHY MODELS

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The present day plate boundary between the Eurasia and North America plates, the Gakkel Ridge, runs through the Eurasia Basin in the High Arctic, and is considered the slowest mid-ocean ridge on Earth (c. 6-13 mm/yr). The Eurasia Basin is floored by oceanic crust c. 57-0 Ma old, which formed under intermediate-slow seafloor spreading regime in the first 10 myrs, and slowed down since the Eocene until the present day. Here we present new results regarding the crustal accretion asymmetry inferred from new seismic reflection data, a model for the crustal thickness derived from gravity inversion and an analysis of available upper mantle tomographic models. The new seismic and other available geophysical data reveal the asymmetry of the basement and sedimentary structure of the Eurasia Basin. Asymmetry in oceanic crust accretion occurred both at old and younger seafloor spreading stages in the conjugate Nansen and Amundsen sub-basins, with a general trend of higher spreading rate in the Nansen Basin. Since the Miocene, a dramatic decrease in spreading rate led to the formation of high mid-ocean ridge flank topography and thicker crust. Upper mantle tomographic models consistently image low velocities at both ends of the Gakkel ridge in the upper 50 km and relatively higher velocity under the central Gakkel Ridge which roughly corresponds with thin crust and sparsely magmatic spreading processes. The AMISvArc tomographic model presents an image of the inflow of hot North Atlantic asthenosphere into the Eurasia Basin suggesting a major effect of the inflow on the character of the seafloor spreading.
The new geophysical data, the updated ISC+EMSC earthquake catalogues from 1960 to 2016 and recent tomographic models reveal in greater detail the segmentation of the Gakkel Ridge and may indicate possible links between the upper mantle heterogeneities and surface processes.

ESC2018-S12-748

DEVELOPMENT OF OPEN-ACCESS WEB-BASED INTERFACE FOR SEISMIC DATA ANALYSIS

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As part of an international scientific networking program (NOR-R-AM), we are building a database for the Circum-Arctic region, where published geophysical data is easily visualized and retrieved. We have recently found an easy-to-implement solution suitable for geoscience-related spatial databases. The proposed geo-referenced database utilizes some web services provided by Google and standard KML format (tagged text files containing geographic coordinates). KML is a mark-up language that employs a tag-based structure with nested elements, attributes, and follows the more general XML standard. The similar GPML format is used in the free-access plate kinematics visualization and analysis software GPlates. We supplied kml-files with information about the data type, quality, bibliographic codes/doi for publications, and include links to the data repositories. The ASCII or bitmap files are retrieved using HTTP queries. We integrated the database with processing or modeling software using MATLABs or Pythons scripts. The collection of kml files contains several pre-defined elements (Geometry, LAT, LON, Data_Type, DataURL, Author_Year, DOI). We import the collection of kml files into Google Fusion Tables for navigation through the database, as well as for filtering by attributes (e.g. by author, location or data type). The Google Fusion Table is a well suited for joint and shareable work. The advantages of working on a shared project through a web interface are availability without local installation requirement and possibility for dynamical change. Selected users (group or public) have access and opportunity to information in database. The interactive maps are also easily shared, available for editing and embedded as web-page content. The concept of the web-database is that we fill it with various content, then import the data to Google Earth or to the Google Fusion Table from which we can

share and upload data for further analysis. Input data can be raw data or final models, therefore both vector and raster data (e.g. through WMS/WCS services), as well as detailed metadata. Simple scripts convert input xyz data by adding metadata, geometry in the form of KML format, and retrieve the xyz data in readable form when required. So far we have included into this project several raster data, lines and point information: active-source seismic reflection and refraction profiles/crustal thickness and velocities distributions with description of interpretation for lines and seismic images (451 profiles); permanent/temporary seismic stations (5 stations); heat flow measurements (7 stations); earthquake locations and magnitudes; information on geological sampling (e.g. Gakkel Ridge, NW Spitsbergen); sonobuoy measurements (80 stations); magnetic isochrons/picks and plate boundaries. We introduced a structure for facilitating work and cataloguing information. All elements for KML files contains specified structure with description of authors of publication, Digital Object Identifier (DOI), data type, possible live link to data source server/archive and published seismic image/interpretation.

ESC2018-S12-865

3D DENSITY, THERMAL AND COMPOSITIONAL MODEL OF THE ANTARCTIC LITHOSPHERE

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In this study, we use an integrative approach combining gravity and tomography data with mineral physics constraints aiming to create a 3D density, temperature and composition model of the Antarctic lithosphere. In the first step, an initial model of the crust based on available seismic, receiver function and tomography data is created. Based on this model, the residual mantle gravity anomalies and residual topography are calculated. In addition, the effect of deep density heterogeneities, which is based on recent global models, is also removed from the residual anomalies. Next, S-wave velocities from two independent tomography models (SL2013sv and AN1-S) are converted to temperature and temperature induced density variations. These density variations are employed to correct the residual fields for the effect of temperature variations in the uppermost mantle. The resulting residual gravity and topography fields are then jointly inverted to obtain a 3D density model of the lithospheric mantle and compositional changes linked to the density changes in cratonic East Antarctica are estimated. On the basis of the new compositional model, a new temperature model is calculated and the scheme repeats until convergence is reached. Our results show a clear distinction between East and West Antarctica in both temperature and density up to a depth of about 200km. The strongest negative compositional density anomalies can be found at a depth of 200km, close to the pole, in the Wilkes Subglacial Basin, along the eastern flank of the Transantarctic Mountains

ESC2018-S12-913

SEISMIC OBSERVATIONS OF THE SUBGLACIAL ENVIRONMENT AND IMPLICATIONS FOR THE COUPLING BETWEEN SUBGLACIAL HYDROLOGY AND GLACIER BASAL SLIDING.

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Glacier dynamics governs the response of mountain glaciers to external forcing such as increasing surface temperature, and thus exerts a key control on their contribution to sea level rise under a rapidly changing climate. To better predict the future of the Cryosphere it is essential to properly understand and model the different component of glacier dynamics. Ice internal deformation and sliding at the ice-bedrock interface are the two major components of this system. While the former is relatively well known, the process of basal sliding remains poorly known mostly because of the difficulty to directly observe the sub-glacial environment. In this study we use on-glacier seismic measurements to overcome the traditional limitations of field observations. We deployed four borehole seismometers over the tongue of Argentière glacier, a typical alpine glacier located in the Mont Blanc Massif, France, over an entire year. We analysed this data set with a special focus on the relation between sub-glacial hydrology and glacier dynamics. We demonstrate that the analysis of the seismic power in relation

with water discharge and basal water pressure allows for a complete monitoring of the sub-glacial hydrology drainage system evolution throughout the melt season. We observe simultaneous changes in basal water pressure, seismic power and sliding velocity during rapid episodes of increasing water discharge. We also observe long term changes in the seismic power related to seasonal changes of the sub-glacial hydrology system. High frequency seismic content (200 to 400 Hz) containing stick-slip events is often observed during the period following rapid changes of in basal water pressure. These observations allow us to better constrain the relation between water discharge, basal water pressure and basal sliding velocity. We also propose the presence of solid type friction at the ice-bed interface under certain conditions to accommodate stress concentrations. We consider that this complete set of observations is crucial to resolve sub-glacial processes and expect promising implications for glacier basal sliding understanding.

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SESSION 13

ESC2018-S13-77

LARGE DEEP SLIP RATES OF THE LONGMENSHAN FAULT ZONE AND ITS IMPLICATION FOR STRONG EARTHQUAKES

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The May 12, 2008 M7.9 Wenchuan earthquake ruptured the middle and northern segments of the Longmenshan fault zone (LMSFZ) at the eastern margin of the Tibetan Plateau. Prior to the Wenchuan earthquake, the LMSFZ had been seismically quiet for several centuries, there were no hints that suggested such a M~8.0 earthquake might strike the area. The long-term geological investigations and short-term geodetic measurements before the Wenchuan earthquake generally agree that the horizontal slip rate along the LMSFZ is very limited. The low deformation rate observed at the surface around the LMSFZ may not reflect the true deep deformation where the devastating Wenchuan earthquake nucleated. We investigated deep slip rates along the Longmen Shan fault zone where the devastating M7.9 Wenchuan earthquake occurred using repeating earthquake data recorded by two digital seismic networks near the fault. Using cross-correlation analysis of waveform data from May 2000 to April 2008, we identified a total of 12 repeating earthquake clusters in the source region of the Wenchuan earthquake. Most of the clusters are located at the edge of locked areas where large coseismic slips were observed during the Wenchuan earthquake, suggesting a close spatial relationship between microearthquakes and impending large devastating earthquakes. The measured in situ deep slip rates appeared to increase with depth and varied from 3.5 to 9.6 mm/yr at depth range of 4–18 km. They are approximately twice as large as those inferred from surface GPS and geological data. Our observations here suggested that seismic hazard could be underestimated if surface measurements alone are employed. In order to validate the depth-related slip rate pattern, based on regional tectonic characteristics of the LMSFZ, a two-dimensional viscoelastic finite-element model with contact algorithm is established to simulate evolution process of the crust and upper mantle during an earthquake cycle. Our simulating results confirm that the depth-related lateral slip rate pattern around the LMSFZ revealed by the seismological observation of repeating earthquakes. Furthermore, the LMSFZ and its surrounding regions are prone to accumulate strain and strain rate potential with the highest stress concentration area of 5-19 km in depth, suggesting that this area may essentially is nucleated strong earthquake over time. It is found that the slip deficit area in the northeastern Japan subduction zone estimated from repeating earthquakes is very consistent with the rupture zone of the 2011 Mw 9.0 Tohoku-oki earthquake. We suggest that slip rates at seismogenic depths are of critical importance in seismic hazard analysis. Repeating earthquakes can be regarded as the “subsurface creepmeters” to measure the in-situ deep slip rate of tectonic deformation.

ESC2018-S13-218

WAVEFORM CROSS-CORRELATIONS - PRECISION, LIMITATIONS AND CONSEQUENCES

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In recent decades a relative techniques (master-event, double-difference) for earthquake location have been developed, tested and widely used by number of seismologists. The methods are capable of high-precision location of earthquakes closely co-located together and forming small cluster or clusters. The methods make use of delay times between phase arrivals of two or more earthquakes. To achieve high-precision locations a high-precision differential times estimates are desired – and waveform cross-correlation is believed to be the technique with capability of achieving such precision. However, despite the number of applications, the precision of differential times estimates has not yet been reliably evaluated. In this work we compared differential times computed manually and automatically by means of waveform cross-correlation. We used earthquakes from West Bohemia earthquake swarm area. Monitoring and research of the area has been running for more than 30 years. Activity behavior and earthquakes characteristics are well known. As a result the manual readings are of unusually high precision, what makes them ideal for our comparative study.

We focused on time differences between manually and automatically processed differential times and their dependence on magnitude difference between paired signals. Unsurprisingly, the dependence has been observed, but the amplitude of such a difference was unusual. With magnitude difference higher than 2 (e.g. ML=1.5 and ML=3.5) the cross-correlated differential time can be longer by 0.08 s that the manual one (for both, P and S waves). The trend is systematic and only slightly affected by selected frequency range, time window used for correlation etc. Observed results imply the question if and how relocations obtained by double-difference methods with cross-correlations are affected by observed phenomenon and how to prevent it. Tests showed that hypoDD, the most widely used double-difference application can resolve the cluster shape, but cannot deal with the strongest events when cluster of non-uniform magnitude distribution is analyzed. Master-event technique is practically unusable. Relocating standard mainshock-aftershock sequences might be a big problem leading to mainshocks mislocation. Mapping the fault geometry by relocated earthquakes distribution might be affected too and reliability of such an analysis must be provided. As a conclusion we state that waveform cross-correlation technique improves the relocation results in general, but in some circumstances it can be strongly biased and lead to corrupted results.

ESC2018-S13-220

MODELLING A VOLCANO-TECTONIC STRUCTURE AT MT. ETNA (SICILY): CONSTRAINTS ON THE FAULT ZONE FROM A MULTIDISCIPLINARY APPROACH

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Multidisciplinary studies on active faults are commonly applied in tectonic domains following a large earthquake; they are aimed at modelling geometry and dynamics of the structures by integrating seismological data and geodetic measurements and, if surface faulting occurs, considering field structural observations as well. By contrast, in volcanic areas the deformation dynamics is considerably faster but shows complex patterns, such as phases of inflation or deflation of the volcanic edifice due to volume variations in the magma feeding system, or asymmetrical deformation related with dyke intrusions or flank instability processes. At Etna volcano, Sicily, specific studies aimed at modelling individual faults whose activity does not strictly depends on volcanic processes, are relatively few. Moreover, even if the integration of well-constrained multidisciplinary data obtained by the monitoring systems has become a routine in recent times, the chance of observing tectonic processes marked also by surface faulting is not frequent. In this paper, we present the results of a multidisciplinary analysis aimed at modelling the S. Leonardello fault, an active structure located in the eastern flank of Mt. Etna. Characterized by a well-known seismic history and behaviour along strike, this fault had a renewal of activity in May 2009, when pre-seismic creeping along the southern segment of the fault preceded a ML 3.6 earthquake in the northern segment. This event represents the mainshock of some twenty aftershocks located in a small area. Again, in March-April 2016, creep events reactivated the southern section of the same fault. Both the seismic and aseismic phenomena produced significant field evidence along strike, and were recorded by the seismic and GPS networks operating at the INGV-Osservatorio Etneo; this tectonic activity also left an evident footprint in the pattern of ground deformation detected by InSAR satellite measurements. These different typologies of data have been analysed and correlated in order to constrain a model of the fault. Although the faulting mechanisms here described occur at a very small scale compared with the ones of a purely tectonic setting, this case-study may represent a perfect lab for improving our basic knowledge of seismogenic processes at Etna and in other fault zones characterised by stick slip vs stable-sliding fault behaviour.

ESC2018-S13-336

NEAR-SURFACE GEOPHYSICAL IMAGING OF THE MAIN FRONTAL THRUST (MFT): IMPLICATIONS FOR TECTONIC GEOMORPHOLOGY AND SEISMIC HAZARD ASSESSMENT

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The Kingdom of Bhutan presents significant challenges for active fault characterization. Located in the eastern part of Himalayas, the seismic potential of this area remains poorly understood (Drukpa et al., 2006). Although this area is currently marked by a low seismic activity, recent geomorphological and paleoseismological studies in south central Bhutan suggest an Holocene uplift rate of 8.8 +/- 2.1 mm/yr on the Main Himalayan frontal thrust (MFT) and reveal the occurrence of at least two major seismic events during the past millennium (Berthet et al., 2014; Le Roux-Mallouf et al., 2016). For the most recent event, calculations based on newly translated historical eyewitness reports, macroseismic information and re-assessed damage reports suggest a magnitude 8±0.5 earthquake on May 4th, 1714 (Hetényi et al., 2016). Considering this seismic activity, the fault dip angle is a key parameter to improve seismic hazard assessment by converting uplift rates into overthrusting slip rates along the MFT. Taking advantage of these previous investigations, a geophysical survey is carried out in the same area along the MFT to image the geometry of this major fault at shallow depth. Our approach is based on high-resolution near-surface geophysical investigations, which include electrical resistivity (ERT), seismic refraction and gravity measurements. Each data set is first inverted using a stochastic procedure providing quantitative constraints on both the fault geometry and the physical parameters of layers at shallow depth around the fault (Drukpa et al., 2017). Considering the investigation depths of the three geophysical methods used, we obtain (1) a very shallow part up to 5 m depth well-constrained by both field observations and seismic data considering the ray coverage; (2) an intermediate depth part well-imaged by ERT sections between 5 and 40 m depth due to high-resistivity contrasts across the fault zone; (3) a deeper part documented by gravity measurements below 40 m depth. The results of the stochastic inversion suggest a flat and ramp geometry of the MFT that is dipping northward with a dip angle of about 20°-30° at the top (0-5 m), steeply dipping with a dip angle of 70° in the middle (5-40 m) and flattening (20°) at deeper depths (>40 m). These findings lead to a minimum slip rate of 10 +/- 2 mm/yr on the MFT that corresponds to ca. 60% of the 17 mm/year reported from GPS studies (Marechal et al., 2016). On the basis of these results, we cannot rule out that the deformation is distributed over several faults, including the MFT, but also other thrusts such as the Main Boundary Thrust north of the MFT or the Frontal Back Thrust emerging in the Brahmaputra plain. This significant deformation partitioning may have strong implications in seismic risk assessment. In addition, assuming a constant slip rate, dip angle variations of the fault at shallow depths induces variations in uplift rate as a function of the distance to the front. This highlights the weaknesses of approaches commonly used for estimating Holocene slip rates on seismogenic faults from river terraces studies, which assumes a constant fault dip angle estimated from surface observations only.

ESC2018-S13-371

DECOUPLING BETWEEN LOWER AND UPPER PLATE DEFORMATION ALONG THE TINDARI-ALFEO FAULT SYSTEM, CALABRIAN ARC (CENTRAL MEDITERRANEAN SEA).

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The subduction of the Ionian oceanic crust under the Calabrian Arc is one of the major structural elements in the evolution of the central Mediterranean basin. The Calabrian subduction zone is characterized by a narrow slab that, in its south-western part, terminates on the Tindari-Alfeo Fault System (TAFS). This fault system represents a major NNW-SSE trending subduction-transform edge propagator (STEP) that plays an important role in the recent evolution of the Calabrian Arc. Thanks to a dense set of multichannel seismic reflection profiles with high penetration (up to 12 s), that allowed for a 3D reconstruction of the geological structures in the area, the TAFS results to presently be one of the best documented STEP systems in the world. We were able to characterize the geometrical arrangement, the timing of the deformation and

the interplay between the Ionian lower plate and the upper-plate accretionary prism during the Plio-Quaternary. Our study highlights the presence of a mechanical decoupling between the lower plate and the upper plate. The Ionian oceanic (and/or transitional) crust in the lower plate hosts the master faults of the TAFS which do not propagate across the thick accretionary prism in the upper plate. This latter is affected by secondary deformation (bending-moment faulting, localized subsidence, stepovers, and restraining/releasing bends) associated to the activity of the TAFS at depth. The analysis of the secondary deformation in the upper plate, and in particular of the syn-tectonic Plio-Holocene basins, associated to the activity of the TAFS at depth, allow us to constrain the age of inception of the TAFS in the study area and to calculate the vertical component and the propagation rate of the deformation. Our findings highlight the mechanical behaviour that can be expected along major lithospheric boundaries that interact with previously formed structures and provide key elements to understand the significance of shallow geological structures with respect to the master faults at depth.

ESC2018-S13-372

NEW EVIDENCE OF ACTIVE TRANSTENSIONAL DEFORMATION IN APULIA FORELAND (N-IONIAN SEA).

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The response of continental forelands to subduction and oblique collision is a widely investigated topic in geodynamics. The deformation occurring within a foreland shared by two opposite-verging chains, however, is not very common and poorly understood. The Apulia block, at the southern end of the Adria microplate, Central Mediterranean, represents one of these latter cases, being the common foreland of the Dinarides and Apennines orogens. In its southern part, the Apulian foreland has preserved the Mesozoic paleomargin at the transition with the old oceanic Ionian crust that conversely underwent subduction under the Calabrian and Hellenic arcs. For these reasons, Apulia represents an interesting and rare case of study where double orogens and subduction have interacted with the foreland block. As described by various authors, the almost symmetrical bending of the Apulia foreland due the opposite load of the adjacent chains, produced a system of NW-SE trending normal faults. The precise age and the role of these faults have not been yet determined due to the lack of available information. In this contribution we investigated the internal deformation of the Apulia foreland using geophysical data at various resolutions and scales over a wide area. We used multichannel seismic profiles, part of which are provided in the collaborative framework between Spectrum Geo and INGV, recorded up to 12 s and provide a consistent imaging of the upper crustal setting of the Apulia foreland. High-resolution multichannel seismic profiles, multibeam high-resolution bathymetry and CHIRP profiles recently acquired by R/V OGS Explora provide constraints on the recent activity of the major fault systems identified. The analysis of this multiscale dataset highlights the presence and the role of a major NW-SE oriented active fault system which obliquely cuts the Apulia foreland. The presence of this fault system has already been hypothesized based on sparse seismic profiles, but its lateral continuity has never been documented. From the seismic viewpoint, this structure lies in a relatively silent area. Nonetheless, it hosts the 1743 Southern Apulia Mw 6.8 earthquake which widely damaged the Salento (S-Italy) and Ionian Islands (Greece) regions and whose source is still a matter of debate. This new geophysical dataset allowed us to reconstruct the 3D geometry of this fault system, whose architecture suggests a transtensive kinematics, and to analyse the syn-tectonic basins associated with the major faults which recorded the Late Quaternary to Holocene deformation. This work is being developed in the frame of the project “FASTMIT”, funded by the Italian Ministry of University and Research.

ESC2018-S13-429

THE 2016 SOUTHEASTERN SICILY EARTHQUAKES SEQUENCE: SEISMOLOGICAL AND TECTONIC ASPECTS

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Between February 6 and 12, 2016 the Hyblean foreland domain in SE Sicily (Italy) experienced an earthquake sequence that affected mainly the provinces of Siracusa and Ragusa. In just a few days approximately 120 were the shocks occurred in close succession. Since most of the events were recorded by few stations, only 34 earthquakes with magnitude Ml between 1.0 and 4.3 have been located. Despite the low magnitude of most events, the sequence represents one of the largest episode of strain release in the Hyblean area over the last 20 years. In particular, the mainshock (Ml =4.3 on February 8), located 10 km NNE from the town of Ragusa, was felt throughout the southeastern Sicily, in a range of about 70 km from the epicenter, by causing very slight damage in the vicinity. In the present work we integrated the structural-geological data, within and near the epicentral area, with the analysis of earthquake fault plane solutions in order to define the geometry and the kinematics of the active fault segment. The characterization of the active geological structure, responsible for the seismic sequence, is of great interest to assess the problem of seismic risk mitigation of the region. In addition, earthquake ground motion simulations have been provided in order to generate earthquake scenarios for the strongest event of the seismic sequence, in terms of ground motion parameters. In particular, we applied a stochastic approach to simulate high-frequency ground motion through the EXIM code (Motazedian and Atkinson, 2005; Boore, 2009), which has been developed for earthquake simulations using stochastic finite-fault modelling and dynamic corner frequency approach. The seismic source has been represented by a rectangular fault plane oriented in agreement with the focal plane solution obtained in this study, while the crustal model has been calibrated through the information available in seismological literature. Moreover, the available instrumental data have been used in order to check the performance of the simulations. The resulting ground-shaking scenarios are consistent with the ones produced by a fault plane trending about N20°E, dipping at about 70° ± 20° to the east, varying in size from 0.2 to 2 km.

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ESC2018-S13-477

GUIDED-WAVE FAULT EXPLORATION

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Locating faults in the near-surface beneath highly urbanized settings is challenging because urbanization obscures geomorphic evidence of faults in relatively short time periods. Yet, urban faults can represent major hazards because they directly underlie large populations. Such is the case along the Raymond and Hollywood faults in Los Angeles, California (USA), the San Andreas Fault in the San Francisco Bay area, California (USA), the West Napa Fault in Napa, California (USA), and the HuangZhuang-GauLiYing (HZGLY) Fault in Beijing (China). It is particularly important to identify the main and auxiliary traces that may underlie homes, buildings, and other structures. Paleoseismic trenching and other invasive techniques offer the clearest evidence of faulting, but long trenches cannot be economically excavated in highly urbanized areas or zones where faulting is widely distributed, such as fault step overs. We have begun using alternative, non-invasive approaches, whereby we use tomographic Vp/Vs ratios to precisely locate faults and peak ground velocities (PGV) of guided-wave energy to laterally map faults. For the PGV guided-wave method, we input active-source seismic energy into the fault zone and record that energy with fault-perpendicular seismic arrays, located up to 1 km from the source. In highly urbanized areas, we use repeatable active sources to mitigate the effects of cultural noise, such as vehicular traffic, thereby providing largely noise-

free, stacked seismic energy. In Los Angeles, for example, we observed four distinct zones of high PGV values along our recording array that coincide with fault traces inferred from geologic mapping, borings, and pre-urbanization (1923 and 1928) aerial photos, and none of the high PGV zones coincide with roadways or other local noise sources. In Beijing, the San Francisco area, and Napa, we similarly located and laterally mapped the HZGLY Fault, the San Andreas Fault, and the West Napa Fault, respectively. These methods are equally effective for fault mapping in rural areas and can be excellent alternatives to exploratory paleoseismic trenching, thereby greatly reducing the costs associated with fault mapping.

ESC2018-S13-583

SEISMOTECTONICS STUDY OF THE MEDIA VALLE UMBRA AREA AT DIFFERENT SPACE AND TIME SCALES: AN INTEGRATION OF GEOMORPHOLOGICAL, GEOPHYSICAL AND REMOTE SENSING DATA

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The Valle Umbra is a NW-SE 20 km long and 10 km wide Quaternary alluvial basin located in the internal sector of the active extensional tectonic Apennine chain, central Italy. This area historically suffered major earthquakes such as in 1832 (Me=6.3; I0=X) and 1854 (Me=5.6; I=VIII), both localized in the valley. It was marginally affected by the recent seismic event localized in the Colfiorito basin (M 6.0; September 1997) and more recently suffered from damages to buildings caused by the last seismic sequence (main shock, Norcia, PG, Mw 6.5, 30 October 2016) of Amatrice-Visso-Norcia. The main fault systems bordering the Valle Umbra basin crop out both east and west of the valley, while some other active segments may be hidden under the unconsolidated deposits filling the basin. We integrate single station ambient noise measurements and Time-Domain ElectroMagnetic soundings (TDEM) with previously acquired seismic reflection data and surface geology in order to reconstruct the subsurface geometry of the basin and localize buried faults. Preliminary results from the ambient noise spectral ratios show, in general, one resonance peak at around 0.8 - 1 Hz for stations installed on the lower Pleistocene deposits overlapping the Miocenic bedrock and two resonance peaks for stations installed in the Quaternary alluvial infill deposits in the central portion of the valley. In addition an accelerometric station of the national civil protection provided us additional constraints about the level of amplification of the site, (connected to the presence of impedance contrasts in the subsoil) as recovered by spectral ratio analysis of several earthquakes recorded from the 1986 up to date. Moreover, the availability of more than 20 years of SAR data archives for the studied area, allowed us the observation of a differential ground subsidence, detected by means of the application of Differential InSAR techniques. The subsidence can be due to either human induced aquifers withdrawal or to tectonic setting of the area, and we interpret that the shape of the bedrock can be co-responsible for the observed subsidence pattern, in terms of extension and surface geometries. Through the correlation of the time-series of observed recent ground deformations with the buried geological structures identified using geophysical techniques, we made an attempt of detecting and characterizing the geologic heterogeneities in the subsurface, defining the geometry and kinematics of the buried faults and eventually addressing the seismogenic potential of the area.

ESC2018-S13-596

THE ROLE OF FAULT SEGMENTATION AND TECTONIC INVERSIONS IN THE CENTRAL APENNINES NORMAL FAULT SYSTEM SEISMIC SEQUENCES AS REVEALED BY ADVANCED TOMOGRAPHIC IMAGES

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The role of inherited geological structures and crustal heterogeneities in limiting faults extent and earthquakes maximum magnitude is a key issue for the comprehension of central Apennine seismotectonics, as well as a fundamental concept for a correct seismic hazard assessment. Nevertheless, several tectonic phases affected the

central Apennine during its evolution causing an overprint of deformational features that could mask the surface expression of deep structures. The central Apennines represent an exemplary case, since the alternation in time and space of compressional and extensional stages also created the conditions for episodic tectonic inversions. In this context, it is rather difficult to estimate the potential slip deficit pending on unbroken segments of fault systems, due to the uncertain lateral and vertical continuity of faults and their possible decoupling. With this contribution based on a new tomographic inversion developed in the areas interested by the 2009 L'Aquila and the 2016-2018 Amatrice-Norcia-Visso seismic sequences, we show how inherited compressional structures interfere with the active extension, since still dominating the Apennines belt crustal-scale architecture. We present seismicity and new velocity tomograms of an 80-km long section of the normal fault system, highlighting how the extensional seismic sequences partially reactivated previous compressive structures. Moreover, the complexity deriving from the irregular geometry of normal faults and inverted thrust ramps lie behind the observed intense fragmentation of the current ex-tensional system, and the capability of even large magnitude earthquakes generation. Finally, we infer that fluid overpressure is the most viable mechanism that can more realistically describe and justify the observed partial re-mobilization of unbroken segments of the entire fault system.

ESC2018-S13-603

TIME AND SPACE SCATTERED VOLCANISM IN THE MT. ETNA AREA DRIVEN BY STRIKE-SLIP TECTONICS

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Although Mt. Etna area (eastern Sicily, Italy) provides one of the most intricate and studied example of magmatismat the front of a collisional belt, its origin andspatial-temporal evolution are still object of debate. New high resolution seismic reflection profiles were acquired offshore Mt. Etna by the "Istituto Nazionale di Geofisica e Vulcanologia - Osservatorio Etneo" in 2014,within the TOMO-ETNA experiment (FP7 Project "MED-SUV", Ibanez, et al., 2016), to shed light on the relation between tectonics and volcanism. The present study focus on the continental margin offshore southeastern Mt. Etna, where the oldest (ca 500 ka) dated volcanic products were found (Branca et al., 2011). The coupling between seismic imaging and bathymetric datahighlights the high degree of tectonic deformation involving thearea, which is dominated by a 75 km2, rhombus-shaped morpho-structural high, the Timpe Plateau (TP), pertaining to the Hyblean foreland. It is in fact bounded by inherited NNW-SSE and NE-SW lineaments, respectively belongingto the Malta Escarpment fault system and tothe foreland flexure beneath the Apenninic-Maghrebian fold-and-thrust belt(Lentini et al., 2006), as observed on the Hyblean Plateau. The whole TP and its continental slope,down to the bathyal plain, are strongly affected by strike-slip tectonics, highlighted by a large, wedge-shaped, roughly symmetric push-up, developing along WNW-ESE to NW-SW faults. Splay faults are characterized by apparent transpressive or transtensive kinematics, producing an overallremarkable shortening. Locally,NNW oriented, ENE verging en-echelon folds and fault-bend anticlines, typical of positive tectonic inversion,were found. This processinvolved also the basinal Plio-Pleistocene succession, suggesting a formerdistensive phase. The study area presents evidence of scattered Plio-Quaternary volcanics, mostly localized in correspondence of the main faults. This setting suggests the occurrence of a former transtensive phase, favouring the uprising of magmatic bodies through pull-apart basins offshore Mt. Etna. The ongoing strike-slip tectonics led to the development of a transpressive regimehampering magma ascent, and to the north-westward migration of transtensive structures, with the shifting of magmatismup to the younger Etna volcanic centers.

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ESC2018-S13-657

CHARACTERIZATION OF RECENT DEFORMATION IN THE PIANI DI PEZZA BASIN (CENTRAL ITALY) FROM HIGH-RESOLUTION TOPOGRAPHIC DATA AND NEAR-SURFACE GEOPHYSICAL INVESTIGATIONS

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The Piani di Pezza (PdP) fault is located in the Central Apennines (Central Italy) and corresponds to the central segment of the 35 km long Ovindoli-Piano di Pezza-Campo Felice active normal fault system, which links the Fucino basin to the L'Aquila basin. Although paleoseimological studies documented a high Holocene vertical slip rate of about 1 mm/year, the area is characterized by a quite low level of instrumental seismicity and a lack of historical earthquakes. Both the proximity to major seismogenic structures and the reccurence time of paleo-earthquakes in this area motivate the investigation of the seismic potential of this fault, its capability of generating future strong earthquakes, as well as its potential interactions with other segments. Geophysical surveys have been carried out across one section of the Piano di Pezza fault to characterize both the fault geometry at shallow depth and the cumulative displacement accomodated by this structure. Electrical resistivity tomography images show a cumulative vertical offset of about 15 m affecting an interface attributed to the Last Glacial Maximum and confirm the vertical slip rate ca. 1 mm/y across the fault zone during the Holocene. Considering the lateral extension of the fault, this high vertical slip rate suggests a complex geometry of the fault zone at depth or a more complex kinematics across the basin. In parallel, we investigated the surface deformation in relation to the overall structure using terrestrial laser scanner surveys (1 cm resolution). We mapped the fault trace with unprecedented detail and quantified surface deformation affecting alluvial fans as well as glacial moraines. We obtain a mean vertical offset of 2.5 m +/- 0.3 m for the most recent features, well in agreement with paleoseismological data. Near-surface geophysical methods were used to image the basement-sediment interface across the basin (gravity and time domain electromagnetic measurements) and shallow structures along several profiles intersecting the main scarp (electrical resistivity tomography, gravity and H/V ambient soundings). Beneath the scarp, geophysical data reveal a complex faulting geometry with several parallel strands and two minor blind splays. Recovered 1-D resistivity models from time domain electromagnetic data suggest that the maximum depth to bedrock is in the order of 250 m in the center portion of the PdP basin. Gravimetric anomalies across the basin indicate that the sedimentary fill has recorded a finite cumulative throw of the PdP fault system of 110-140 m. This suggests an average vertical slip rate of 0.2-0.3 mm/year since the Pleistocene, which contrasts with the post-LGM slip rate. This finding has important implications on the short-term history of the PdP fault system. We may hypothesize that the PdP fault is a quite young active normal fault compared to other mature normal fault systems active since 2–3 Ma in this portion of the central Apennines. The difference in slip rates may also denote a periodic activity of the fault marked by a short period of high seismic activity (0.2-0.5 ka) and a long interval seismic quiescence (4.3 ± 0.9ka).

ESC2018-S13-685

GANOS FAULT ZONE NETWORK: IMAGING NORTH ANATOLIAN FAULT ZONE IN THE WESTERN MARMARA REGION, TURKEY, BASED ON A DENSE LOCAL SEISMIC NETWORK

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The Ganos fault has been activated in a M7.4 event in 1912 and is believed to be a first-order linear and vertical fault that is currently locked down to ~15 km depth. A 40-station dense seismic network has been deployed in September 2017 at the northeastern part of the Ganos Fault to study the fault-zone geometry at depth. The station layout comprises a higher station density on top of the fault core/damage zone as well a larger inter-station distance away from the fault in different azimuths to ensure both high-resolution fault-zone imaging and good azimuthal coverage for locating local seismic events. Having a network across the fault is an efficient tool to gain a high resolution image of the fault at depth with several methods. These include imaging the velocity contrast across the fault using fault zone head waves, which arrive at a station before direct P arrivals in case the station is located on the slow side of the fault or using delay times of P arrivals from local events to identify damage asymmetry across the fault, which are of high importance due to their control on properties of earthquake ruptures. Preliminary results from GANOS network showed variations in seismograms of stations, including significant reflections, which are useful in identification of the properties of the fault zone and further investigations as will be presented and discussed.

ESC2018-S13-692

SEISMIC LAND STREAMER DATA REVEAL ACTIVE FAULTING AND FOLDING BENEATH THE SALT LAKE CITY URBAN CENTER

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An active source seismic land streamer campaign reveals the location, slip history and properties of faults beneath the downtown Salt Lake City, Utah urban corridor. From more than 15,000 shot gathers along 22 city paved streets, 35 km of two meter spaced seismic data provide detailed character of late Quaternary stratigraphy and tectonics within a step over region of the Wasatch normal fault system that defines the eastern boundary of the Basin and Range Province in the western US. We use first arrival tomography to obtain Vp distributions to 20-30 m depth, Rayleigh wave inversions to provide Vs profiles to about 30 m depth, and reflection imaging to 200-300 m depth to map the distribution of late Quaternary faults, folds, and lithologic boundaries. From these data, we provide 1) an updated city-wide Vs30 high frequency site response map, 2) stratigraphic mapping of transgressive and regressive paleolake Bonneville deposits, 3) distributions of tectonically induced lateral spread and colluvium deposits, 4) water table depths and zones of both confined and unconfined groundwater systems that influence liquefaction susceptibility, and 5) distributions of active faults related to the Wasatch fault system. We find that complex near surface conditions highlighted in both Vp and Vs tomograms directly relate to changing hydrostratigraphy and active faulting. We identify growth faults that contain both high and low Vp/Vs ratios that point to fluid and matrix properties within the faults. We also identify shortening within late Quaternary strata between within the step over region that constrains slip rates of the two active faults that extend beneath the downtown corridor. From these results, we reassess fault hazards for the urban portions of the Wasatch fault system.

ESC2018-S13-721

650 KM LONG ACTIVE STRIKE-SLIP FAULT REVEALED IN SOUTHERN MEXICO

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Secular GPS recorded velocity vectors are oblique to the Middle America trench (MAT) in the Guerrero and Oaxaca states of Southern Mexico. The along-trench GPS velocity components in this area abruptly diminish from the Pacific coast to the north by 4-5 mm/year across the La Venta-Chacalapa fault zone (LVC), which was so far considered as inactive paleo-fault. The LVC is striking at ~105 km inland from the MAT along the Pacific coast of Guerrero and Oaxaca states for approximately 650 km. The along-trench velocity slump represents a partitioning of the oblique convergence between the Cocos and North America plates with a sinistral motion of a forearc

sliver. Large, equivalent to Mw~7.5, subduction thrust slow slip events (tSSE) are periodically observed with the GPS data about every ~4 years in Guerrero, Mexico. The last tSSE was recorded 2017. Long-term GPS records show that the tSSEs are always accompanied by the strike-slip SSEs (sSSE) on the La Venta-Chacalapa fault. GPS displacement records in Guerrero reveal that during the inter-SSE periods the LVC fault is mainly locked, and the shear rate across it is only about of 2.0 mm/year. During the tSSE episodes there was a noticeable increase of lateral displacement on several GPS stations located on the coast, south off the fault, which is interpreted as the sSSE occurring on the LVC concurrently with the tSSE. The subduction zone in Guerrero may be an unusual region where the SSEs of two different types are occurring concomitantly.

ESC2018-S13-725

APPLICATION OF THE PROBABILITY-BASED ELECTRICAL RESISTIVITY TOMOGRAPHY INVERSION (PERTI) METHOD TO IMAGING TECTONIC FEATURES OF THE KISSAMOS AND PALEOHORA AREAS, WESTERN CRETE (GREECE).

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2D Electrical Resistivity Tomographies (ERT) were conducted in northwest and southwest Crete with the aim to model geotectonic features at selected sites. The study area is located within the central forearc of the Hellenic subduction zone. Thirteen ERT profiles were realized using the dipole–dipole electrode and/or the Wenner-Schlumberger arrays. In order to model the resistivity distribution, the probability-based electrical resistivity tomography inversion (PERTI) method has been applied. As testified by the comparison between ERT obtained with commercial software (e.g. the RES2DINV), the PERTI procedure provided a good performance in drawing geological sections. As a general property, it has been proved that the probability algorithm is independent of the technique used for their acquisition (WS or DD array) and acts as an intrinsic filter. Since there are strong evidence that the ERT obtained with the RES2DINV is in same cases influenced by noise and correlated phantom effects, the PERTI result provides a simultaneous smoothing of the uncorrelated noise along with a greater recognition capability of real structures. In principle, this property derives from the circumstance that such types of disturbances have zero probability of being associated with true anomaly sources within the context of the geoelectrical theory.

ESC2018-S13-726

INVESTIGATION OF THE BI-MATERIAL INTERFACE VELOCITY CONTRAST ALONG THE NORTH ANATOLIAN FAULT ZONE

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In this study, bi-material interface has been investigated throughout the western edge of the North Anatolian Fault Zone (NAFZ) between Sakarya and Sapanca segments by using teleseismic events in order to estimate lateral velocity contrasts across the northern and southern branches of the NAFZ in the same region. We used a waveform correlation technique to compare the differences between the observed and estimated teleseismic arrival times in the proximity of 71 broadband seismic stations of FaultLab Array which operated between early May 2012 to late September 2013, for 16 months. A total of 108 teleseismic earthquakes at epicentral distances greater than 30 degrees with magnitudes greater than 5.5 used for the analysis. The analysis of the delay differences indicates a velocity contrast across both branches of the fault in the study area as high as %12 and 35% with assumed bimaterial thicknesses of 35 km and 10 km, respectively. The findings play a significant role to minimize biases and errors in earthquake locations, fault plane solutions and source analysis for the future studies in the region.

ESC2018-S13-752

HIGH-RESOLUTION SEISMOLOGICAL DATA OF THE COLLALTO SEISMIC NETWORK REVEALS THE DEEP GEOMETRY OF THE MONTELLO BLIND THRUST (NORTHEAST ITALY)

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Faults images can be obtained by several techniques able to investigate the earth crust at different depths, each one featuring its own resolution power and uncertainties. Besides to surface structural or geomorphological analyses and some geophysical methods, typically useful to map the fault plane trace or to detect its existence in the first hundreds meters of depth, seismicity pattern analyses may outline the geometry of fault planes in the first kilometers of depth. In Northeast Italy, the Montello thrust belongs to the fold-and-thrust system of the Southern Alps. Even if not outcropping, this active fault has been recognized by integrating surface and sub-surface geomorphological, geodetic and geophysical data. From the seismological point of view the Montello thrust is defined 'silent', as no significant earthquake has been associated to it, neither in historical times, nor recently. Nonetheless, geometrical considerations assign it a very high seismogenic potential, as it is considered capable of earthquakes with M > 6. Over geological times, the activity of the Montello thrust has generated a gentle anticline, the Montello hill hosting a natural gas reservoir formed at about 1.5 km of depth. After its depletion, since 1994 this reservoir has been exploited as gas storage by Edison Stoccaggio S.p.A., and since 2012 it has been monitored by a local seismic network, installed for safety issues to detect the seismicity eventually induced by the storage activities. This monitoring network, named Collalto Seismic Network (in Italian Rete Sismica di Collalto, RSC), features high-resolution power as well as high sensitivity, being very dense above the reservoir and having sensors deployed underground for reducing the anthropic noise effect. In about six years of continuous recording, more than seventeen hundreds earthquakes have been located in a 50 km x 50 km area surrounding the reservoir, with local magnitude ranging from -1.8 and 3.8; a completeness magnitude of about 0.0-0.2 has been estimated in the area close to the reservoir. All the seismicity is located at more than 3 km distance from the reservoir boundaries, thus it can be considered entirely of natural origin for this kind of activity, according to the Italian Ministerial Guidelines for monitoring the underground activities. Moreover, the deep pattern of microearthquakes depicts a listric geometry likely corresponding to the Montello thrust surface. In this presentation, we describe the most recent and detailed picture of the natural microseismicity obtained by analyzing the data acquired by RSC. They provide the first clear imaging of the geometry and microseismic activity of the Montello thrust, a picture ever seen until the today's increase of monitoring capabilities.

ESC2018-S13-793

THREE DIMENSIONAL PASSIVE SOURCE DEPTH MIGRATION OF CONVERTED WAVES FOR CRUSTAL SCALE IMAGING OF THE MW 6.5 NORCIA EARTHQUAKE SEISMOGENIC ZONE (CENTRAL ITALY): FIRST RESULTS

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A detailed knowledge of the crustal structure in seismogenic areas is crucial to understand the mechanisms that play a key role in nucleation of earthquakes with moderate-to-large magnitude. Some studies demonstrate that reflected/transmitted mode-converted waves from passive source data can be exploited to image detailed crustal-scale seismic horizons related to strong impedance contrasts. In particular, three-dimensional (3D) depth-migration techniques, currently used in exploration seismology, have been successfully applied to process micro-earthquake signals in different tectonic contexts. We present the first results of the analysis and modeling of passive source mode-converted waves in the area of the 2016 Mw 6.0 Amatrice and 2016 Mw 6.5 Norcia earthquakes (Central Italy) where the INGV surveillance system located more than 90,000 earthquakes from August 2016 and March 2018. During the analysis of the seismic sequence high-amplitude secondary waves were observed. Due to their amplitude, polarization and dominant frequencies, some phases can be interpreted as SP transmitted waves generated at depths of shallow crustal discontinuities (down to 1-3 km depth) in the Norcia-Castelluccio region. In this area, the SP phases could correspond to the impedance contrast existing at the contact between the buried low-velocity turbidites deposits and the high-velocity carbonates located in the footwall of the Mt. Sibillini thrust. Other phases detected after the S-wave arrivals may be interpreted as

reflections at deeper impedance contrasts, probably close to the cutoff of the seismogenic zone. We relocate the seismicity of the sequence in a 3D tomographic model of the area using the first-arrival time pickings revised by the analysts of the Italian Seismic Bulletin and applying a non-linear, probabilistic hypocenter location algorithm. Then, selected passive sources having local magnitude lower than 2.0 and good location quality are fixed: the waveforms are migrated in depth with a technique similar to the Kirchhoff migration and using the 3D tomographic model as macromodel. We discuss our first results by comparing the migrated images with the current the geological models of the region.

ESC2018-S13-803

FAULT ZONE IMAGING FROM CORRELATIONS OF AFTERSHOCK WAVEFORMS

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Imaging the fault zone architecture is important for the understanding of fault and rupture behavior, and for the associated hazard and ground motion scenarios. Multi-scale resolution of the hierarchical fault structure requires an array of complementary investigation methods. Seismological imaging techniques for the study of fault zone environments include regional earthquake travel time and adjoint tomography teleseismic arrival time analysis, and reflection seismics. Better constraints on small-scale velocity variations associated with important structural and mechanical units such as fault cores or primary slip surfaces can be obtained from fault zone waves. Here we extend the use of earthquake array records for fault zone imaging. We reconstruct deterministic phases from multiple scattered wave fields by cross-correlating complete seismograms of aftershocks. We image an active fault zone environment using cross correlations of 154 15 s long 1992 M7.3 Landers earthquake aftershock seismograms recorded along a line array. A group velocity and phase velocity dispersion analysis of the reconstructed Rayleigh waves and Love waves yields shear wave velocity images of the top 100 m along the 800 m long array that consists of 22 three component stations. Estimates of the position, width, and seismic velocity of a low-velocity zone are in good agreement with the findings of previous fault zone trapped waves studies. Our preferred solution indicates the zone is offset from the surface break to the east, 100-200 m wide, and characterized by a 30% velocity reduction. Imaging in the 2-6 Hz range resolves further a high-velocity body of similar width to the west of the fault break. Symmetry and shape of zero-lag correlation fields or focal spots indicate a frequency and position dependent wave field composition. At frequencies greater than 4 Hz surface wave propagation dominates, whereas at lower frequencies the correlation field also exhibits signatures of body waves that likely interact with the high-velocity zone. The polarization and late arrival times of coherent wavefronts observed above the low-velocity zone indicate reflections associated with velocity contrasts in the fault zone environment. Our study highlights the utility of the high-frequency correlation wave field obtained from records of local and regional seismicity. The approach does not depend on knowledge of earthquake source parameters, which suggests the method can return images quickly during aftershock campaigns to guide network updates for optimal coverage of interesting geological features.

ESC2018-S13-809

RECONSTRUCTING THE GEOMETRY OF A FAULT-BOUNDED EXTENSIONAL BASIN BY INTEGRATING GEOPHYSICAL SURVEYS AND SHEAR WAVE SPLITTING ANISOTROPY: THE STUDY CASE OF PIAN GRANDE DI CASTELLUCCIO BASIN (CENTRAL ITALY)

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The Pian Grande di Castelluccio (PGC) located in the central Apennines of Italy is a Quaternary intermontane basin bounded by a normal fault-system responsible for the 30 October 2016 Mw 6.5 Norcia earthquake. Following this event, coseismic surface breakages occurred along one of the basin-bounding faults and a further splay in

the inner part of the plain. To constrain the shallow and deep geometry of the PGC, we integrate electrical resistivity tomography (ERT) and time-domain electromagnetic soundings (TDEM), focusing on a transect across coseismic ruptures within the plain. Here, the top-bedrock displays a bumpy topography and it deepens down to ~260-300 m below the ground level, due to the presence of previously unreported subsurface fault zones: they are characterized by a low-resistivity signature and throws of several tens of meters. We also analyze seismograms recorded by temporary stations to calculate horizontal-to-vertical spectral ratio (HVSR) curves of ambient vibrations and to estimate the splitting anisotropic parameters from small-magnitude earthquakes. The retrieved peak resonance frequency varies from about 1.5-2.0 Hz down to 0.4 Hz according to the topography of the top-bedrock as suggested by TDEM results. The pattern of shear wave splitting parameters indicates a dominant fault-parallel fast polarization direction for stations close to the basin borders and near the inferred subsurface fault zones, suggesting that crustal anisotropy in the PGC basin is likely controlled by the geological structures and, also, by the presence of a broad zone around the faults with fault-parallel cracks or shear fabric. By combining surface and geophysical data with shear-wave splitting analysis, we propose a geological cross-section depicting the PGC basin structure. The latter is a complex half-graben related to the interference of two fault systems of different age (possibly Early-Middle Pleistocene), the older one trending about N30° and the younger one trending about N150°. The latter is currently active and responsible for the present-day seismicity, moreover it episodically displaces the topographic surface during M > 6 earthquakes.

ESC2018-S13-811

RECONCILING THE CRUSTAL GEOLOGICAL MODEL AND THE 2016-2018 CENTRAL ITALY SEISMIC SEQUENCE: PRELIMINARY RESULTS AND NEW INSIGHTS FROM RETRACE-3D (CENTRAL ITALY EARTHQUAKES INTEGRATED CRUSTAL MODEL) ACTIVITIES

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The RETRACE-3D project has been launched as a challenging idea to develop a new, robust and of broad consensus, 3D crustal model of the area interested by the 2016-2018 Central Italy seismic sequence, gathering the multi-disciplinary skills of the Italian National Research Council (CNR, IGAG and IREA), the National Institute of Geophysics and Volcanology (INGV) and the Geological Survey of Italy (Department of ISPRA). This coordination was actively promoted by the National Department of Civil Protection, of which these research institutes are Competence Centers. Retrace-3D activities are based on the best available geological, geophysical and satellite datasets, with the main aims to: i) build up a high quality 3D model of the seismogenic sources of the crustal volume possibly involved during the seismic sequence; ii) redefine the 3D subsurface tectonic setting and distribution of the geologic units in those areas, to analyze the possible improvement of velocity models currently used to locate the seismicity; iii) better understand the potential role played by structural features inherited from previous tectonic regimes; iv) develop dynamic models of seismogenic structures through multiparameter optimization of ground deformations from remote sensing data; and, eventually, v) provide 3D crustal and velocity models to be tested for their possible application in future seismic micro-zonation studies. The project involves more than 50 researchers (the RETRACE-3D Working Group) from the aforementioned Competence Centers, collaborating on voluntary basis, sharing and distributing data among the participants. The study area was extensively investigated for hydrocarbon exploration and the whole seismic and deep well dataset has been kindly provided by ENI and TOTAL companies for the purposes of the project, along with their expertise. Surface geological data have been harmonized and codified according to a regional stratigraphic and structural scheme, together with velocity, gravimetry, magnetometry, tomography and Receiver Function data. We present here the preliminary results of the 3D geological modeling in time domain obtained by the interpretation of the seismic profiles and deep wells dataset, also integrating the available information extended to

the depths of the whole 2016-2018 Central Italy seismic sequence coming from other seismological studies. Preliminary results show the first order 3D underground structural architecture of the study area down to the seismogenic depths, which allow inferring on the relationships between the distribution of the 2016-2018 seismic events and the principal discontinuities recognized and reconstructed into the crustal volume. The 3D model in time domain will be depth converted using a dedicated 3D velocity model and integrated with grav-mag modeling and tomography. A following phase of geometric and kinematic validation, together with a crosscheck with independent information of coseismic surficial effects, is expected to contribute for the identification of possible inconsistencies and the general improvement of the geological model robustness. A final model will also serve as a starting point for following geomechanical numerical simulations. We believe that the benefit of RETRACE-3D is represented by the development of a multi-expertise coordinated working group, formally organized, in which the different teams operate in a harmonized frame to gain altogether a shared result. Being this result achieved in the frame of the Civil Protection field of interests, it has not only a scientific value, but also a societal one. Moreover, the large number of involved investigators from several research institutes as well as the publication of main results on mainstream platforms makes the project objective much more easily accessible also for civil protection purposes, representing the outcome of a large and qualified community idea. Finally, the framework of integrated activities proposed by RETRACE-3D would also represent a "ready-to-go tool" that could be easily exported for the achievement of similar objectives in others areas.

ESC2018-S13-848

SHALLOW HIGH-RESOLUTION GEOPHYSICAL INVESTIGATION ALONG THE WESTERN SEGMENT OF THE VICTORIA LINES FAULT (ISLAND OF MALTA)

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The Victoria Lines Fault (island of Malta) is a 15 km-long and WNW-striking segmented normal fault-system, probably inactive since the late Pliocene. In the westernmost part, the Fomm Ir-Rih fault segment hosts in its hangingwall thin patches of Middle Pleistocene clastic deposits (red beds), poorly preserved elsewhere. We acquired two seismic transects, by collecting ambient vibration recordings, processed by using horizontal-to-vertical spectral ratios (HVSR), complemented by one high-resolution 2-D refraction tomography survey crossing this fault, locally covered by red beds and recent colluvium.
A clear seismic signature characterizes the Fomm Ir-Rih segment of the Victoria Lines Fault, mostly due to low seismic velocity and high amplification of ground motion. The HVSR functions show a peak at 1.0 Hz in the hangingwall block, whereas clear peaks in the range 5.0-10.0 Hz appear when approaching the subsurface fault, and we relate them to the fractured bedrock within the fault zone. The Vp tomography (performed by non-linear inversion of handpicked first arrival traveltimes) shows a high-Vp shallow body (Vp 2200-2400 m/s) that we relate to the weathered top of the Miocene Upper Coralline Limestone Fm., bounded on both sides by low-Vp regions (1400 m/s). The latter are the smeared images of steep fault zones. We further image a thick (15-20 m) low-Vp (1000 m/s) zone, which could be a syn-tectonic wedge of colluvial deposits developed in the downthrown block. We also perform multi-channel surface waves analysis (MASW). The results indicate lateral changes of the average shallow shear wave velocity, with Vs 130 m/s within the inferred fault zone, and Vs > 230 m/s above the weathered top-bedrock. We hypothesize that, during the Middle Pleistocene, activity of the Fomm Ir-Rih fault may have affected the basal part of the red beds, so that this segment of the Victoria Lines Fault may be considered inactive since 0.6 Myr ago.

ESC2018-S13-853

IMAGING THE LEIPZIG-REGENSBURG-ZONE (EAST GERMANY) APPLYING MOMENT TENSOR INVERSION TO LOW MAGNITUDE LOCAL EARTHQUAKES

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The Leipzig-Regensburg-Zone (LRZ) is a region of increased seismic activity in eastern Germany. Since the year 2000 the universities of Leipzig and Jena together with Saxon State Office for the Environment, Agriculture and Geology and Thuringian Regional Office for the Environment and Geology established a dense regional seismic network. From this network a comprehensive seismological database has emerged with a magnitude completeness of ML -0.5. The largest observed earthquakes had magnitudes of ML 3.5, although there are records of historical earthquakes near the city of Gera with estimated magnitudes ML 5. In contrast to the NW-SE striking major tectonic features in the region of central Germany, the earthquake distribution of the LRZ is along N-S direction in a 40 km broad strip that is not related to a single major fault. The LRZ could be seen as an extension of the highly seismic active Eger-Rift in the north west of the Chech Republic, but the source characteristics are quite different. It lags the typical earthquake swarms and the sources tend to be deeper. Moment tensor solutions are well established in global seismology and an optimal tool to better understand source mechanisms. Nevertheless, it is difficult to get stable moment tensor solutions for low magnitude local earthquakes. Our aim is to calculate moment tensor solutions as low as ML 2.0. In order to get results with good error estimations we use the Grond-package based on the Pyrocko-tool-box developed by Sebastian Heimann (GFZ-Potsdam). This package is based on a bootstrap algorithm to calculate the moment tensor solutions and provides an excellent estimation of the solution errors, but is computationally demanding. So far, we are able to gain stable solutions down to ML 2.5. For the inversion of events below ML 3 it has proven to be advantageous to use not only P- and S-waveforms but also the amplitude spectra as an inversions target. The resulting high quality moment tensor solutions will enable us to perform stress analysis of the area and provide new insights in the earthquake and fault dynamics of the Leipzig-Regensburg-Zone. Therefore, it will be useful for improving hazard assessment in this region.

ESC2018-S13-889

SEISMIC IMAGING IN TECTONIC ENVIRONMENT BY ANALYZING MICRO-SEISMICITY: INFERENCES ON FLUID-DRIVEN EARTHQUAKE PROCESSES AT THE IRPINIA FAULT SYSTEM IN SOUTHERN ITALY

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This study focuses on the active faults system that ruptured during the Ms 6.9, 1980 Irpinia earthquake, the strongest and most destructive seismic event of the last decades in southern Italy. An integrated, multi-constrained and multi-scale picture of the upper crustal structure of the Irpinia active faults system was obtained by combining geological evidences, lithological properties, accurate, double-difference relocated, micro-seismicity pattern, high resolved P- and S-wave velocity and attenuation tomographic images and information about rock micro-parameters (porosity, type of permeating fluids, saturation percentage, and consolidation parameter) [Amoroso et al. 2014, 2017; De Landro et al., 2015]. The double-difference location was obtained applying an innovative, non-linear, probabilistic and relative location technique implemented in the NonLinLoc package. The high resolved 3D velocity model was obtained using an iterative and linearized tomography approach in which the P and S arrival times were inverted for the earthquakes location and velocity values. Attenuation model was obtained using the same approach applied to the t* (i.e., the ratio between travel time and attenuation quality factor) measurements obtained by Zollo et al. [2014]. The high-resolution and low-smearing model regions, are estimated through the analysis of the derivative weight sum, the resolution matrix and checkerboard tests. For the rock micro-parameters estimation, we considered a method in which the retrieved values of velocities and attenuations are our input data set, following a downscaling procedure. Using the Pride (2005) poro-elastic theory, we developed an up-scaling procedure and from the direct comparison between up-scaled and tomographic macro-parameters, we recovered the estimates of host rock micro-parameters (i.e., porosity, relative saturation of a two-phases fluid and fluid types). We performed this comparison for all discrete

nodes available within a rock volume containing Irpinia earthquake hypocenter in order to obtain a 3D micro-parameters image. The relocated micro-seismicity, approximately confined within the same volume of the 1980s Irpinia earthquake faults, is absent in the volume bounded by the first and the second fault segments activated during the event. We hypothesize that this geometrical barrier could have played a key role during the 1980 Irpinia event, and possibly has controlled the delayed times of activation of the two rupture segments. The velocity images down to 20 km depth reproduce the main lithological units and discontinuities within this portion of the Apennines chain, showing evidence of a wide and confined high VP/VS and low VP×VS volume, co-located with the present-time background seismicity. The QP model reaches the highest values in the volume containing the Irpinia 1980 event hypocenter between 8-12 km depths. The QS model also shows strong lateral variations along a SW-NE direction with a major variation occurring in correspondence with the 1980 earthquake rupture. In the volume in which QP reaches its highest values, at about 10 km depth, we constrain the porosity and consolidation in the ranges 4–5% and 5–9, respectively, with the possible fluid mixes being both brine-CO2 and CH4-CO2. The consolidation parameter range indicates high pore pressures at these depths. These results indicate that the investigated volume is a geologically complex and intensely fractured system. At location where the 1980 earthquake faults dislocated and where most of the current micro-seismicity occurs there is evidence of gas saturation and high pore-pressure,. This suggest that the most probable seismicity triggering mechanism at the fault zone is related to the fluid-induced pore pressure changes.

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ESC2018-S13-905

SEISMOTECTONIC MAP OF THE NORTHERN SICILY CONTINENTAL MARGIN (NSCM) AND IMPLICATIONS FOR GEOHAZARD ASSESSMENT

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The Sicily dominates the central Mediterranean Sea. The Northern Sicily Continental Margin (NSCM) is a segment of the Appeninic-Tyrrhenian System whose upbuilding refers to both the post-collisional convergence between Africa and a very complex “European” crust (Bonardi et al., 2001) or AlKaPeKa (sensu Boullin, 1986) and the opening of the Tyrrhenian back-arc basin. Seismo-stratigraphic and structural analysis of a large number of available (from ViDePi project) and unpublished (from Department of Earth and Marine Science of the University of Palermo) multichannel seismic reflection profiles acquired across the NSCM, allow us to produce an accurate seismotectonic map, in order to obtain a useful tool for the assessment of the seismic hazard of the sea-land region. This first seismotectonic map has been realised from the overlapping of different geological layers that represent the main identified seafloor and sub-seafloor features, such as tectonic elements (normal and revers faults), earthquakes, heat flow, gravimetric (Bouguer) and magnetometric anomalies, Moho depth, mass-wasting, fluid escape structures (e.g. pockmarks,

mounds, gas flares, and gas chimneys), sedimentary successions, and lateral and vertical motions. The NSCM is suitable to test this approach because it is located in a transitional area between the Sicilian-Maghrebian chain to the south and the Tyrrhenian back-arc basin to the north. Along this transect the Moho depth ranges from about 10 km, in the Marsili bathyal plain, to about 40 km, towards the northern Sicily coast. The Bouguer anomalies change from 180 mGal in the Tyrrhenian region to negative anomalies in central Sicily (-100 mGal), while positive magnetic anomalies characterize the volcanic edifices, both submerged and buried. While, the heat flow shows very high values across the southern Tyrrhenian Sea (200 mW/m-2) that decrease (30-40 mW/m-2) towards the stable sector of the foreland area (Iblean plateau in SE Sicily). Along the NSCM, we distinguished, at a regional scale, different shallow and deep seismogenetic volumes. The eastern part of the Sicilian continental margin is characterised by a deeper seismicity related to the Ionian subduction, which is prevailingly linked both to extensional fault systems (Pollina, Messina strait) and to right-lateral NW-SE transcurrent systems (Vulcano-Lipari and Tindari-Giardini). While the western region shows shallow earthquakes (up to 25 km) of low to moderate magnitude (max Mw 5.9 on September 2002) occurring along an E-W trending belt and resulting from the brittle deformation of the Maghrebian chain. The focal mechanisms related to the main seismic shocks are in agreement with a dominant NW-SE compressive offset direction, with a right strike-slip component, and an antithetic NE-SW fault trend.
Evidences of mass-wasting processes have been identified across the continental shelf and the continental slope and their spatial distribution, geometry, and seismic character suggest that the fluid seepage, oceanographic processes and the slope oversteepening could be important preconditioning factors, while the tectonic activity showing fault displacements during earthquakes is the main trigger. During the last 125 ky tectonic activity is evidenced by an uplift/subsidence patterns, decreasing from E to W. The continental regions are raised while offshore areas are subsiding, suggesting the occurrence of vertical differential movements. The GPS measurements document the active deformation with differential movements of individual blocks northward-directed, in agreement with the shallow seismicity, as well as with the convergence between Sicily and Sardinia, with values of about 2-6 mm/y. The first step of this work produced the detailed seismotectonic map between the Castellammare and Palermo gulfs, including both the terrestrial and marine areas. Across the NSCM, we defined two main seismogenetic volumes that are produced by a NW-SE oriented compressional stress field defining an intraplate shallow seismogenetic zone. Though these results are only preliminary, we are developing a scientific product that can provide useful information in terms of seismic hazard in a complex region that includes both continental and marine sectors. Therefore, the identified geological features may be potentially geohazard elements for the neighbouring population and for the near goods, as well as submarine infrastructures (i.e. cables) and our seismotectonic map represent an important tool for monitoring the potentially seismogenic structures and assessing geohazards in marine and coastal environments.

ESC2018-S13-911

TOWARDS A JOINT INTERPRETATION OF VP, VP/VS AND RESISTIVITY MODELS OF THE HIGH AGRI VALLEY (SOUTHERN ITALY)

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The interpretation of earth subsurface models provided by the inversion of geophysical data is a very subjective issue of any geological study. Therefore, in order to have more constraints for the interpretation of geophysical models, very often a comparison between properties inferred by the inversion of different kind of data is carried out. We present a geophysical study of the High Agri Valley (southern Italy), which is a region characterized by a very high seismogenic potential. In addition to its natural seismicity, there were documented a) fluid-induced microseismic swarms due to the injection through the CM2 single-well of the wastewater produced from the exploitation of the Val d'Agri oil field, the biggest on-shore oil field in west Europe; b) continued reservoir induced seismicity due to effects of the presence of the artificial Pertusillo

lake. These two kinds of seismic activity are clustered mainly SW of CM2 injection well and SW of Pertusillo lake, respectively. Several works carried out in this region in the recent past demonstrated the importance of the pore fluid pressure diffusion in the triggering processes of earthquakes in this area. In our work, independent geophysical data were integrated through the comparison of 3-D seismic velocity models, earthquake locations and resistivity model. The first two results were retrieved by inverting P- and S-wave arrival times recorded in the period January 2002-December 2012 by the seismic stations belonging to the trigger-mode network managed by ENI Oil Company; in addition to them, the arrival-time dataset was integrated with data provided by the temporary seismic network installed in the High Agri Valley by INGV in the period 2005-2006. A very high-resolution 3-D tomographic model was retrieved in the subsurface volume where the two main clusters of seismicity are located. Furthermore, a 2-D resistivity model was obtained from the inversion of data collected by a MagnetoTelluric (MT) survey performed in the area. It consisted of about 28 soundings aligned along an about 30 km long profile oriented at about N40 direction, crossing both clusters of seismicity. The comparison of earthquake locations with velocity and resistivity models allowed us to have a better understanding of the shallow structural setting of High Agri Valley. Furthermore, a new insight on rheological properties of the subsurface, mainly in terms of presence of fluids permeating the rocks, is achieved.

ESC2018-S13-1031

VP/VS ESTIMATION FROM DIFFERENTIAL TIMES

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VP/VS, the ratio of seismic velocities of P and S waves is widely estimated parameter used for description of rock medium the waves are propagating through. In this work we focused our efforts to develop and test methods allowing its estimation with high spatial resolution - estimating VP/VS of Earth's volumes densely covered with clustered earthquakes, like earthquake swarms, hydraulic stimulation induced earthquakes etc. For this purpose two methods are presented: a double difference Wadati method and modified master-event method. The first one is fully applicable on earthquake clusters with dimensions much shorter than hypocentral distances and expected geology is 'straightforward' - can be approximated by a layered velocity model with VP/VS increasing towards surface. The method makes use of absolute differential times between P and S waves of paired earthquakes and doesn't need the information on event locations or origin times. The latter method - modified master event - is a standard master event relocation technique where seismic velocities are not assumed to be a-priori known and are searched by grid search. The method requires a high quality data and produces unbiased results even for complex geologies expressed by complicated velocity models (with velocity ratio inversions). Both method were applied to earthquake swarm data from West Bohemia. In the area the activity is believed to be triggered by overpressured fluids in focal zone and decreased VP/VS is associated wit this effect. Both methods show expected results and revealed temporary decrease of velocity ratio bellow 1.6 against velocity model predicted 1.73.

ESC2018-S13-1047

FIRST RESULTS OF A REPROCESSING WORKFLOW ON A 2D VINTAGE REFLECTION SEISMIC PROFILE ACROSS THE AREA STRUCK BY THE 2016 MW 6.5 NORCIA EARTHQUAKE (CENTRAL ITALY).

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Starting from the August 2016, the Central Italian region was struck by a series of strong earthquakes characterized by 9 events of Mw > 5 and a mainshock of Mw = 6.5 occurred the 30th October 2016 (Chiaraluce et al., 2017). This destructive event enucleated at about 7 km depth between Norcia and Mt. Castelluccio di Norcia basins (Monti Sibillini chain), generating impressive surface ruptures particularly visible along the Mt. Vettore fault (Pucci et al., 2017). However, despite a large amount of datasets collected by geoscientists, several studies published so far and even currently in progress,

the definition of the subsurface structure of the area is a challenge. Recently, a geological model has been proposed by Porreca et al. (2018), integrating surface geology, seismological and subsurface data, including boreholes and vintage seismic reflection profiles of variable quality. In particular, the time-migrated seismic section labelled NOR2, intercepting both the basins of Norcia and Castelluccio di Norcia, displays a low-medium quality depending on several factors: different lithologies, highly variable topography and structural complexity, but also some "migration smiles" contaminating the data from its bottom sector. Following such considerations, we decided to reprocess NOR2 to improve the interpretability of the subsurface geological structures. We restarted the analysis from the raw data (courtesy of ENI S.p.a.) aiming to experiment an accurate revision of the processing flow, in order to generate a new stack section: among the main steps, we focused on the velocity analysis, static corrections and filters, aiming to increase the data Signal-to-Noise (S/N) ratio. We have initially revised the entire analog and digital material available and then we imported the SEG-Y data in Claritas software. After a first analysis of the raw data, we revise all the acquisition parameters. The shot gathers were collected using explosive sources, for a total number of about 61000 traces characterized by 2 ms of sample interval and a record length of 9.2 s. After setting-up the geometry, we have first killed the noisy traces, then we recovered the amplitudes and designed customized filters to suppress the very high and low frequency noise components. Following the application of the source/receiver statics and a topography correction, we corrected for the Normal Move Out using a customized velocity model. A post-stack FX-deconvolution was finally useful to increase the continuity of reflectors. The new stack section obtained displays several improved details that may contribute to enhance the interpretability level of the line, shedding light on the subsurface structure of the study area. The Norcia and Castelluccio di Norcia basins are clearly detectable following the discontinuity between the Quaternary deposits and the underlying bedrock. Reflectors continuity and discontinuity aid to delineate the main faults of the area, like the steep W-dipping Monte Vettore fault. Below about 3.0 s depth, clear high-amplitude E-dipping reflectors allow to extend more in depth previous interpretations. The results of this work confirm that a reprocessing effort done on vintage seismic lines, originally collected for oil/gas exploration, may help to improve the knowledge on the subsurface structures in tectonically complex areas. Our workflow represents an effective approach to valorize such unique datasets collected using configurations (e.g. explosives sources) and economical resources nowadays difficult to achieve in Central Italy.

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SESSION 14

EARTHQUAKE RUPTURES AND LONG TERM RATES OF OCCURRENCES IN FAULT SYSTEMS

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In the past decades, fault segmentation provided an important framework for quantifying fault-based PSHA and several features were proposed as potentially factors that control the location and length of seismic rupture. However, in the last years, complex coseismic ruptures (e.g. 2010 M 7.1 Canterbury, 2012 Mw 8.6 Sumatra, 2016 Mw 7.8 Kaikoura, 2016 Mw 6.5 central Italy) imposed to pay particular attention to the treatment of all possible combinations of rupture scenarios for PSHA. In particular, as regards the modelling of complex fault ruptures and the evaluation of possible fault-to-fault earthquake ruptures, Chartier at al. (2017) published a new approach, SHERIFS (Seismic Hazard and Earthquake Rate In Fault Systems) that allow converting the slip-rate of each fault in earthquake rates, by means of an iterative random procedure that selects different rupture scenarios, composed of both single fault and complex fault ruptures. This work presents two alternative approaches to evaluate the long-term rate of earthquake ruptures in complex fault systems: SUNFiSH (SUbsectioNs of Fault in Seismic Hazard) and FRESH (Floating-Rupture for Seismic Hazard). SUNFiSH's approach is the following: (i) the entire length of a fault system is divided into several equal-length subsections, whose length is about half of the seismogenic thickness; (ii) the minimum rupture length is imposed to be approximately equal to the seismogenic thickness, therefore, a rupture must contain at least two adjacent subsections; (iii) a slip-rate value is assigned to each rupture; (iv) size and slip rate of the rupture are used to compute the seismic moment rate of that particular rupture; (v) a target value of the total seismic moment rate of the fault system is used to normalize the sum of the seismic moment rate of each rupture; (vi) the seismic moment rate of each rupture, after normalization, is used to build a magnitude-frequency distribution. FRESH's approach is articulated in the following steps: (i) generating ruptures for each expected magnitude according to a magnitude–area scaling relationship (e.g., Wells and Coppersmith, 1994), given an aspect ratio value; (ii) ruptures are placed on all possible locations on the fault surface, ruptures characterised by a surface lower than the whole fault surface are floated to cover the fault surface; (iii) a slip rate is assigned to each of these ruptures, by computing the integral mean of the slip rate profile between the two endpoints of the rupture length; (iv) magnitude and slip rate of each rupture are used to compute the rate of occurrence of that particular rupture; (v) a target value of total magnitude-frequency distribution of the fault system is used to normalize the sum of the rate of occurrences of each rupture for a certain magnitude. We show results of a comparison of PSHA using SHERIFS, SUNFiSH and FRESH with the geometries and slip rates provided in an available seismogenic source database (DISS 3.2.0, http://diss.rm.ingv.it/diss/) for the faults of the Montello fault system, located in NE Italy, and assuming a specified maximum magnitude and seismic moment rate. These three approaches were also compared with two methods not including fault-to-fault rupture. Beyond the PGA hazard maps resulting from the 3 FtF approaches, which closely reflect the variability and complexity of geological information, the aspect that we consider important to highlight is that by anticipating the possibility of complex earthquake ruptures will hopefully reduce the number of "surprising events" in the future.

Acknowledgments
Authors warmly thanks the FAULT2SHA members group for fruitful discussions and suggestions on the overall complex fault topics. We also thank Graeme Weatherill for the help with the OpenQuake python tool to build ruptures for FRESH, and Pierfrancesco Burrato for the detailed information on the slip rate. FV is supported by FIRS 2016 - Visini F. - 0865.054 and CPS funds. A.V. is supported by Department INGeo funds (I. Raffi, responsible for "fondi dottorato" fund). T.C. is supported by AXA Research Fund. B.P. is supported by Department DiSPUTer funds (B. Pace, responsible for "ex 60%" fund).

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ESC2018-S14-114

THE GROWTH OF A CONTINENTAL FAULT SYSTEM IN THE ALBORAN SEA CONSTRAINED BY GEOLOGICAL AND SEISMOLOGICAL DATA

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Plate boundaries are defined by their seismic activity. In these tectonically active areas, well-delineated faults generate large earthquakes that over time become topographic features, implying a seismic hazard. These paradigms are called into question in the Alboran Sea, which hosts a complex boundary between the Eurasia and Nubia plates. On the 25th January 2016, a magnitude Mw 6.4 submarine earthquake struck the north of the Moroccan coast, the largest event ever recorded in the Alboran Sea. The quake was preceded by an earthquake of magnitude Mw 5.1 and was followed by numerous aftershocks whose locations mainly migrated to the south. The mainshock nucleated a releasing bend of the poorly known Al-Idrissi Fault System. According to slip inversion and aftershock distribution we assume a rupture length of 18 km. We use both seismological and geological data (i.e. multi-scale bathymetric and marine seismic reflection data with a resolution comparable to the studies on land) to document Quaternary activity on the >100-km-long Al-Idrissi Fault System, the largest structure of the Trans-Alboran Shear Zone that cuts in two the prominent South Alboran Ridge thrust fault. We report evidence of left-lateral strike-slip displacement, characterize their fault segments and demonstrate that Al-Idrissi is a basement fault, source of the 2016 earthquake events. Located along a lithospheric boundary, the Al-Idrissi Fault System is a young structure. Its central segment, transpressive, developed during the Early Pliocene while the north and south transtensional segments are of Quaternary age. All these observations suggest that the Mw 6.4 earthquake has been able to break adjacent fault segments. Thus, propagation and linkage of the Al-Idrissi Fault System with neighbouring faults might generate a greater rupture (up to Mw 7.6), increasing the potential hazard of the structure.

ESC2018-S14-137

ACTIVE TECTONIC STRUCTURES IN THE GULF OF CADIZ: A MULTISCALE VIEW

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The Gulf of Cadiz is located in the southwestern margin of Iberia, along the NE-SW convergence between the African – Eurasian plate boundary (3.8-5.6 mm/yr). The area has been the source of historical and instrumental earthquakes, most of them with a moderate magnitude (Mw ≈ 5.5), although large and great earthquakes also occurred in the area, such as the 1st of November 1755 Lisbon earthquake and tsunami (Mw 8.5) and the 28th February 1969 Horseshoe earthquake. Recent studies of turbidite paleoseismology in the external part of Gulf of Cadiz found that the regional recurrence interval for Great earthquakes (Mw ≥ 8) is about 1800 yr. We have investigated the Gulf of Cadiz area for more than 15 years, carrying out bathymetric, sidescan sonar, shallow and deep multichannel seismic, wide-angle seismic and sediments sampling surveys. We focus our investigations on active structures located at the external part of the Gulf of Cadiz, corresponding to two main families of active faults compatible with the current plate convergent in the region: the WNW-ESE dextral strike-slip faults (Lineaments) and the NE-SW thrusts faults. The activity of these lineaments (Lineament N and S) is demonstrated by the presence of deep (>4 km) mud volcanoes formed along the faults traces, evidence of rising deep fluids and formation of gas hydrates, as well

as their seismic activity, characterized by shallow to intermediate depths (8-55 km). The LS, is a dextral strike-slip fault of more than 600 km long, and has been considered as the boundary between the African and Eurasian plates. Regarding the NE-SW trending faults, they consist of thrusts, and they are active since the Neogene. The main faults are: (1) The Marquês de Pombal Fault a 55 km long west verging monocline thrust and characterized by the presence of mass movements, likely triggered by earthquakes. (2) The Horseshoe Fault is an NE-SW trending, 110 km-long anticline thrust. (3) The Coral Patch Ridge Fault is a 160 km long fault with a rhomboidal shape that separates the Horseshoe Abyssal Plain from the Seine Abyssal Plain. There are composed by two main anticline NW-verging thrust faults. These faults cut, fold and show growth-strata configuration in the most recent sedimentary units of Holocene age, indicating that they are active. (4) The Gorringe Bank is by far the most prominent structure in the Gulf of Cadiz. It is a compressive structure raised by a large-scale thrust over the Tagus Abyssal Plain. Nowadays, the Gorringe Bank is a source of low-magnitude seismicity located at depths between 20 and 40 km. In the forthcoming INSIGHT cruise (May 2018) we will carry out specific high-resolution surveys in some of these areas to obtain detailed and accurate high-resolution data of seismogenic structures. In this cruise, we will use the AUV "Abyss" to carry out microbathymetric survey and ultra-high resolution seismic profiles. The new information will be complete with high-resolution 2D multichannel seismic profiles. High-resolution multiscale data will allow us to carry out an accurate interpretation and understand better the active tectonic processes occurring in the Gulf of Cadiz.

ESC2018-S14-231

INPUT GROUND MOTION FOR SITE EFFECTS ASSESSMENTS FROM FAULT-BASED PSHA: CENTRAL ITALY AFTER THE 2016 M6.5 NORCIA EARTHQUAKE

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This work focuses on how the progress in earthquake science that follows a large, deeply-studied earthquake might be promptly combined with updated approaches of seismic hazard analysis to guide applicative choices of seismic risk reduction, such as post-event Seismic Microzoning (SM) and building design. Both SM and seismic design of structures require strong motion records to perform numerical site response analyses. These records have to be related to the seismotectonic contest and historical seismicity of the investigation area. In this paper, we first performed a fault-based Probabilistic Seismic Hazard Analysis (PSHA) in the area struck by the 2016 Central Italy seismic sequence to individuate reference Uniform Hazard Spectra (UHS) at rock conditions. In particular, we used two different earthquake models, one considering twenty-seven individual seismogenic sources in the surrounding of 2016 epicentral area, and the second one involving grid-point seismicity, with a fixed-radius smoothed approach and the historical catalogue used to evaluate seismic activity. The geological and seismotectonic data of the 2016 seismic sequence were used to update the model of individual seismogenic sources. Then, we performed a deaggregation analysis to evaluate the contribution of the individual seismogenic source in the hazard of four representative sites and to select the magnitude-distance (M-R) pairs useful in the selection of the real accelerograms. The deaggregation analysis has been performed for different spectral acceleration and for different values of magnitude. Finally, we select, for each site, a set of natural accelerograms based on the M-R pairs and compatible on average with target UHS spectra

ESC2018-S14-340

STRUCTURE AND SEGMENTATION OF THE OVINDOLI - PIANO DI PEZZA - CAMPO FELICE FAULT SYSTEM (CENTRAL APENNINES, ITALY) AND IMPACT ON SEISMIC HAZARD ASSESSMENT

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Active deformation in the Central Apennines is mostly accommodated by NW-SE normal faults systems triggering moderate to large earthquakes

at shallow depth. Recent examples include the 1915 Mw≈7 Avezzano earthquake (Fucino basin) and the 2009 Mw=6.1 L'Aquila earthquake (Aterno basin) which were both associated with major loss of life and massive damage to buildings and infrastructure. Here, we study the 40-km-long Ovindoli – Piano di Pezza – Campo Felice – Monti d'Ocre (OPCM) fault system, a major NNW-SSE system that potentially links the Fucino and the Aterno fault-systems. The OPCM exhibits linear and arcuate sections with four main segments, from south to north: the linear N-S-trending Ovindoli fault (OF), the arcuate N-S- to E-W-trending Piano di Pezza fault (PPF) and Campo Felice fault (CFF) that branch out from the OF, and the linear Monti d'Ocre fault (MOF) that borders the eastern margin of the Aterno basin. Paleo-earthquake rupture data on the PPF and CFF exhibit remarkable rupture synchronicity with the Fucino fault system, with the most recent surface-rupturing earthquake likely occurring in the XIVth century. In order to better understand the relationships between these four segments and assess potential earthquake rupture scenarios, we focus on the basin geometry and fault surface expressions of the Piano di Pezza and Campo Felice structures, combining geomorphology and subsurface geophysics. Our observations suggest that the fault segments displaying a horsetail-like geometry are actually the surface expression of a major strike-slip fault (OF) which re-activated pre-existing arcuate reverse faults that formed during the Mio-Pliocene compressive stage as normal faults (PPF and CFF; see companion contribution by Gautier et al., ESC 2018). Hence, possible earthquake ruptures along the OPCM structure may encompass scenarios involving one, two or three segments depending on the rupture initiation and propagation direction. We test the impact on seismic hazard assessment of these various scenarios by calculating hazard curves at key regional locations (e.g., Avezzano, L'Aquila, Rome) for scenarios that involve the whole OPCM fault system (cumulative rupture length ca. 40 km) or rupture termination along the PPF (cumulative length ca. 15-20 km). Additionally, we explore the role of the OPCM structure in a potential strain transfer from the Aterno to the Fucino systems, a major question in terms of regional seismic hazard, in particular regarding the potential activity of mapped faults outside of the primary Aterno – OPCM – Fucino active system.

ESC2018-S14-397

FIRST STEPS OF THE FAULT2SHA-BETICS GROUP: DISCUSSING FAULT RUPTURE HYPOTHESES WITH THE HELP OF THE SHERIFS APPROACH

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In the last years, geological data has become increasingly more important to model seismogenic sources in different regions of the world. One of the shortcomings of this approach is the lack of communication between data users and data providers when it comes to consider faults data as inputs into seismic hazard assessments. For this reason, the FAULT2SHA ESC working group was born in 2014 to motivate communication between field geologists, fault modellers and seismic hazard practitioners. Within this framework, in 2017 we created the FAULT2SHA-Betics group, devoted to share active tectonics data from the faults of the Eastern Betic Shear Zone (EBSZ, SE Spain), to develop common standards in the estimation of crucial parameters (e.g., slip rate) for these faults, and learn and experiment about fault-source modelling. The EBSZ was chosen by the Fault2SHA group as a working laboratory for testing fault-source seismogenic models, since it is a major tectonically active area in Europe and its seismic potential is under debate. To take the first steps of the work, more than 20 earthquake geologists/geophysicists with previous experience in the EBSZ were involved. In November 2017, most of them (18 participants) gathered in a two-days seminar in order to 1) promote a constructive discussion on the currently available geological data of the faults that form the EBSZ and 2) come up with agreed values of different seismic parameters (i.e. fault rupture models, slip rate) and the uncertainties affecting them. This general meeting and further group-sessions pinpointed the variety of sources of uncertainty, often not properly defined in publications. These are, for instance, coming from age dating methods, the measurement of the slip

or the source geometrical complexity. As a result, we agreed on the need to 1) use a common representative time frame (upper Pleistocene) to express the slip-rate, 2) simplify the fault source geometries and 3) try to define fault sectioning rules adapted to the Betics' tectonic setting, which might differ from those published for Italy and California. Among the main achievements of this collective work was the definition of five different earthquake rupture hypotheses/models for the EBSZ, not envisaged to date, in which the main active major faults of the area are involved. These rupture hypotheses seem structurally and geodynamically feasible and, some of them, consider a linking behaviour among the different fault sources (multi-fault ruptures). The data agreed for the EBSZ allowed us to preliminarily implement the SHERIFS approach of Seismic Hazard and Earthquake Rate Modelling In Fault Systems, developed by Chartier et al. (2017) in the frame of the FAULT2SHA group. This method allowed us to calculate the rate of ruptures of the faults considering a Gutenberg-Richter (GR) magnitude-frequency distribution (MFD) defined at the system level and for five different hypotheses of multi-fault ruptures explored. Then, we performed a "consistency check" to analyse the fit between every modelled MFD and the short-term seismicity rates deduced from the regional seismic catalogue. We observed that the four hypotheses that allow multi-fault ruptures produce maximum magnitudes (Mwmax) over 7.0-7.5 and up to 8.0 in some cases. The mean cumulative annual rates for these Mwmax are between 10-5-10-8 earthquakes/year (eq/yr), being the hypotheses with largest ruptures the ones with lower annual rates. The hypothesis that does not allow multi-fault ruptures, produces lower Mwmax (around 6.5-7.0) with mean rates of 10-4-10-6 eq/yr. For the consistency check, we observed that the hypothesis that allows the propagation of multi-fault ruptures within three separate fault sub-systems but not between them has the most consistent fit with the short-term seismicity data and predicts its annual rates especially well for Mw between 4.0-5.0. Thus, this is our preferred model. Conversely, the modelled GR MFDs from the other four hypotheses explored have less consistent fits with the catalogue's seismicity rates. The one with the largest multi-fault ruptures (more than 300 km long) is the least consistent of all the hypotheses, since it strongly underestimates the annual rates with respect to the seismicity data. Lastly, we compared the MFDs modelled with SHERIFS to the GR earthquake rates obtained by modelling different rupture hypotheses with the Anderson & Luco (1983) equations. This permitted to identify the most consistent models for both methodologies besides of the catalogue's consistency check. It is important to remark that these results are preliminary since this research is currently ongoing and thus, we are yet not capable to affirm which rupture model seems more appropriate for modelling the EBSZ hazard assessment. Further geological evidence is needed to evaluate the likelihood of such multi-fault ruptures, e.g. by analyzing the consistency between the models and the long-term seismicity rates deduced from geological data. However, the preliminary results of this work suggest that the EBSZ dynamics could imply longer fault ruptures than those conceived up to date.

ESC2018-S14-560

DISTRIBUTED FAULTING OF THE OCTOBER 30, 2016 CENTRAL ITALY EARTHQUAKE (MW 6.5): CONSTRAINTS FOR IMPROVING FAULT DISPLACEMENT HAZARD ASSESSMENT

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Moderate to strong earthquakes (i.e., Mw > ca. 6.0) commonly produce a complex network of ground ruptures, which are responsible for significant damage. Expected displacements due to distributed faulting (DF) can be estimated through a probabilistic approach (PFDHA – Probablistic Fault Displacement Hazard Assessment; ANSI/ANS-2.30, 2015), considering the distance from the primary fault and earthquake magnitude. Albeit other factors may rule the spatial pattern of DF occurrence, they are not adequately addressed in the current modeling, due to a sensible lack of information. We study the October 30, 2016 Central Italy event (Mw 6.5), which generated surface faulting along a plethora of fault strands, resulting in over 40 km of mapped surface ruptures (Civico et al., 2018). We exploited the database of coseismic ruptures compiled by the Open Emergeo Working Group (Villani et al., 2018) analyzing the spatial pattern and geometric characteristics of primary and distributed faulting (Ferrario & Livio, accepted).

We analyze 5404 observation points, where offset measurements (heave, throw, displacement vectors) were recorded. Strike, dip and length of the ruptures and information on the local lithology were also gathered. From the lithological point of view, we categorized ground ruptures into 3 classes, based on faulted and juxtaposed lithology at surface: bedrock-bedrock (8.76% of the points), bedrock-loose sediments (5.34%) and sediment-sediment (82.78%). A fourth class includes all the occurrences on anthropic structures (i.e., roads, buildings; 3.12%). Bedrock accommodates coseismic deformation on discrete breaks with high throw values, whereas loose sediments are prone to a broader deformation. Vertical and horizontal offsets, percentage of offset related to the primary fault, number of scarps and rupture zone thickness were calculated using stacked profiles orientated perpendicularly to the primary fault. We found that among the factors ruling the distribution of faults and the partitioning of the deformation, key parameters are distance from the primary fault, geometry (strike, dip), geology (lithology, mechanical properties of the sediments) and structural setting (synthetic vs antithetic system, relay zones). We compute the conditional probability of DF occurrence as a function of distance from the primary fault for the October 30, 2016 earthquake and for all the events that generated surface faulting in the Italian Apennines since 1980 (i.e., Mw 6.8 Irpinia 1980; Mw 6.0 Colfiorito 1997; Mw 6.3 L'Aquila 2009; Mw 6.0 Amatrice, August 2016). We use the approach proposed by Youngs et al. (2003) and find that the conditional probability of DF occurrence peaks at 1 km from the primary fault and then generally decreases with distance; other peaks are present in the far-field, in the hangingwall sector, in correspondence of previously mapped faults. Our results show that the currently adopted DF-distance relations, which are based on traditional field surveys, significantly underestimate DF occurrence and do not capture its complex spatial pattern. We argue that the hazard underestimation is related to epistemic uncertainties deriving from an incomplete mapping of subtle DF features, especially in areas far from the main rupture. An increasing number of case histories documented with modern technologies, which complement field surveys with remote-sensed datasets (e.g., InSAR, Lidar, close-range photogrammetry), will provide clues for understanding how strain partitions and enhancing DF-distance relations. Deterministic constraints, specific for the local structural and geological setting, can lead to the definition of weighted factors to be implemented in PFDHA procedures and mitigation strategies.

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ESC2018-S14-605

FAULT PARAMETERS FOR FAULT2SHA IN THE CENTRAL ITALIAN APENNINES - RESOLVING DISCREPANCIES AND MAKING DATA ACCESSIBLE

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The central Apennines Fault2SHA laboratory has been set up to provide a forum within the Fault2SHA ESC Working Group for collaboration between those with research relating to fault-based seismic hazard in the central Apennines region. The central Italian Apennines fault system

is a good case study field area for conducting fault-based seismic hazard assessment. The normal faults capable of producing large magnitude earthquakes are mostly exposed at the surface. This allows the fault traces to be mapped with high precision and the constraining of the geometry, kinematics and rates of faulting. At many places, the age of the offsets have been determined, allowing long-term displacement-rates across the faults to be constrained. Palaeoseismic investigations along many of the known faults confirm activity, constrain the most recent events, and reveal the amount of slip in past events. The region also has an extensive historical record that is considered complete back to 1349 for events >Mw5.8. One barrier to using fault data in seismic hazard assessment, including probabilistic seismic hazard assessment (PSHA), is a lack of consistency between how primary data is recorded. For instance, the precisions of data location and measurements are variable. There remains debate regarding how to reconcile discrepancies among authors and build an open-access database on active faults, in particular how to account for debate regarding which faults are active. The central Apennines Fault2SHA laboratory will bring together fault data from different research groups. The amalgamated dataset will be created in a format that can be of use to those working on fault-based PSHA. Data will include the locations of the active faults, fault geometry, slip-rates measured using different techniques, palaeoseismic data and associations between faults and historical earthquakes. In addition, the database will offer the opportunity to identify priorities for reducing the uncertainties on poorly known or debated/doubtful faults. The central Italian Apennines is, like other regions worldwide, an important area to study seismic hazard because earthquakes have a high impact both in terms of human fatalities and economic losses. Within Europe, this region has had the two deadliest seismic sequences of the last ten years: the 2009 L'Aquila sequence and the 2016 Amatrice-Norcia sequence. The latter event occurred along a known mapped fault that had not ruptured in the historical record; this event highlights the importance of using faults in seismic hazard assessment, rather than relying solely on historical records. Expanding the inclusion of fault data in seismic hazard assessments is one of the key aims of the Fault2SHA Working Group. It is the hope that our academic research will help to reduce both the human and economic losses from such events in the future.

ESC2018-S14-621

IS VISCOELASTIC RELAXATION A GUIDE FOR SECULAR EARTHQUAKE CASCADES? INSIGHTS AFTER THE CENTRAL ITALY 2016-17 SEISMIC SEQUENCE

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Central Italy is characterized by a network of active faults which interact in a complex manner. Coseismic Coulomb stress changes have been invoked by several authors to explain the concatenation of moderate-to-strong earthquakes in this region, but none has considered the time-dependent viscoelastic relaxation of the lower crust and upper mantle as a possible additional source of stress changes at a regional scale. Here, starting from the 1915 Mw 6.9 ± 0.2 Fucino earthquake, we calculated the coseismic plus postseismic Coulomb failure stress changes (CFS) due to eight moderate-to-strong earthquakes which struck central Italy in the last century and culminated with the 2016-2017 sequence. Results from this modeling coupled with some synthetic tests on normal faults with different magnitudes, allowed us to highlight the importance of postseismic processes of Mw> 6.5 on a centennial time-scale. In addition, using these results, we identified other earthquake clusters in the historical catalog (last 618 years), which like the 1915-2017 series were potentially controlled by both coseismic and postseismic processes. Finally, considering our calculations combined with historical and paleoseismological data, we suggest that several faults in central Italy may be at present close to failure.

ESC2018-S14-820

NEW PALEOSEISMIC DATA ON CARBONERAS FAULT (SE IBERIA): EVIDENCE OF AN EARLY HOLOCENE EARTHQUAKE?

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The Eastern Betics Shear zone (EBSZ), to which the Carboneras fault belongs, is an active slow deformation zone that absorbs part of the shortening between Iberia and Africa and concentrates most of the seismicity in southeastern Iberia. Despite the lack of moderate-large earthquakes in historical times (only the Almeria 1522 EMS Int=IX has epicenter in the nearby), previous paleoseismological analyses have defined the Carboneras fault, (southern tip of the EBSZ) as a seismogenic fault. Our study aims to better constrain its seismogenic parameters (slip-rate, mean recurrence period and slip per event) by analyzing a parallel fault trace at la Serrata range. The CF is a 150 km long left-lateral strike-slip fault with a long-term slip rate estimate of 1.31 mm/yr (based in the geomorphology onshore and offshore). The onshore 50 km long trace is divided in 4 segments defined by its surface expression. La Serrata Range segment is a 12 km contractional duplex that has been analyzed in its northwestern trace where the geomorphologic evidence of tectonic activity is more noticeable. We focused on the Tostana site, along the southeastern trace, located on the apex of a Late Pleistocene alluvial fan whose source area is a very local wedge of Jurassic limestones in la Serrata range. The general upper stratigraphy of the fan consists of two large and wide channel systems that incise into an older fan surface that has a well-developed carbonate caliche crust on top. The filling of those two channels consists of an alternation of loose gravel channels, and layers of debris and mud flows. The paleoseismic survey was made in two phases, a first phase were 7 trenches were dug and a second one with 6 trenches and 12 slices. The trenches dug perpendicular to the fault evidenced 4 to 5 events defined by capped fault plane traces and colluvial wedges, and the last one reaching the top soil deposits. The trenches dug parallel to the fault showed a number of channels that were used as piercing lines to define the offset produced by the fault for different time periods. We defined and correlated a minimum of 8 channels along the trenches, having the old larger offsets than the young suggesting a continuous fault activity during the Late Pleistocene. The incremental offsets between channels of different age define at least 4 events of deformation. Following a preliminary radiocarbon dating, an offset of about 5 m in the last 28 ka and of 9 m in the last 37 ka, was obtained, yielding a preliminary slip-rate of 0.2-0.5 mm/yr for the southeastern trace of La Serrata. The survey provided evidence of a very young channel (possibly upper Holocene in age) being offset a minimum of 2 meters, possibly produced by a unique event and, thus, suggesting a minimum of 2m of slip per event. This scales with a Mw 7 earthquake and to a rupture length of about 48 km. The young age of the channel to be confirmed (radiocarbon dating in course), could correspond to the Almeria's 1522 (EMS IX) earthquake. Its rupture length would imply a review of the actual segmentation model of the fault.

ESC2018-S14-898

SEISMIC HAZARD AND EARTHQUAKE RATE IN FAULT SYSTEMS - SHERIFS: APPLICATION TO THE DEAD SEA FAULT

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Modelling the seismic potential of active faults and the associated epistemic uncertainty is a fundamental step of probabilistic seismic hazard assessment (PSHA). SHERIFS (Seismic Hazard and Earthquake Rate In Fault Systems) is an open-source python code to build hazard models allowing earthquake ruptures involving several fault sections (or Fault-to-Fault : FtF ruptures). SHERIFS contains tools to calculate the annual rate of FtF ruptures and background seismicity rate as well as to set up and to weight the logic tree exploring a wide range of epistemic uncertainties. Rates of earthquakes on faults are computed following three constraints: the magnitude frequency distribution (MFD) of earthquakes in

the fault system as a whole (faults + buffer zone) must follow an imposed shape, the rate of earthquakes on each fault is controlled by the specific slip-rate of each section depending on the possible FtF ruptures and the rates of earthquakes in the background is defined by the hazard modeler as the ratio of on-fault/off-fault seismicity for different ranges of magnitude. As a consequence, the MFD of each individual fault is not imposed and is allowed to differ from the shape of the MFD of the entire system. SHERIFS aims to help hazard modelers and data providers explore and weight epistemic uncertainties. To do so, SHERIFS contains tools to compare modelled earthquake rates to the available local data (earthquake catalog and paleoseismological data). This comparison can be used to weigh different hypotheses explored in a logic tree and discard the hypotheses that are not in agreement with the data. SHERIFS outputs are in OpenQuake compatible format that can be run directly with the Openquake Engine. An interesting aspect of SHERIFS is that, depending of the fault system and the considered hypotheses, part of the geologic slip rate of certain faults may be considered as non-seismic slip (interseismic creep or post-seismic relaxation). SHERIFS aims to be versatile and applicable to a wide range of different fault systems and was first tested in the Western Corinth Rift, Greece (Chartier et al 2017). Applications are presently being carrying out for the Betics Sea fault system (Spain, see Gomez-Novell et al. in this session) and the Dead Sea fault system (Israel, Jordan). In this poster we present the earthquake rates modelled with SHERIFS for the southern Dead Sea fault, taking advantage of good slip-rate determinations at different time scales combined with a unique catalogue of historical seismicity. Thus the modelled rates are compared to the rates estimated using the high quality paleoseismological data recently published by Lefevre et al 2018 in order to select the input hypotheses that best explain the paleoseismological data.

ESC2018-S14-902

DEVELOPING COULOMB STRESS ANALYSIS BY INCLUDING FAULT GEOMETRY AND PRE-STRESS FOR ROBUST TIME-DEPENDENT SEISMIC HAZARD

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Following major earthquakes, Coulomb stress transfer (CST) is calculated and used to speculate on the location of possible aftershocks or further damaging earthquakes. Typically, this is done by modelling faults as planar surfaces and only including CST from the most recent earthquake or occasionally including a few earthquakes. Based on this typical modelling, it is often assumed that the nearest-neighbour fault will have the highest CST and therefore will rupture next. However, in a study of a long sequence (667 years) of earthquakes in the central Italian Apennines, the next fault to rupture is never the nearest along-strike neighbour. Therefore the typical approach to CST modelling that leads to the nearest-neighbour fault having the highest CST has limited potential to improve seismic hazard assessments for a number of reasons. We suggest solutions to this problem. Firstly, non-planar faults should be used because the fault geometry affects the magnitude of CST. Secondly, Coulomb pre-stress (i.e. the stress that has accumulated during previous events beyond just the most recent event) is not considered and may be an order of magnitude greater that the coseismic CST. We present a solution to these problems, by providing a method for the inclusion of strike-variable faults and Coulomb pre-stress in CST modelling. We demonstrate our modelling through the example of 667 years of historical seismicity and interseismic loading in the central Apennines, Italy. We model the CST associated with 34 historical earthquakes and the interseismic loading from underlying discrete ductile shear zones onto the strike-variable brittle (seismogenic) portions of normal faults. Using this, we calculate the “Coulomb pre-stress” prior to each earthquake in the historical catalogue. We show that the magnitude of the pre-stress is ~±50bars, an order of magnitude greater than coseismic CST (~±2bars), therefore it is rare that the coseismic CST will overwhelm the pre-stress. For the historical record in central Italy, historical earthquakes tend to nucleate on regions of positive Coulomb pre-stress (from coseismic and interseismic loading) and propagate across both positively and negatively stressed regions. These findings highlight the issues of the traditional

approach to modelling CST and demonstrate that strike-variable faults and Coulomb pre-stress are ignored yet vital factors for earthquake triggering.

ESC2018-S14-944

IS A GENERAL-PURPOSE FAULT MODEL (GPFM) FOR EARTHQUAKE HAZARDS POSSIBLE?

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In the last decade, there has been an increasing concern toward multi-hazard assessment as a tool for disaster risk reduction (e.g. Hyogo Framework 2005-2015, Sendai Framework 2015-2030, GAR15). Although the multi-hazard definition refers to a large variety of natural and human-induced processes, a significant role in disaster risk reduction is played by assessing hazards posed by geological faults that can generate earthquakes. Faults are naturally very complex geological structures whose geometry and behavior are commonly simplified to meet the variety of requirements for the calculation of the different types of earthquake-related hazard. Ground-shaking hazard analyses require 3D mapping at a rather coarse scale depending on the scale of the hazard analysis, (cf. region-wide and site-specific hazard analyses); the geometry of the fault at depth is crucial to describe the fault plane that will undergo elastic slip. Surface-displacement hazard analyses require 2D mapping at the ground surface at a rather detailed scale but the geometry of the fault at depth is irrelevant. Tsunami hazard analyses - limited to tsunami generated by earthquakes - also require 3D mapping of faults at a rather coarse scale, and the focus is on faults that can generate very large earthquakes, typically mega-thrusts in subduction zones in ocean basins; in smaller sea basins and for local and site/specific studies, however, major crustal faults also play an important role. Human-driven earthquake hazard analyses, such as those that deal with triggered and induced seismicity, require multi-scale 3D detailed mapping of the faults and of the hosting geological structures. All the above hazard analyses are conducted with a combination of deterministic and probabilistic strategies, and the description of the fault behavior needs to comply with different requirements depending on the adopted approach. The fault behavior description depends also on the time range of the forecast the hazard analysis is concerned with, including time-dependence and time-independence frameworks. These hazard analyses are characterized by remarkable differences, but they also have large overlaps, so that parts of the procedures developed for one type of hazard analysis can be easily borrowed by another. However, if the complementary parts to these overlaps are not properly addressed, some confusion can be generated, either on the side of the data producers or on the side of the users or on both sides. There are cases in which this confusion was even reflected in engineering regulations, with the risk that fault models developed for a certain specific purpose are used for another. The ideal solution, which would address these issues all at once, is represented by a General-Purpose Fault Model (GPFM). The main features of a GPFM would be a scalable geometric definition and a flexible behavior characterization. Despite the many efforts produced in fault mapping projects and in creating fault databases in many parts of the World, such a model does not exist yet. In this presentation, I will address some of the fundamental questions that need to be answered to design a proper GPFM. Provided that undertaking this challenge may take several years, and that multi-hazard risk analyses require urgent solutions, what do we do in the meantime?

ESC2018-S14-979

THE NEED FOR DETAILED FAULT GEOMETRY AND SLIP-RATES FOR CALCULATING EARTHQUAKE SHAKING INTENSITY EXCEEDANCE PROBABILITIES

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The locations of faults and fault slip-rates are increasingly being used to improve seismic hazard assessments. However, such hazard assessments rarely incorporate detailed fault geometry or high spatial resolution changes in slip-rates along a fault. Instead, in fault-based seismic hazard assessment faults are generally modelled as simplified planar structures with along-strike throw-rate or slip-rate profiles projected from one

or a few measurements. However, it is known that faults have variable geometry and that the changes in local fault strike and dip complicate along-fault throw-profiles. Using a case study from the central Italian Apennines, we demonstrate the importance of incorporating detailed local fault geometry and throw-rates for fault-based seismic hazard assessment. We show PSHA (probabilistic seismic hazard assessment) is altered by incorporating detailed fault data because: (1) calculated ground shaking intensities at specific sites are altered due to changes in the source-to-site distance for ground motion prediction equations (GMPEs); and (2) calculated earthquake rates are altered because calculated strain-rates and hence moment release rates are changed. Therefore, annual rates of exceeding specified ground shaking intensities at a specified site are changed when calculated using detailed fault geometry and throw-rate profiles rather than planar faults and simplified throw-rate profiles. Our example demonstrates that the changes in implied recurrence intervals and expected shaking intensities can be beyond observed natural variability in earthquake recurrence rates and intrinsic uncertainties in GMPEs used for calculating shaking intensities. Therefore, we advocate the use of detailed fault geometry and throw-rates in the calculation of shaking intensities in seismic hazard assessment and we suggest that uncertainties relating to unknowns in fault geometry and along-strike changes in throw-rate need to be included when modelling earthquake rates and shaking intensities.

ESC2018-S14-996

SUBDUCTION EARTHQUAKE SOURCES FOR SEISMIC HAZARD ANALYSIS

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Subduction earthquake sources are the most productive and energetic sources globally and, perhaps, also the most problematic ones from a hazard analysis perspective. Subduction-related earthquakes are generally classified as interface, intraslab, shallow crustal events or outer-rise (Kishida et al., 2017). The former three produce the most relevant events from a seismic hazard perspective. A comprehensive characterization of subduction sources is of crucial importance for a robust calculation of seismic hazard but the approaches currently adopted for the construction of subduction earthquake sources are scantily discussed in the literature and comparisons between the different methods are infrequent. Differences between the various approaches include, for example, the geometry used to describe the different sources, the typologies of magnitude frequency distribution adopted, the methods selected for floating the ruptures on fault surfaces and the interrelation between the ruptures generated by the same earthquake source. Taking as an example the case of subduction interface sources, while recent literature shows a moderate consensus amongst the definition of the seismogenic portion of the interface along the dip (e.g. Lay et al., 2012), various interpretations are used to justify segmentation along the strike. This reflects on the values of maximum magnitude assigned to the various sections (e.g. Brizzi et al., 2018) and on the corresponding rates of occurrence computed. Overall, this variability suggests the definition of large logic tree structures in order to account for the full set of epistemic uncertainties. In this contribution, we examine some the approaches adopted for the modelling of subduction earthquake sources used in national and regional probabilistic seismic hazard analyses and we illustrate some of the methodologies currently developed at the GEM Secretariat.

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SESSION 15

ESC2018-S15-40

DATA HARMONIZATION AND EARTHQUAKE-RATE FORECAST FOR THE PALESTINIAN TERRITORIES

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Evaluation of the seismic hazard is requires the incorporation of all relevant datasets and applicable information on the geology, seismology and tectonics. Generally, earthquake catalogues are the prime data available, while geological information is often complementary used. Herein, we summarize the process of collection, analysis and harmonization of seismic data for the Palestinian territories. Firstly, an earthquake catalogue is compiled for the whole Dead Sea Transform Fault Zone (DSTFZ), by critically reviewing and merging various sources, and is harmonized in terms of moment magnitude (Mw) using newly derived conversion equations; it contains more than 5000 events with Mw≥3, spanning a time-interval of 2050 years. Moreover, active faults along DSTFZ were compiled from two main sources: the corresponding dataset. compiled within the Earthquake Model of the Middle East (EMME) Project and from peer-reviewed publications. Associated uncertainties are quantified and embedded in the fault dataset, which consists of fully parameterized seismically active faults, capable of generating moderate to large magnitude earthquakes.

ESC2018-S15-65

VERIFICATION OF THE INTENSITY PREDICTION EQUATION FOR AUSTRIA.

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Improvements to the intensity prediction equation (IPE) for Austria are undertaken continuously. As is known, Austria is characterized by a moderate seismicity and rather low hazard areas. However, earthquakes can still cause great damage and losses, especially in densely populated and industrialized areas. The goal of this study is therefore, to obtain an intensity prediction equation for risk and hazard assessment with the final aim of updating the Austrian seismic hazard map from the macroseismic data base. So far, the IPE model has been obtained using an ordinary Least Square Adjustment. Once the model was computed, a geology correction, based on a classification of eleven geological units, was obtained and applied to the data set. Finally, a new approach for correcting the topographic effect has been developed. The topographic correction approach shows the behaviour of intensity residuals due to the differences in hypocentral distances and altitudes. Now, as a further step, we present the relationship between Vs30 measurements and intensity data. A side from this, we have also verified of our ground-shaking model. The data set includes more than 250 earthquakes between the years 1000 and 2014. The selected earthquakes had to meet the following criteria: the moment magnitude was constrained to be greater than or equal to 3; only IDP's with local intensities equal to or greater than III were kept; and exclusively events with at least 10 IDP's were used. As verification of the IPE, the events, which met the same requirements as the ones to compute the model, from the period 2015-2017 were evaluated. The data set comprises a total of 19 earthquakes and almost 17.000 IDP's. The results will be presented in the meeting.

ESC2018-S15-139

A BRIEF HISTORY OF CANADA'S EARTHQUAKE HAZARD MODELS AND PROPOSED UPDATE FOR THE 2020 NATIONAL BUILDING CODE

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In this presentation, we outline the history of Canada's earthquake hazard models and summarise the key changes to the 2015 probabilistic model that are proposed for the 2020 National Building Code (NBC) of Canada. Canada spans a variety of tectonic and geological settings, including an active plate boundary (with active subduction as well as divergent and transcurrent

plate motions), a stable craton with the oldest rocks on earth, and an ancient passive margin. As the second largest country in the world, and with such a variety of tectonic settings, creating a national hazard map is a challenging endeavour. The earthquake hazard model that is utilised in the NBC is updated every 5 years (although not all updates are major). The first earthquake provisions in the NBCC were incorporated in 1953; beginning in 1970 a probabilistic seismic hazard model was adopted; the 1985 maps provided peak horizontal acceleration and peak horizontal velocity; the 2005 model provided spectral parameters; and the most recent model (used in the 2015 NBCC) became a fully-probabilistic one, treating alternative source zones and Pacific margin subduction zone sources in a weighted logic tree. Anticipated changes to the 2020 model for seismic hazard include: updated rates for the Juan de Fuca subduction zone and a new geometry for inslab earthquake sources under Puget Sound; a more conventional use of alternative (and newer) ground motion models in a weighted logic tree to replace the innovative Atkinson-Adams 2013 scaled-backbone approach. Furthermore, it is intended to replace the use of soil amplification factors applied to a single hazard map by direct calculation of hazard for each soil class. We also note that for the first time, we have used the OpenQuake engine for development of the Canadian earthquake hazard model. Ongoing questions and discussions include the adaptation and validation of GMPEs developed with data from elsewhere around the world, the use of smoothed seismicity representations, declustering of the earthquake catalogue, minimum magnitude, and challenges associated with a short historical catalogue (especially for large subduction earthquakes, and rare, large intraplate earthquakes), and incorporating GPS deformation rate data into hazard models. Many of these topics are also relevant for seismic hazard evaluations in Europe and elsewhere in the world.

ESC2018-S15-175

NEW SEISMICITY MODELS FOR THE NEXT ATIONAL ITALIAN SEISMIC HAZARD MODEL

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In 2015 the Seismic Hazard Centre of the National Institute of Geophysics and Volcanology started to promote and coordinate the activities of a project aimed at producing the new national probabilistic seismic hazard model for Italy. In this work, we present the results of the activities of the task 3: “seismicity models”, focused on the definition of a set of seismicity models and on the analysis of their uncertainty. 12 working groups produced 11 seismicity models covering the entire Italian territory and 1 model is built ad hoc for the volcanic Etna area. A large number of models allows the exploration of uncertainty in the definition of seismic sources. The models will be combined according to an elicitation phase and a ranking with respect to the observations. Area Source Models: 4 seismicity models are based on seismogenic zonations defined according to the regional seismotectonic settings and past seismicity. Seismicity rates are computed from the declustered parametric catalog of Italian earthquakes (CPTI15, Rovida et al., 2016). 3 of the 4 area source models use macro-areas (groups of zones), to evaluate regional parameters of Gutenberg-Richter (GR) distributions, specifically the models A1, A3 and A4. Then, the seismicity rate for each zone is estimated from the rates of the macro areas using different approaches. Instead, A2 computes seismicity rates on each individual zone, by individuating the change-point between two Poisson processes: the rate of occurrence of part considered as complete of the data set of events is then assumed as representative of the long-term seismic rate occurrence. Fault-based models: A first model, F1, uses exclusively geological information taken from the DISS 3.2.1 (update of http://diss.rm.ingv.it/diss/). The seismic moment rate ?s of a seismogenic fault is derived from the geologic moment rate. To evaluate off-fault seismicity rates F1 follows an empirical approach aimed to capture the natural distribution of observed earthquakes around faults and the inherent location uncertainty of both earthquakes and faults. The second model, F2, combines the seismic rates obtained for the faults, computed using the seismic-moment conservation principle that allows the estimation of the seismic moment rate from long-term slip rate and geometry of the fault source, with a background seismicity obtained using the smoothed-seismicity approach

proposed by Frankel (1995). Smoothing seismicity models: A first model, G1, merges two different smoothed seismicity models following the well-known and widely applied fixed (Frankel, 1995) and adaptive smoothing methods. A second model, G5 follows the Woo (1996) approach to propose a zone-free method solely based on the use of the earthquake catalog. Moreover, given the availability of some earthquake-fault associations in the DISS database, G5 also uses an anisotropic kernel function when there is a connection between faults and earthquakes. Geodetic models: A first model, G3, estimates the seismicity rates over the whole Italian territory using 919 GPS derived horizontal velocities. The strain rate tensor field is calculated on a regular grid taking into account the variable station spacing for the optimal smoothing parameters and finally applying a Gaussian filter. The model converts the strain rate in seismic moment rate and then to earthquake rate under the assumption (Ward, 1998) that earthquakes magnitudes follow a tapered GR distribution, where the b-value and corner magnitude are given. The second model, G4, follows the approach proposed by Bird et al. (2010) with some adaptations to Italy. To evaluate expected rate of seismicity: (1) the long-term strain-rate tensor is computed by GPS data; (2) for a given grid point a certain amount of strain-rate and slip-rate, and the tectonic moment rate are computed; (3) the tectonic moment rates are reduced to derive compatible-declustered seismic moment rates; (4) the magnitude-frequency of the expected rates are obtained by scaling the computed rate using the beta and corner magnitude estimated for the relevant tectonic class. Etna model: For the volcanic area of Mt. Etna an ad hoc seismicity model has been developed (Azzaro et al., 2017; Peruzza et al., 2017). The reason is that the seismicity in a volcanic area has specific features, which may be significantly different from the seismicity in tectonic regions, which includes also the use of different frequency-magnitude relationship. This ad hoc model avoids introducing significant biases in seismic hazard.

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ESC2018-S15-199

OUTCOMES OF HYPSTHER PROJECT (PART I): CALIBRATION OF HYBRID GMPES IN SOUTHERN ITALY

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HYPSTHER (HYbrid ground motion prediction equations for PSha purposes: the study case of souTHERn Italy) is a research project funded by INGV (Istituto Nazionale di Geofisica e Vulcanologia), mainly devoted to the development of ground motion prediction models, based on the integration between recorded and synthetic data (hypsther.mi.ingv.it). We selected the Southern Italy (Calabria and Sicily regions), as study area, since the expected hazard is high, but the seismic activity was scarce in the last decades. We present some specific project results, concerning the calibration of the Ground Motion Prediction Equations (GMPEs) for the study area. We exploited the empirical accelerometric records available on ESM (Engineering Strong Motion database at esm.mi.ingv.it) and ITACA (ITalian ACcelerometric Archive at itaca.mi.ingv.it), integrating the the data-set by velocimetric waveforms. The data-set enumerates about 3200 three-component waveforms from about 230 recording stations. We developed an empirical GMPEs (SI17ref) for shallow active crustal regions in Southern Italy (for PGA and SA at 0.3, 1, and 3s), introducing a site category for the reference rocks in the functional form, in order to predict the ground motion of sites unaffected by soil amplifications (Felicetta et al. 2018). SI17ref is valid up to 200km in the

magnitude range 4.0-6.0. These empirical GMPEs are not well constrained in near fault conditions, since very few recordings are available at distance lower than 10km. Within the project, we produced a dataset of more than 180.000 synthetic records for hard rock condition according to two different simulation methods: the EXSIM (Extended Fault Simulation; Motazedian and Atkinson, 2005), to model a set of finite sources in the magnitude range 5.0-7.5; the SMSIM (Stochastic-Method SIMulation; Boore, 2003) to model point-like sources characterized by lower magnitudes. The main contribution to the data variability derives from different combinations of rupture velocities, nucleation points and stress parameters. We assembled a dataset of ground motion parameters derived from both empirical and simulated data. We developed a methodology to derive the hybrid GMPEs (SI17hyb). Model predictions are larger with respect to SI17ref in near-fault conditions for PGA and lower magnitudes. At distances larger than 50km, SI17hyb predictions are controlled by empirical data, because they attenuate faster with distances, with respect to simulated data. Since the standard deviation (σ) of the total residuals of GMPEs has a strong influence on the results of PSHA, we propose a heteroscedastic model for SI17hyb, including a dependence on magnitude. These values were compared to those proposed in the NGA-West2 project (Bozorgnia et al. 2014). We also investigated the dependence of the stress parameter, which is an input parameter of the numerical simulations, on the GMPEs predictions and associated standard deviation. These GMPEs were employed to perform region-specific Probabilistic Seismic Hazard Assessment in the study area.

ESC2018-S15-209

TOWARDS A NEW SEISMIC HAZARD MAP OF AUSTRIA

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For hazard assessments, ground motion measurements from felt earthquakes in Austria were collected and various statistical parameters were derived. The local earthquake catalogue has been verified for the completeness and was compared with those of neighbouring countries. Source mechanisms were determined and collected and local site effects were investigated. GMPEs for intensity and ground motion were developed and selected. The results lead to a new ShakeMap algorithm which is implemented into the real-time system of the local Seismological Service of Austria. Now we are looking for the next steps towards a new seismic hazard map of Austria. We show first results derived from our input data with the OpenQuake-engine from GEM (Global Earthquake Model). We are discussing the challenges we are facing during the development of a hazard map in a mountainous region and the definition of local fault and area sources.

ESC2018-S15-212

APPRAISAL OF EMPIRICAL MACROSEISMIC INTENSITY MODELS FOR USE IN PROBABILISTIC SEISMIC HAZARD ASSESSMENT IN SWITZERLAND

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Macroseismic data and models carry essential information on the earthquake effects on the natural and built environment, and implicitly define the link between earthquake hazard and risk assessment. A natural advantage of macroseismic data compared to instrumental records is its large availability for historic earthquakes that occurred way before the establishment and development of seismic networks, as its availability from un-instrumented sites and for post-event collection. In this contribution, we present our approach to select empirical macroseismic intensity models (GMICEs and/or IPEs) suitable for application in the wider Swiss region based on their performance with respect to the macroseismic observations (EMS-98 scale) available in the Earthquake catalogue of Switzerland ECOS-09 (www.seismo.ethz.ch/research-and-teaching/products-software/earthquake-catalogues/index.html).

Two types of models are investigated: Ground Motion to Intensity Conversion Equations (GMICEs) and Intensity Prediction Equations (IPEs). The former link ground-motion levels yielded by Switzerland-compatible Ground Motion Prediction Equations (GMPEs) and

macroseismic intensity; whereas the IPEs directly incorporate the earthquake source, path and site effects into macroseismic intensity predictions. The inherent uncertainties associated with the appraisal procedure are presented and discussed. The results of this process are used to define a logic tree of macroseismic intensity models for the update and extension of the 2015 Seismic Hazard Model for Switzerland.

ESC2018-S15-222

COMPARISON OF DIFFERENT TOOLS FOR PROBABILISTIC SEISMIC HAZARD ANALYSIS IN A *REPRESENTATIVE CASE STUDY*

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Probabilistic Seismic Hazard Analysis (PSHA) is widely used by governments and industry in order to develop building code requirements and to produce official hazard maps. In the Oil and Gas industry specific seismic hazard assessments are performed to provide the design earthquake loads. The methodology for probabilistic seismic hazard assessment used nowadays is based on the original work of Cornell (1968). Two types of uncertainties are modeled in PSHA: aleatory uncertainty, that corresponds to the random variability in natural phenomena and epistemic uncertainty, that is the uncertainty due to gaps in our knowledge. While aleatory uncertainty could not be reduced, epistemic uncertainty could potentially be reduced by gathering more data or by refining models. A case study representative of a complete PSHA analysis is illustrated. The site is located in a high seismicity active shallow region in Turkey, near the North Anatolian Fault. Epistemic uncertainty is addressed by a logic tree approach, introducing several branches weighted according to the degree of confidence in each model. Main branches takes into account several assumptions on: the seismotectonic model (area and fault sources), the GMPEs selected, the maximum magnitude and the activity rates parameters. In details, we introduced three alternative seismotectonic models, two area source models and a fault source plus background model, based on available literature for the investigated area. Reference literature area and fault source models were developed for Europe in the SHARE project (Woessner et al., 2015) and for Turkey in a national program to re-evaluate seismic hazard conducted for AFAD (Sesetyan et al., 2016 and Demircioglu et al., 2017). Referring to the activity rates a local and a regional estimation of b-value were performed and introduced in the logic tree frame. The maximum magnitude values were estimated according to an historical and literature criterion. As further investigation, different seismic hazard tools were compared to cross-validate the results and to test the introduction of alternative software in the company. Main analyses were performed with the commercial software FRISK88M (Risk Engineering Inc., 2017), while comparisons were performed with open-source software, i.e. OpenQuake and Crisis. The OpenQuake software is a hazard and risk software developed by GEM (Global Earthquake Model). OpenQuake implements the classical PSHA methodology as described by Cornell (1968) and by McGuire (1976), which also forms the basis for proprietary software FRISK88M (Pagani et al. 2014). On the same theoretical basis, the CRISIS code was developed by Prof. Ordaz at UNAM University (Meléndez et al., 2017). The codes were compared on simplified cases and then the full logic tree was built and compared. Potential influence of software choice in the logic tree construction was also discussed. A main difference between FRISK88M and the other two software is related to the treatment of distance metrics and the 3D geometry of ruptures in the area sources. Openquake automatically computes distance metrics required by a specific GMPE while FRISK88M for area sources provides only epicentral and hypocentral distances therefore empirical correlation between different distance metrics have been introduced in the GMPEs according to Goda et al. (2010). Another relevant argument in the PSHA software choice is the availability of built-in GMPEs and the possibility to add new ones. From this point of view Openquake and Crisis provided a wide range of available built-in GMPEs already validated that allow a quicker realization of PSHA studies. Indeed, the introduction of open-source software in private company is now possible thanks to the strong development of online expert communities and the rigorous validation process of these tools.

ESC2018-S15-224

DEVELOPMENT OF A SEISMIC SOURCE MODEL FOR PROBABILISTIC SEISMIC HAZARD

ASSESSMENT IN ITALY, CONSIDERING SEISMICITY AND FAULT MOMENT RELEASE

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In 2015 the Italian Department of Civil Protection, started a project for upgrading the official Italian seismic hazard map (MPS04), inviting the Italian scientific community to participate in a joint effort for its realization. We participated providing spatially variable time-independent (Poisson) long-term annual occurrence rates of seismic events on the entire Italian territory, for magnitude bin of 0.1 units from M4.5 up to M8.1 in cells of 0.1°x0.1°. Our final model was composed by two different models, merged in one ensemble model: the first one realized by a smoothed seismicity approach, the second one using the seismogenic faults. The spatial smoothed seismicity was obtained using the smoothing method introduced by Frankel (1995) with completeness magnitude correction applied to the historical and instrumental seismic catalogs. For the historical catalog, two different completeness criteria (historical and statistical respectively) were adopted. In this approach we adopted a tapered Gutenberg-Richter relation with a b-value fixed to 1 and a corner magnitude estimated with the bigger events in the catalogs. For each seismogenic fault provided by the Database of the Individual Seismogenic Sources (DISS), we computed the annual rate, assuming that the seismic moments of the earthquakes generated by each fault are distributed according to the same tapered Gutenberg-Richter relation of the smoothed seismicity model. The annual rate for the final model was determined in the following way: if the cell falls within one of the seismic sources, we merged the respective value of rate determined by the seismic moments of the earthquakes generated by each fault and the value of the smoothed seismicity model with three different weight combinations; if instead the cells fall outside of any seismic source we considered the rate obtained from the spatial smoothed seismicity. Here we present the final results of our study to be used for the new Italian seismic hazard map.

ESC2018-S15-248

SIGNIFICANT TEMPORAL B-VALUE VARIATIONS DURING EARTHQUAKE SEQUENCES

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Forecasting models currently used in statistical seismology and in Operational Earthquake Forecasting (e.g., ETAS) typically consider the spatial and temporal changes in the activity rates whilst spatio-temporal changes in the earthquake size distribution, the b-value, are not included. Statistically significant variations in the earthquake size distribution have been widely documented, related to style-of-faulting, applied stress, presence and migration of magmatic and hydrothermal fluid, and hypocentral depth. Laboratory experiments on rock samples show an increasing relative proportion of larger events as the system approaches failure, and a sudden reversal of this trend after the main event. We investigate whether these lab-scale observations also apply to natural earthquake sequences and can help to improve our understanding of the physical processes generating damaging earthquakes and improve forecasting ability. We demonstrate with the results of both detailed case studies and a systematic analysis of more than 30 high-quality sequences that significant and meaningful temporal b-value variability can be detected. Such observations, critically dependent on monitoring capabilities and homogeneous reporting of events, require and motivate the systematic study of many sequences to investigate whether general patterns exist that might eventually be useful for time-dependent or even real-time seismic hazard assessment.

ESC2018-S15-291

IMPLEMENTATION OF PROBABILISTIC SEISMIC HAZARD MAP IN KOREA

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Based on the initial Countermeasure act for natural disaster, the first Probabilistic Seismic Hazard Map (PSHM) in Korea was publicly

suggested in 1997. The first PSHM was very helpful for us but included basic problems, because of the limitation of research period and lack of various essential input data. The first PSHM had constructed by using only historical and instrumental earthquake catalogs without consideration of catalog completeness. Because of no adequate seismic attenuation formula for Korean Peninsula, PSHM was calculated by using the attenuation formula of United States Central and Eastern regions. After publication of the first PSHM, more historical and instrumental earthquake information has continuously accumulated. Not only seismological research relating to making PSHM, such as attenuation formula, waveform modeling, etc., but also geological research, such as active fault, seismo-tectonic map, etc., had been actively performed. These recent research result could reduce the aleatory and epistemic uncertainties of the first PSHM. New Procedure for PSHM was decided through comparison with various PSHM methodology as a preliminary. At the first step, all available earthquake information was gathered from Korean and neighboring country's existing catalogs, ancient documents, papers, etc. To make a historical earthquake catalog, standard criteria was established to infer intensity from the historical earthquake description in ancient documents, such as damage degree of human, animal and architecture, natural phenomena, size of felt area, etc. Locations of historical earthquakes were also determined by several criteria based on shape of felt area, the most destructive site, ancient capital cities, etc. These criteria was fixed by co-work with specialist committee. Korean historical earthquake catalog was consisted of 1,951 events from AD. 2 to 1895 and 13 events among them have maximum MMI VIII~IX intensity. Because instrumental observation in Korea was done 1905~1943 and 1978~present, catalog of this blank period was implemented by other country and organization catalogs. Instrumental earthquake catalog was consisted of 2,793 events and the biggest earthquake was happened in 1952.3.19 near south Pyeongyang and maximum magnitude was Mw 6.2. Sensitivity analysis of input parameters were conducted including historical and instrumental earthquake catalog, attenuation formula, intensity-magnitude conversion formula, seismo-tectonic zone, etc. Comprehensive PSHM have to consider the total effect of seismic, geological, and site specification. To calculate the effect of active faults and the site amplification factor, new procedures were developed and applied to the south eastern part of Korean Peninsula where active fault survey was conducted and 5 metropolitan areas, Seoul, Busan, Daegu, Daejeon, and Kwangju, where subsurface velocity structure DB was available, respectively. Finally, historical and instrumental earthquake catalogs were revised with specialist committee. PSHM was firstly analyzed and new PSHM was updated using more reliable input parameters under operating specialist committees and holding the public hearing procedures. Also the PSHM calculating procedures was improved to quantitatively calculate the effect of active faults and site amplification in 5 metropolitan areas.

ESC2018-S15-296

THE ITALIAN SEISMIC HAZARD MODEL PROJECT

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In 2015 the Seismic Hazard Centre (Centro Pericolosità Sismica – CPS) of the National Institute of Geophysics and Volcanology (INGV) was commissioned to engage and coordinate the national scientific community with the aim of elaborating a new reference seismic hazard model, mainly designed to update the seismic code. The Civil Protection Department (DPC) funded the project; the main requirements for the model were defined throughout meetings with national experts in earthquake engineering that will then participate to the revision of the building code. The CPS outlined a roadmap to release within three years a significantly renewed PSHA model, with regard to both the updated input elements and the strategies to be followed. Since the beginning, CPS fixed some key constraints that had to be honoured when building a seismic hazard model for practical purposes. These points, which basically aim to guarantee a large participation and the scientific and non-scientific consensus, can be summarized as follows: (i) the

use of international standards according to the state of the art in Probabilistic Seismic Hazard Assessment (PSHA) (e.g. SHAAC, 1993); (ii) open and transparent procedures that guarantee totally reproducible outcomes; (iii) the use of outputs to be approved by the stakeholders; (iv) the involvement of Italian scientific community as large as possible in proposing data, models and approaches; (v) a full and coherent exploration and representation of the epistemic uncertainty in the final seismic hazard model; (vi) the implementation of a robust testing phase, and of an elicitation session with national and international independent experts, in order to check the reliability of each component of the seismic hazard model. A public call was opened in order to involve in the initiative the larger number of researchers: about 150 people from universities and research institutions are currently involved in the project. The activities were organized in 6 tasks: T1) project management, T2) input data, T3) seismicity models, T4) ground motion and intensity predictive equations (GMPEs and IPEs), T5) computation and rendering, T6) testing. T1 planned the activities and managed the other 5 tasks to ensure achievements of the Project scopes. This task helps to integrate results and data collected and elaborated by the other ones. Finally, it ensures and coordinates respect of time frame, both short term and overall deadline. T2 selected the most updated information about historical and instrumental seismicity, seismogenic faults, and deformation (both from seismicity and geodetic data) and compiled the necessary databases. T3 elaborated the seismicity models in terms of classic source areas, fault sources and gridded seismicity based on different approaches, with associated seismicity rates. Each earthquake rate model has to be reproducible; this means that modellers have to clearly explain how the model was built and which data have been used. Moreover, modellers have to explore the epistemic uncertainty related to their model, i.e., how the model outcome varies as a function of the variability of the parameters of the model itself. This step is crucial to estimate an overall epistemic uncertainty of the final model, which includes the uncertainty of each model and the uncertainty among models. T4 selected the most recent models accounting for their tectonic suitability and forecasting performance. The forecasting performance of each GMPE has been evaluated through the comparison with accelerometric records available in the Italian (itaca.mi.ingv.it) and European (esm.mi.ingv.it) strong-motion databases and, for the IPEs, with Italian macroseismic data (emidius.mi.ingv.it/DBMI15). In this way, each GMPE has been ranked according to different specific metrics, so that the best performing GMPEs can be identified. T5 identified the code OpenQuake (www.openquake.org) for calculation because of several reasons: it is open source, so everyone can reproduce the outcomes and verify how the code works. Moreover, since OpenQuake is developed by GEM (www.globalquakemodel.org), it is possible to interact with the developers team to modify or integrate the code, as well as to ask for the development of new dedicated functions. T6 performed statistical procedures to test, with the available data, the whole seismic hazard models, and single components such as the seismicity models and the GMPEs. T6 also organised the elicitation session and finally weight the different models. In this talk we summarize the overall strategy for building the new Italian PSHA model, show some preliminary results and discuss in detail important novelties that we put forward. More specifically, we adopt a new formal probabilistic framework to interpret the outcomes of the model and to test it meaningfully; this requires a proper definition and characterization of both aleatory variability and epistemic uncertainty that we accomplish through an ensemble modelling strategy. We use a weighting scheme of the different components of the PSHA model that has been built through three different independent steps: a formal experts' elicitation, the outcomes of the testing phase, and the correlation among the outcomes.

ESC2018-S15-298

THE IMPACT OF THE NEW CPTI15 EARTHQUAKE CATALOGUE ON THE ITALIAN PSHA

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Since the release of the current Italian Seismic Hazard Model, named MPS04, in 2004 the knowledge on past seismicity has continuously and significantly improved, as regards data

collection, interpretation and elaboration. MPS04 is based on the second version of the Parametric Catalogue of Italian Earthquakes ("Catalogo Parametrico dei Terremoti Italiani") CPTI04, which represented the state-of-the-art at the time of itscompilation. However, for the period before 1980, the content of CPTI04 was the same as the previous version CPTI99, released in 1999, apart from the empirical conversion of Ms into Mw. Only the time-period 1981 to 2002 (which was the end of the catalogue) was entirely re-compiled with instrumental data available at that time. In 2016, a new version of the catalogue, named CPTI15, was released. Spanning from the year 1000 to 2014, it represents a significant improvement with respect to the previous versions, as it relies upon: i) more than 3000 macroseismic intensity distributions of historical and recent earthquakes, collected in the new release of the Italian Macroseismic Database ("Database Macrosismico Italiano") DBMI15, and ii) the most reliable instrumental parameters available. CPTI15 considers about 500 updated Mw assessments and a new set of conversion relations from different magnitude scales to Mw. Newly determined magnitudes were used for updating the calibration of the algorithm (known as "Boxer") used for deriving earthquake parameters from intensity distributions. The magnitude and intensity thresholds – respectively M 4.5 and I 5-6 - of the previous releases of the CPTI catalogues, were lowered to magnitude 4.0 and intensity 5, with the specific purpose of deriving more reliable estimates of the seismicity rates in probabilistic seismic hazard assessment. CPTI15 is being used in the project aimed at revising the reference Italian PSHA, and for this reason it was thoroughly compared with the CPTI04 in terms of contents and compilation procedures, and, mostly, for what concerns its influence on the assessment of seismic hazard. Apart from the increased number of earthquakes, due to the introduction of previously unknown historical events, the most important difference between the two catalogues consists of a general decrease of magnitude values smaller than 5.5, and an increase in larger ones. Such a variation results in a more homogenous distribution of the number of earthquakes in the different magnitude classes, particularly in low magnitude levels that mostly contribute to PSHA with return period equal or lower than 475 years. The reason for such variations has to be found in the parametrization of the new macroseismic intensity distributions instead of the conversion of epicentral intensity to magnitude through a linear regression. In addition, many epicentral intensity values in CPTI04, in particular those equal to intensity 5 and 6, derived from the first Italian earthquake catalogue (the "Progetto Finalizzato Geodinamica"- PFG catalogue) published in 1985, when intensity distributions were available only for a few large earthquakes. Later and recent historical studies generally resulted in a considerably downsize of the macroseismic effects, and then in the magnitude estimate, of most of the earthquakes listed in the PFG catalogue. In addition, for magnitudes lower than 5, also instrumental determinations in CPTI15 are also generally lower than those in CPTI04, mostly as a result of the increased number of events with recorded Mw is a such range, and the new conversion relations that are more constrained at low values. As a consequence of the overall reassessment of magnitudes, the annual earthquake magnitude-frequency distribution of CPTI15 shows a slope ~1. The differences between the CPTI04 and CPTI15 catalogues remarkably affect the estimates of probabilistic seismic hazard. Sensitivity tests performed with the completeness assessment, the same area source model, and the same GMPEs as in MPS04, show that the number of earthquakes in each area source decreases when using CPTI15 instead of CPTI04, especially for Mw

ESC2018-S15-388

HYPSTHER PROJECT: HYBRID GROUND MOTION PREDICTION EQUATIONS FOR PSHA PURPOSES

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The aim of the project HYPSTHER (HYbrid ground motion prediction equations for PSha purposes: the study case of souTHERn Italy), supported by Italian research institute INGV (Istituto Nazionale di Geofisica e Vulcanologia), was to develop a methodological approach to set up hybrid Ground Motion Prediction Equations (GMPEs) for hard rock sites, based on the integration between

recorded and synthetic data. Calabria and Sicily in Southern Italy were chosen as target area due to the high seismic hazard levels (Italian official seismic-hazard map MPS04; zonesismiche.mi.ingv.it) and a long history of destructive earthquakes (CPTI15 and DBMI15; emidius.mi.ingv.it/CPTI15-DBMI15/ Rovida et al., 2016; Locati et al., 2016) despite the low seismicity recorded in the last decades (ITACA2.3; itaca.mi.ingv.it Luzi et al., 2017). The project developed through four steps: 1) Generation of an empirical flat-file (HYPST_emp_db) mainly based on the Engineering Strong Motion database (ESM; esm.mi.ingv.it Luzi et al., 2016), which contains metadata and ground motion intensity measures of about 3,200 three-component waveforms generated by 174 earthquakes (magnitude larger than 3.5 and epicentral distance less than 200 km) and acquired by about 230 recording sites for a variety of soil conditions. 2) Generation of a synthetic flat-file (HPST_syn_db) by using region-specific ground motion simulations representative of different fault mechanisms, ruptures size and geometry, and hard rock sites. 3) Calibration of empirical and hybrid GMPEs for PGA and SA (0.3, 1, and 3 s) for reference rock sites (Felicetta et al., 2018) with an applicability range characterized by moment magnitudes between 4.0 and 7.5 and source-to-site distances up to 100 km. 4) Sensitivity analysis to evaluate the impact on the seismic hazard assessment of alternative GMPEs, such as the reference ground motion model for Italy (ITA10, Bindi et al., 2011) and those calibrated during the project. Testing the performance of region-specific GMPEs for magnitude-distance pairs poorly sampled by recorded data, we highlighted the variability of the seismic hazard in terms of probability of exceedance of the ground motion parameters in response to the use of different attenuation models. We assessed the impact on the seismic design of some critical infrastructures (ports, refineries, chemical plants) settled along the shoreline of the investigated area, for specific return periods that correspond to Serviceability Limit State for damage control and Ultimate Limit State for collapse prevention. In particular, using the region-specific hybrid model, a reduction of the hazard levels is observed, up to 50% with respect to the empirical GMPEs. The results achieved at the end of the HYPSTHER project (hypsther.mi.ingv.it) show that including hybrid region-specific GMPEs into probabilistic seismic hazard analysis could be a sounding strategy. This applies especially to near-source regions, where the paucity of empirical data makes it difficult to fully capture the peculiarities of the ground motion. Keywords: hybrid-GMPEs; region-specific PSHA; critical infrastructures; Southern Italy

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ESC2018-S15-433

INCORPORATION OF LONG-TERM PERSISTENCE IN THE SEISMIC PROCESS INTO PROBABILISTIC SEISMIC HAZARD ANALYSIS

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Probabilistic seismic hazard analysis (PSHA) has undergone significant improvements in recent years, both for the methodological aspects and parameterization of the input models. For instance, the use of logic trees and hazard disaggregation have become standard practices in modern PSHAs. On the side of input models, significant efforts have been devoted to the refinement of ground-motion prediction equations and source models. However, less has been done within the framework of long-term earthquake forecasting. Nowadays, time-independent models based on the assumption of seismicity as a Poisson process are still widely used worldwide in PSHA. Although various models have been proposed as an alternative to the Poisson model in recent decades (e.g., Shimazaki and Nakata, 1980; Kiremidjian and Anagnos, 1984; Ogata, 1988; Ogata, 1998; Matthews et al., 2002; Faenza et al., 2003; Marzocchi and Lombardi, 2008), most of them have limited applicability due their extensive parameterization and lack of the experimental data (e.g., observations of repeated events on individual faults) required to estimate the model parameters. Moreover, some of them seem not to actually reflect the seismic process. For instance, empirical observations contradict the notion of periodicity (or quasi-periodicity), which forms the foundation of renewal models and characteristic earthquake notion. Examples are reported in Kagan and Jackson (1991), Lomnitz, (1994), Jackson and Kagan (2006), and many others. In particular, it was observed that regions of recent high seismic activity have a larger than usual chance of producing new strong earthquakes. On the other hand, seismically quiet periods tend to be followed by quiet years. This implies that the process of accumulation and release of seismic strain is governed by long memory (or long-term persistence), which manifests itself in earthquake clustering. All these features are incorporated in the forecasting model that was recently developed by Barani et al. (2018). Such model is consistent with the notion of self-organized criticality (Bak and Tang, 1989), and is based on a simple empirical power law that elates the storage capacity of a seismic source (expressed in terms of scalar moment) to time. The model will be presented and discussed in Session S16 of this assembly. In this study, we present an application of the probability model of Barani et al. (2018) within the framework of a PSHA in two areas in Italy that were recently struck by strong seismic episodes. These are the 2012 Emilia seismic sequence in the Po Plain, Northern Italy (main shock of Mw = 5.9), and the 2009 L'Aquila (with main shock of Mw = 6.3) and 2016-2017 Central Apennines (with main shock of Mw = 6.5) sequences in central Italy. These two areas are located in different tectonic environments that present different seismicity levels. This will imply the use of different computational strategies (smoothed seismicity vs. area sources). Our ground-motion forecasts will be compared to those obtained by applying the conventional PSHA approach based on the Poisson assumption. The first results show that assuming the Poisson model yield an underestimation of the actual seismicity rates, thus resulting in under-conservative hazard estimates.

ESC2018-S15-455

SENSITIVITY STUDY TO SEISMOTECTONIC SOURCE MODELS FOR PSHA IN METROPOLITAN FRANCE

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The appreciation and propagation of uncertainties is critical to assess properly a seismic hazard for safety purposes. Among other sources of uncertainties, the ones associated with the seismic source parameters are still considerable and are likely to remain high for many more years given the limited progress in resolving the French fault activity. Epistemic and aleatory uncertainties associated to input data and seismic source models are principally coming from the subsampling of seismicity at seismic cycle scale and the absence of well-documented faults in metropolitan France, which implies controversial discussions on regional seismicity behaviors. Indeed, at national scale, the return period of major earthquakes is large compared to the historical and instrumental seismicity catalog durations, and the seismogenic potential of active fault is not well constrained due to challenging determination of fault segmentation, interseismic

slip, and seismic coupling. With this scope in mind, here we present a PSHA study on different sites in metropolitan France, where debates are still opened with divergent opinions, and strong efforts devoted to the characterization of fault and seismic activity. We explore the variability of the computed Peak Ground Acceleration (PGA) hazard curves, illustrating the current diversity of seismotectonic zoning schemes and different implemented individual fault models. Among others, we incorporate the CEA/LDG instrumental earthquake catalogue up-to-date, the historical earthquake catalogue (SisFrance) converted in moment magnitude, and the latest version of the CEA/LDG seismotectonic zoning scheme, integrating several neotectonic indices recently documented. We also include two alternative seismogenic source models to take into account different interpretations existing among specialists, and we investigate extreme cases of fault activity models. PSHA computation is performed using the open-source seismic hazard software, OpenQuake, with the implementation of logic trees and taking into account both epistemic and aleatory uncertainties. Finally, this study illustrates the sensitivity of the solution to these geological inputs at various time scales and opens the discussion towards alternative models of seismicity generation in intra-continental regions.

ESC2018-S15-467

SEISMIC SCENARIOS AND HAZARD ASSESSMENT IN THE ISLAND OF ISCHIA (NEAPOLITAN VOLCANIC DISTRICT, ITALY): A PROBABILISTIC APPROACH BASED ON MACROSEISMIC INTENSITY DATA

On August 21, 2017, a Md 4.0 earthquake struck the volcanic island of Ischia, producing heavy damage and two casualties at Casamicciola, locality known for having been destroyed by the famous 1883 event with a life toll of 2300 victims. The macroseismic features of the 2017 earthquake as well as the historical ones, are those typical of the seismicity in volcanic areas: damage affecting small areas, impressive intensity attenuation within very short distances, high epicentral intensities vs moderate magnitudes. Evaluating the ground motion attenuation in these geologic conditions is still a point of issue. The numerous relationships adopted in tectonic domains cannot be used since they produce an excessive overestimation of the expected shaking at a site or, conversely, underestimation of the epicentral intensity when calculated from the instrumental magnitude. For these reasons, it is necessary to tackle the problem with studies specific for each volcanic zone, since they show an extreme variability in the characteristics of the source and propagation of the seismic energy in the shallow crust. A first deterministic approach to the analysis of the macroseismic attenuation in the Italian volcanic districts was performed by Azzaro et al. (2006), who found specific attenuation trends for Etna and Ischia showing the highest decay of intensity with the epicentral distance ($\Delta I=4$ in 20 km). A probabilistic approach to model the attenuation of the macroseismic intensity was later applied to Mt. Etna volcano, exploiting the huge amount of data available from the local historical earthquake catalogue. This procedure allowed estimating the probability distribution of the intensity at a site (Is) conditioned on the epicentral intensity of the earthquake (I0) and the epicentre-site distance through a binomial-beta model (Zonno et al., 2009). In this paper, we apply the same probabilistic approach to model the attenuation of macroseismic intensity at Ischia, a major issue in the seismic disaster prevention dramatically highlighted by the last 2017 earthquake. The application of this procedure at Ischia requires an ad-hoc calibration of some parameters through a reference macroseismic dataset, which is characterised by a seismic catalogue extremely poor for the island. The Parametric Catalogue of Italian Earthquakes (CPTI15, Rovida et al., 2016) reports twelve events with I0 ≥ VI-VII MCS but only three of them have a number of intensity data points suitable to model the intensity decay (Nip≥10 as for Etna). Therefore, in order to limit the uncertainties due to poorly constrained parameters we selected the 1828, 1881 and 1883 earthquakes; in addition, we used the 2017 event. In all, 78 intensity data spread through the island of Ischia are available for the analysis. The procedure to estimate the parameters of the binomial probability distribution is reported in Rotondi et al. (2016): i) summarizing the set of epicentre-site distances for each decay value ΔI of the macroseismic fields with fixed I0 through some statistical summaries, ii) collecting this information in a matrix and applying a hierarchical

agglomerative clustering method to identify classes of fields with similar attenuation trend. For each class, a beta-binomial probabilistic model was estimated, following a Bayesian approach, so as to obtain the probability distribution p(Is | I0, d) of the intensity Is at any site, conditioned on I0 and the epicentre-site distance d. In the light of the most recent macroseismic database DBMI15 (Locati et al., 2016), the procedure has been repeated starting from the detection of the isoattenuation classes, and then updating the probability distributions p(Is | I0, d). The graphical comparison among the attenuation of the Ischia earthquakes and the one of the isoattenuation Italian classes confirmed the well-known strong attenuation of volcano seismicity; this issue can be overcome by applying a scaling factor k=20 which makes the attenuation trends comparable. This means that what is felt at distance d in the case of Italian earthquakes in class B, is similar to what is felt at distance d/20 in the volcanic district of Ischia. Consequently, the suitably modified probability distributions of that class was used as prior information on the decay at Ischia; then, the intensity data points of the 1828, 1881, 1883 earthquakes were used to update the parameter estimates and the corresponding distributions p(Is). The seismic scenario of the 2017 earthquake has been forecast and compared with the really observed one. The backward validation of the results also includes the comparison with simulations from a deterministic approach. The entire procedure is implemented into a software to generate probabilistic shake maps expressed in terms of macroseismic intensity. This application may also represent a practical tool for the INGV data acquisition centres for obtaining real-time seismic scenarios. Finally, the matrix of values of the predictive probability function of the intensity at site are used, together with observed intensities, to obtain local probabilistic seismic hazard maps for the island, based on the site approach (SASHA code, D'Amico and Albarello, 2008).

ESC2018-S15-479

PROPOSAL OF GROUND MOTION ESTIMATION METHOD FOR PSHA USING THE GROUND MOTION DATABASE AT SEISMIC BEDROCK

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In the case of targeting the structure with the complicated response characteristics or when the detailed response value of the structural member is required, it is necessary to evaluate the time history of seismic ground motions. For this purpose, strong ground motion estimation method has been proposed (Irikura 2004) and it is possible to evaluate the group of ground motions considering the site-specific seismic activities and site amplification factor. However, it is necessary to appropriately model three characteristics, such as source and propagation, site amplification characteristics using enough data about the source and site. So, it is desired to evaluate ground motions more practically and easily. When performing the estimation method, there is not necessarily enough information to model source and propagation characteristics, so standard values are used in general. In other words, if the macroscopic parameters such as earthquake magnitude and distance from site to source are similar, there is no difference about seismic ground motions evaluated at the seismic bedrock where it is not necessary to consider the site amplification factor. Therefore, we propose the method to evaluate the group of site-specific ground motions for PSHA based on ground motion database at seismic bedrock. In this method, we can commonly use the seismic motion database at the seismic bedrock. And the site amplification characteristics is considered separately for each site, so the accuracy of seismic ground motion evaluation is not impaired.

ESC2018-S15-494

OUTCOMES OF HYPSTHER PROJECT (PART II): REGION-SPECIFIC PSHA IN SOUTHERN ITALY

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The aim of the HYPSTHER (HYbrid ground motion prediction equations for PSha purposes: the study case of souTHERn Italy) project is to develop a methodology to calibrate hybrid Ground Motion Prediction Equations (GMPEs), obtained from the integration of empirical and simulated data. The final goal of the project is to perform a series of sensitivity studies on the hybrid models and different seismic source zonations to evaluate their contribution to the Probabilistic Seismic

Hazard Assessment (PSHA). In this study, we selected three sites (Milazzo, Priolo Gargallo and Gioia Tauro) where critical infrastructures are installed, such as ports, refineries or chemical plants, located along the shoreline of the investigated area, to perform site-specific PSHA and evaluate their impact on seismic design or retrofitting. We tested the PSHA results at different return periods, depending on the relevance of the infrastructure studied, corresponding to the Serviceability Limit State for damage control (SLC) and the Ultimate Limit State for collapse prevention (SLD) of the European seismic codes. The empirical and hybrid GMPEs have been used for hazard calculation in a logic tree with only six branches (two branches for the epistemic uncertainty in the zonation model). The test of the performance of region-specific GMPEs for magnitude-distance pairs poorly sampled by recorded data, highlighted a variability of the seismic hazard in terms of probability of exceedance of the ground motion parameter (i.e. PGA) due to the use of different attenuation models. Using the region-specific hybrid model, a reduction of the hazard levels is observed, up to 50% with respect to the empirical GMPEs. This approach can contribute to update the next generation seismic-hazard maps (i.e. the new release of the Italian seismic hazard map, MPS16), including hybrid GMPEs in areas where recordings are few and ground motion models are not well constrained, especially in near field conditions. Keywords: PSHA; hybrid GMPEs; seismic source zonation; critical infrastructures

ESC2018-S15-501

EARTHQUAKE ACTIVITY RATE ANALYSIS ON FAULT SEISMOGENIC SOURCES IN SLOVENIA

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Probabilistic seismic hazard analysis (PSHA) considers earthquakes over a wide range of magnitudes from all known seismogenic sources in an investigated area. Parametrization of fault seismogenic sources is based on data of active faults, which were the subject of extensive investigations for the past few years, carried out by the Geological survey of Slovenia. The results of these investigations encouraged the detailed analysis of earthquake activity rate, calculated from seismological and geological data. In this analysis, use was made of the historical-instrumental earthquake catalogue and fault seismogenic sources. The earthquake catalogue extends from the year 456 to the year 2014 and contains 1261 main shocks with moment magnitude (MW) > 2.7, of which 390 are within the territory of Slovenia. Moment magnitude of the strongest earthquake in the catalogue is equal to 6.5. For MW 3.5 the catalogue is complete approximately from the year 1866. Fault seismogenic sources are given as 89 fault surface traces with numerous parameters. The shortest fault seismogenic source considered is 6 km long. Spatial relationship between fault seismogenic sources and past seismicity has been established, considering the surface projection of an individual fault seismogenic source plane and the uncertainty in the determination of the epicentral location of each earthquake. In the earthquake activity rate analysis, we calculated seismological earthquake activity rate and geological earthquake activity rate. For comparison, both were calculated as an annual number of earthquakes above the same magnitude threshold for a given fault seismogenic source. Earthquake activity rate has been calculated with the use of doubly truncated exponential magnitude-frequency relationship, where b value was taken to be 1.0. Upper magnitude limit of magnitude frequency distribution has been calculated from empirical relationship between moment magnitude and fault size (area and length). Seismological earthquake activity rate has been calculated from counted number of earthquakes attributed to each fault seismogenic source. By counting the earthquakes for five different magnitude of completeness values, we were able to assess, to some extent, the uncertainty of calculated seismological activity rate. Geological earthquake activity rate has been calculated from fault seismogenic source area and its slip rate. In the calculation of the geological earthquake activity rate we considered only a seismic component of slip rate by multiplying it with a fixed value for all fault seismogenic sources, which was obtained from other studies in similar tectonic environments. We present magnitude-frequency distributions for 34 fault seismogenic sources with at least 5 attributed earthquakes and

for which both seismological and geological earthquake activity rates have been calculated. Some (22) of these magnitude-frequency distributions calculated from seismological earthquake activity rate show good fit with the observed data for most analysed magnitude of completeness values, while others show large discrepancy among seismological earthquake activity rate calculated from various magnitudes of completeness. A possible cause for this discrepancy is relatively short time interval of the earthquake catalogue compared to the return period of stronger events. The difference between calculated seismological and geological earthquake activity rate can be rather large (± 100 earthquakes per year). This is the case in 21 out of 34 fault seismogenic sources. These differences could be due to poorly estimated slip rate, assumptions made (Poisson distribution) or assumed values in calculations. In all other cases (13 out of 34), we observe very good fit between magnitude frequency distributions calculated from seismological and geological data. The results obtained in this study are going to contribute to the current PSHA in Slovenia.

ESC2018-S15-503

INFLUENCE OF CONTACT GEOMETRY ON RESONANCES AND STABILITY OF UNSTABLE ROCK FORMATIONS

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Precariously balanced rocks can be used to provide constraints on estimates of strong ground motions. Standard methodology deals with rigid-body rocking motion, where a rigid block is free to rotate about a supporting point and forcing due to horizontal ground motions is considered. A rigid-body approximation is justified in cases, where elastic eigenfrequencies of the precariously balanced rocks are much higher than ground-motion frequencies, and thus resonance effects may be neglected. There are, however, the cases when lowest eigenfrequencies of the studied bodies can be only several hertz or lower, falling thus into a typical seismic-frequency band and, therefore, resonances may occur. The examples are, e.g., natural rock columns that are of limited heights due to a fundamental vibrational mode or speleothems, where eigenfrequencies can be both measured and calculated theoretically. We first study influence of the rock geometry of several bodies with simple shapes to their eigenfrequencies and demonstrate a key role of the contact with the bedrock. Finally, we deal with the measurements and calculations of the largest rocking stone in the Czech Republic (Husova kazatelna; Hus's Pulpit).

ESC2018-S15-520

ITALIAN SEISMIC HAZARD BASED ON 3D SEISMIC SOURCES

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The geometry and the seismic characterization of the Italian seismic sources, together with the GMPEs adopted, are the ingredients mostly conditioning the seismic hazard assessment, according to the seismotectonic probabilism approach. The earthquake catalogues, geological and tectonic data and studies of the latest years highlighted the possibility of a better definition of the potentially seismogenic zones in several areas of the national territory. This is the starting point for the definition of the new zonation presented in this study, that is developed as an evolution/improvement of the branch A1 of the logic tree that will be used for the new Italian seismic hazard map (MPS16). This new zonation considers dipping planes as seismogenic sources, defined on the basis of all the seismotectonic information available so far. The horizontal areas (the standard seismogenic zones) of the A1 zonation, represent the surficial projection of the inclined planes. Although these dipping geometries are extremely rough because they simplify with a few inclined elements the totality of active faults constituting possible sources, this model mimics the tectonic style better than those based on horizontal planes. The A1, and consequently this new zonation, is generally more detailed if compared to the current Italian national zonation. The main novelties of the proposed zonation consist of the subdivision of some very large zones of the national zonation, due to the presence of seismogenic structures with different geometry and failure mechanism, and the introduction of some new zones referred to areas

not considered seismic until now. The new version of the Italian Parametric Catalogue (CPTI15) has been used for the rates definition, and the Maximum Likelihood method has been adopted to compute the values of the Gutenberg - Richter parameters (a and b values). The maximum magnitude was evaluated for macro areas, representing portions of the Italian territory and surroundings for which it is expected a homogeneous tectonic behavior. The data used for the maximum magnitude assessments are the historical earthquake catalogue (CPTI15) and the composite seismogenic source database (DISS 3.2.0). To compute the preliminary hazard results, a GMPE which takes into account the influence of depth in the source-site distance calculation, is applied. A strict comparison with the values of the previous Italian and European seismic hazard maps is not possible because these maps used different earthquake catalogues and GMPEs as inputs. A comparison is possible only in terms of areal distribution of the expected acceleration values. Key words. Seismic hazard, seismogenic sources, MPS16, Italy A1-MPS16 Working Group: M. Santulin (1), A. Tamaro (2), A. Rebez (2), D. Slejko (2), F. Sani (3), L. Martelli (4), M. Bonini (5), G. Corti (5), M.E. Poli (6), A. Zanferrari (6), A. Marchesini (6), M. Busetti (2), M. Dal Cin (2, 7), D. Spallarossa (8), S. Barani (8), R. De Ferrari (8), G. Barreca (9), C. Monaco (9), F. Piana (10) and A. Irace (10) (1) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano, c/o OGS, Trieste, Italy (2) Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS, Trieste, Italy (3) Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Italy (4) Servizio Geologico, Sismico e dei Suoli, Regione Emilia-Romagna, Bologna, Italy (5) Istituto di Geoscienze e Georisorse, Consiglio Nazionale delle Ricerche, Firenze, Italy (6) Dipartimento di Scienze AgroAlimentari, Ambientali e Animali, Università degli Studi di Udine, Italy (7) Dipartimento di Matematica e Geoscienze, Università degli Studi di Trieste, Italy (8) DISTAV, Università degli Studi di Genova, Italy (9) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Catania, Italy (10) Istituto di Geoscienze e Georisorse, CNR, Torino, Italy

ESC2018-S15-544

CONSIDERING INPUT PARAMETER UNCERTAINTIES FOR GROUND MOTION PREDICTION EQUATIONS WITH NON-PARAMETRIC ARTIFICIAL NEURAL NETWORK REGRESSIONS

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Ground motion prediction equations (GMPEs) are widely used in probabilistic seismic hazard analysis for the computation of uniform hazard spectra. They provide a means of computing the seismic intensity measures (IMs) and their associated uncertainties, based on earthquake magnitude, source-to-site distance and site proxies. The current GMPEs are based on particular functional forms, whose parameters are determined by regression. This makes it difficult to generalize the approach to new IMs. Moreover, vector values GMPEs cannot be easily developed. Non-parametric models, such as artificial neural networks (Derras, Bard, & Cotton, 2014) and Gaussian process regressions (Hermkes, Kuehn, & Riggelsen, 2014), have been used recently to overcome these inconveniences. On the other hand, the input variables are often treated as exact in the computations of the GMPEs. Nevertheless, errors can exist in the determinations of the earthquake magnitude Mw and the thirty-meter shear-wave velocity Vs_30 (Kuehn & Abrahamson,2017). This can lead to overestimation of the aleatory variability of the ground motion models, if the epistemic uncertainties in the input variables are not taken into account. Monte-Carlo simulation, first order second moment method and Bayesian regression are known approaches to deal with epistemic uncertainties in the input variables (Moss, 2011).
In this study, a fully data-driven artificial neural networks (ANNs) GMPEs model is developed. The epistemic uncertainties of M_w and Vs_30 are accounted for in the variance-covariance matrix of the IMs by the first order second moment method. With a non-blockwise diagonal variance-covariance matrix, the maximization of the log-likelihood function is achieved by the ANN training on the basis of generalized least squares. The proposed method is applied to the RESORCE data collected from Pan-Europe earthquakes. Application results show that, after modeling the input uncertainties, both the inter-event uncertainty and the intra-event uncertainty of the GMPEs are reduced. A reduction of 8.7% of the total GMPE uncertainty can be obtained for PGA,

13.2% for PGV, and 4-16% for spectral accelerations, depending on the frequency. The uncertainty reduction is more significant in low frequency ranges than high frequency ranges. This is due to the fact that low frequency spectral accelerations are more sensitive to the variations of M_w and Vs_30, than high frequency spectral accelerations. The median GMPE predictions are only slightly influenced.

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ESC2018-S15-548

ASSESSMENT OF LOW PROBABILITY SEISMIC GROUND MOTIONS FOR CRITICAL INFRASTRUCTURES

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Concentration of high value assets and critical infrastructures (CIs) in vulnerable areas, increase the potential for severe and widespread impacts of rare but devastating and very high impact natural hazards. These events affect the well-being and security of society, but also can induce significant disruption of the economy with special impact on CIs, causing severe loss of function. Among extreme natural hazards, earthquakes represent a major threat as sudden-onset events with limited capability of forecast and high damage potential causing significant disruption to CI networks. Seismic performance level and resilience of CIs can be analyzed by identifying the ground motions leading to failure of selected key elements. Main interest focuses on those exceeding the original design, which should correspond to low probability occurrence. A specific hazard methodology, based on Monte Carlo simulation, has been developed for low probability ground motions affecting CI networks. This approach allows obtaining a representation of maximum amplitudes that follow a general extreme-value distribution. This facilitates the analysis of the occurrence of extremes, i.e., very low probability of exceedance from unlikely combinations, for the development, among others, of stress tests. Extreme ground-motion scenarios have been developed for selected combinations of modelling inputs including seismic activity models (source model and magnitude-recurrence relationship), ground motion models (GMM), hazard levels, and fractiles of extreme ground motion. This approach to seismic hazard is at the core of the risk analysis procedure developed and applied to European CI transport networks within the framework of the European-funded INFRARISK project. Such an operational seismic hazard framework can be used in a timely manner to provide insight to make informed risk management decisions or regulations on the required level of detail or on the adoption of measures, the cost of which can be balanced against the benefits of the measures in question.

ESC2018-S15-549

THE ATTENUATION OF MACROSEISMIC INTENSITY IN ITALY: A PROBABILISTIC APPROACH TO SEISMIC SCENARIOS AND HAZARD ASSESSMENT

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A new Italian seismic hazard map is going to be developed in the framework of an agreement between the Italian National Institute of Geophysics and Volcanology (INGV) and the Department of Civil Protection, to update current map released in 2004. This project involves many national institutions with the aim of delivering a largely shared probabilistic seismic hazard assessment, based on current knowledge and on established methodologies. We present our contribution to this project as for the

development of a new Italian hazard map in terms of macroseismic intensity, a measure of earthquake severity which is worthy of consideration in Italy. A large and accurate Italian Macroseismic Database is published and periodically updated by INGV: the latest version, DBMI15, has been released in July 2016, covers the time-window 1000-2014 and contains 122,701 macroseismic data points related to 3,212 earthquakes (Locati et al., 2016; doi: http://doi.org/10.6092/INGV.IT-DBMI15). Italy has a high level of vulnerability that is not expected to decrease drastically over time because of the great historical, artistic and monumental heritage spread throughout the territory; for this reason, here macroseismic data represent important reference knowledge and clear added value to instrumental data. Rotondi and Zonno (Ann. Geophys., 2004) proposed to estimate the probability distribution of the intensity at a site, conditioned on the epicentral intensity and on the epicentre-to-site distance, by using a beta-binomial model. The choice of the binomial distribution is predicated on respecting as far as possible the ordinal nature of the intensity scale. During the 2012-2013 EU project Projects on Preparedness and Prevention "UPStrat-MAFA" (Grant Agreement No. 230301/2011/613486/SUB/A5), we applied this probabilistic model to macroseismic fields of different European seismic regions with the general aim of contributing to implement common strategies to forecast damage scenarios from macroseismic fields and to assess seismic hazard in different European countries. In the present study, first we update the estimated beta-binomial model based on the latest database DBMI15 under the assumption of isotropic decay. Then we propose how to include the estimated probabilistic attenuation model in the calculation of the seismic hazard map for areal sources. We select a subset of 538 macroseismic fields of good quality from DBMI15 to be used as learning set (related to earthquakes since 1500, with epicentral intensity at least V, and having at least 40 felt reports). Then we group macroseismic fields with similar attenuation in classes by applying the hierarchical agglomerative clustering method known as Ward method (Kaufman and Rousseeuw, Wiley, 1990). The best performance, according to the agglomerative coefficient, is obtained when four attenuation classes are assumed. The four classes contain 362, 108, 47, and 21 macroseismic fields, respectively, and are denoted by A, B, C, and D in decreasing order of steepness (from the steepest attenuation trends to the flattest ones). We perform a Bayesian analysis of the beta-binomial model fitted to each of the four attenuation classes and for each epicentral intensity in the range from V to XI. As for epicentral intensities X and XI, we notice that there is no data in classes C and D and lack of information in class B. According to three validation criteria (logarithmic scoring rule, log-odds score and logarithmic discrepancy), we check that the assignment of few macroseismic fields to class B is poorly supported. Therefore, a unique decay trend on national scale is reasonably assumed for both X and XI epicentral intensity, corresponding to that obtained for class A. As for epicentral intensities V-IX, keeping in mind the goal of setting an attenuation model for areal sources, it is not possible to clearly identify regions in which an attenuation class prevails over others. Therefore, the model for the attenuation decay is defined as a mixture of the estimated binomial distribution of each class, weighted by the proportion of macroseismic fields that are assigned to that class. Nevertheless, we exclude the case of a unique nationwide mixture model because, by applying the Kruskal-Wallis test, we found that there is significant difference in the spatial distribution of the four attenuation classes along the Italian peninsula. Due to the absence of earthquake epicentres of class D in central Italy, we decided to divide the Italian territory into three polygonal regions, roughly corresponding to northern, central, and southern Italy. By applying again the Kruskal-Wallis test to each region, no significant differences are observed in the spatial distribution of the attenuation classes within each region. To conclude, a mixture model for each epicentral intensity from V to IX and for each of the three polygonal regions (northern, central, and southern Italy) is proposed. Weights associated to classes A, B, C, and D are 0.54, 0.23, 0.16, and 0.07 in northern Italy, 0.76, 0.18, 0.05, and 0.01 in central Italy, and 0.68, 0.21, 0.08, and 0.03 in southern Italy.

ESC2018-S15-556

NEURAL-NETWORK BASE PREDICTION OF INELASTIC RESPONSE SPECTRA

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The lateral deformation of structures is an important parameter widely used for assessing the performance of structures. Performance-based design guidelines have proposed various simplified approaches to estimate the maximum global deformation from the response of an equivalent single degree of freedom (E-SDOF) system. This paper will first presents a method to develop directly a Ground Motion Prediction Equation "GMPE" for inelastic response ordinates rather than adopting layer of approximations to derive the inelastic response from elastic response, and then investigates the effects of seismological parameters based on sensitivity analysis. It is worth noting that the proposed model can be readily incorporated in probabilistic seismic hazard analysis (PSHA) to generate directly inelastic response ordinates as intensity measures. The method used in this study is based on Artificial Neural Network (ANN) for which the training dataset is constituted from time history analyses of a range of SDOF systems under various acceleration ground motions extracted from the KiK-Net data base in Japan.A multi-layer perceptron architecture with the error back-propagation learning algorithm is adopted to develop a model with six inputs: four earthquake parameters (i.e. earthquake magnitude, source to site distance and local site condition) and two bilinear oscillator parameters (i.e. natural period and normalized yield strength). The performance of the neural network model shows a good agreement between the predicted and computed values of the inelastic response ordinates. Whereas, a sensitivity analysis demonstrates that the magnitude and the epicenter distance are first order parameters influencing the inelastic response ordinates compared to the focal depth and shear wave velocity down to 30 m which have a smaller impact.

ESC2018-S15-568

A GLOBAL EMPIRICAL PREDICTIVE MODEL FOR ARIAS INTENSITY AND SIGNIFICANT DURATION OF STRONG GROUND MOTIONS

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Integral measures of ground motions and estimates of the duration of significant shaking at a site are used in a broad range of engineering seismology and earthquake engineering applications, including e.g. the assessment of slope stability, liquefaction potential and structural performance. We present in this contribution an empirical predictive model for Arias intensity and significant duration of strong ground motions based on a global dataset of digital high-quality acceleration waveform and carefully curated earthquake and station metadata. We complement the calibration dataset used in our previous studies (e.g. Cauzzi and Faccioli, 2018 BEE) with the recordings of recent major events occurred in Japan, Europe, Iran and New Zealand. The new dataset comprises more than 2000 tri-axial record and allows predictions in the moment magnitude range [4.5;8] at distances within 150 km of the earthquake rupture, in seismically active regions characterized by shallow crustal seismicity. We compare our predictions with other empirical models (e.g. Sandikkaya and Akkar 2017 BEE) as well as with theoretical expressions derived from earthquake source models (e.g. Faccioli 1983 SDEE).

ESC2018-S15-571

MAXIMUM INTENSITIES OBSERVED AND ESTIMATED IN PORTUGAL MAINLAND

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Portugal mainland is located at the southwest edge of Europe and close to the boundary between the African and the Eurasian plates. The interaction between these two plates SW Portugal has been responsible for some large earthquakes that occurred in the past, as the 1st November 1755 Lisbon earthquake with estimated magnitude Mw 8.5–8.7. This event affected not only the whole country but also large regions of Morocco and Spain. Its effects were observed in

many European countries and the following tsunami also caused many casualties and destruction on the surrounding coasts. For slow deforming regions, like Portugal Mainland, the seismic cycle is very long and seismic hazard assessment has to rely on information from historical seismicity. The knowledge on historical earthquakes constrains the maximum magnitude expected and the ground prediction equations that are appropriate for each source domain. In this case one usual procedure is to convert macroseismic intensities do Peak Ground Acceleration (PGA) using some empirical relationship. The macroseismic intensity is the only seismic parameter able to compare the severity of shaking for actual and past earthquakes (despite the different macroseismic scales used). It reflects the effects of earthquakes on human, built structures and natural environment, constituting a unique and valuable information source for the seismologist, the structural engineer, as well as for urban planners and other stakeholders (economists, civil protection managers, decision makers and the insurance industry, for instance). To mitigate seismic risk by the implementation of mitigation measures and techniques, it is critical to understand the impact of past earthquakes, as well as to predict the impact of future earthquakes. One essential tool for seismic risk management is mapping the maximum intensities. This map should represent at each site the maximum macroseismic intensity that has been observed since historical times. In the absence of observations, it should provide for each site an estimate of that maximum intensity as a consequence of known earthquakes. During the eighties, a map of maximum intensities was published by the former INMG (now IPMA), mainly based on isoseismal information collected from the large 1531, 1755 and 1909 earthquakes, as well as from additional further north and Spanish earthquakes. However, this map is strongly conditioned by the aforementioned large earthquakes presenting strict limits between the zones with different maximum intensities very close to the isoseismal curves of those earthquakes. It does not take into account, for instance, the occurrence of smaller magnitude local earthquakes whose intensities may locally have exceeded the ones observed during those strong earthquakes. Moreover, the Portuguese building code for the design of structures for resistance considers two main seismic actions that could affect the Portuguese territory: (1) a high magnitude far earthquake, and (2) a moderate magnitude near earthquake. This National code, developed in the aim of the Eurocode 8 (EC8), is based on a seismic hazard study where the PGA was computed considering separately the far and near seismogenic zones. This source zonation resulting on two code seismic zonation with different reference peak accelerations that will be used on building earthquake resistance computations. The aim of this study is to map the maximum macroseismic intensities observed in Portugal mainland using all available information for felt intensities larger than III. Intensity values from 1110 earthquakes occurred between 1017 and 2015 were used, resulting on 6117 Intensity Data Points (IDP's).With the use of GIS techniques several interpolation methods were tested to better represent the maximum felt intensities at each county and each parish. The data set were separated on near and far earthquakes following the seismic code zonation. The resulting maximum intensity maps were compared and discussed with previous studies, in terms of maximum intensities distribution, seismic hazard assessment and code regulation. Finally, some earthquakes whose epicenter is not completely defined (different authors give different coordinates) are also discussed, as well as their influence on the final results. This communication is supported by FCT-project UID/GEO/50019/2013 - IDL.

ESC2018-S15-589

A PLATE KINEMATICS CONSISTENCY TEST ON PROBABILISTIC EARTHQUAKE RECURRENCE MODELS

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In slowly deforming areas, like Iberia, it is recognized that the earthquake catalogues are incomplete and earthquake hazard estimates are prone to large uncertainties. This fact may explain why three recent Probabilistic Seismic Hazard

Assessment (PSHA) Studies for Portu-gal mainland have shown very different results leading to concerns among the scientific community and doubts among decision makers and the public in general. As a response to these concerns a group of researchers from the Portuguese scientific community initiated a study to evaluate the origin of such differences. The comparison of the earthquake recurrence in terms of zoning and truncated Gutenberg-Richter law parameters showed very different values for the return period of the maximum expected magnitude between models, for two main seismogenic zones in the offshore southwest Portugal. It is common nowadays in PSHA studies to capture the aleatory and epistemic uncertainties by performing Monte-Carlo simulations applied to a logic-tree. This procedure generates a large number of earthquake recurrence models without any consideration on its consistency with known plate kinematics that constrains the seismic deformation that can be accepted. In this work we propose to evaluate the earthquake recurrence models, as single sets of parameters or resulting from logic-tree and Monte-Carlos simulations, by computing the corresponding seismic deformation that can be compared to plate kinematics constrains. This can be done in a simplified way by converting the total seismic moment released into a relative velocity between blocks, for easier interpretation. Here we use typical values of the length of the fault, the seismogenic thickness, the fault inclination and its slip angle, assuming a seismic coupling of 1. From the application of this method to the PSHA studies for Portugal mainland it was possible to verify that all 3 published studies present equivalent veloci-ties of deformation of ~ 2 mm/year for the Lower Tagus Valley, much higher than expected by plate kinematics or geodectic measurements. For the South and Southwest offshore zones, several models also exceed the expected convergence velocity between Africa and Eurasia, ~4 mm/year. When applied to a logic-tree based PSHA study, we conclude that a significant number of the generated models exceed the estimated kinematic constrains, while at the other end, some show very small seismic deformation. Finally, we compare the earthquake recurrence models of the three PSHA with the long-term seismicity moment release estimated from the neotectonic modelling results of Neres et al. (2016). We conclude that: i) PSHA uncertainties exceed those expected from accepta-ble kinematic constrains, and; ii) PSHA studies should include a kinematic constrained earth-quake recurrence model consistency test to eliminate from the computation all models that are not consistent with current knowledge of seismotectonics. This communication is supported by FCT- project UID/GEO/50019/2013 - IDL.

ESC2018-S15-625

UNDERSTANDING EPISTEMIC UNCERTAINTY PROPAGATION IN SEISMIC HAZARD ASSESSMENT

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The prediction of the ground-motion expected at a site is one of the two pillars of Seismic Hazard Assessment (SHA). Since the first developments of empirical ground motion prediction equations (GMPEs) about 50 years ago, a major increase of the awareness of the role of uncertainties associated with these models has been made. It is now considered as standard to split the uncertainties into two main components: on one hand the aleatory variability which is linked with the inherent natural randomness of the physical phenomena; on the other hand the epistemic uncertainty is related to a lack of scientific knowledge or data. The aim of this study is to evaluate how the epistemic uncertainty is currently captured in state-of-the-art Probabilistic Seismic Hazard Assessments (PSHA) and compare various techniques that have recently been used to capture the appropriate level of uncertainty. Epistemic uncertainty is commonly evaluated using a logic-tree approach following the work of Kulkarni et al., 1984. By running retrospective tests of PSHA, we can compare analysis from the past to data available now and qualitatively and quantitatively assess if the epistemic uncertainty would have been correctly assessed at that time and therefore propose a way to better evaluate the present state of uncertainty. Repeating this process with increasingly modern models, and also by decreasing the amount of available data with the use of modern techniques to deal with scarce and limited data (imprecise probability, fuzzy analysis) will help to understand how epistemic uncertainty affects ground motion estimation in SHA. Key-words : Epistemic

uncertainty, Seismic Hazard, Ground-Motion model, Seismology

ESC2018-S15-636

PROBABILISTIC SEISMIC HAZARD ASSESSMENT OF NORTH AFRICA: A GEM'S PRODUCT

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African seismicity is predominantly localized along the East African Rift System (EARS), which is the major active tectonic feature of the Sub-Saharan Africa. Besides the EARS, non-negligible seismicity also occurs along a wide belt bounding the Mediterranean coastline. This region extends discontinuously from Morocco to Egypt and its activity is controlled by the complex interaction between the Nubian and Eurasian plates, with a tectonic regime characterised by transpression in the west and transtensional deformation in the east. The region exhibits a long record of large earthquakes, some of them causing a substantial amount of damage, mostly because of the high vulnerability of the local buildings and structures, a condition that is still largely persistent in this area. Currently, a number of seismic hazard models exist at local and national scales for North Africa, developed within independent projects and created using inhomogeneous or incomplete data sources and different processing techniques. Unfortunately, such diversity makes their direct comparison problematic, obscuring the differences in seismic hazard across neighbouring areas and preventing the development of comprehensive long-term risk mitigation strategies. In fact, the last effort to produce a homogenized model for the whole Africa continent dates back to the GSHAP project, which is almost twenty years old. The creation of a unique seismic hazard model for North Africa, uniform across countries, is therefore a main concern. Since its inception, the Global Earthquake Foundation (GEM) is committed with the creation of a worldwide mosaic of high-quality, reproducible and openly accessible seismic hazard models, uniformly represented using the format adopted by the OpenQuake engine, a state-of-the-art, free and open-source software for seismic hazard and risk assessment. The models included in this mosaic are – preferably – models developed within collaborative projects involving the local scientific community. We summarize in the following the progress done in the creation of a comprehensive PSHA model for North Africa using GEM tools, with the wish of encouraging discussion and further collaborative development in the near future.

ESC2018-S15-640

RAN ACCELEROMETRIC DATA TREND IN A GMPE SHAPE

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In the last few years a lot of ground motion prediction equations (GMPEs) formulations have been proposed in literature for the Italian territory, as Massa et al. (2008), Akkar et al. (2010), Bindi et al. (2014) and Cauzzi et al. (2014). The main characteristics and differences between these formulations are concerning on the distance definition, site classification and the considered fault mechanisms. In this study we have collected, analyzed and elaborated the accelerometric data belonging to the RAN network managed by the National Civil Protection in the time-span 2011-2017. Using an automatic procedure that works daily in a near real time mode at our department (Gallo et al., 2012) we estimated the ground motion parameters for each collected waveform and the moment magnitude values for each event. The entire database counts 1985 earthquakes with a moment magnitude between 3.0 and 6.4 of the strongest event of Amatrice sequence occurred the 30th of October, 2016. The total number of records are 118021 up to 150 km. The availability of this huge amount of high-quality accelerometric data allows us to validate or re-calibrate the existing GMPEs for the Italian territory. The philosophy beyond this study is to start with the simplest reasonable functional form for the equations and then testing term by term adding complexity after a comparison between the predicted ground motions parameters with the observed ones. The selection of functional form is heavily guided by studies found in literature. The ground motion parameters analyzed are the most commonly used: peak ground displacement (PGD), peak ground velocity (PGV), peak ground acceleration (PGA), Arias

intensity, Housner intensity, peak spectral acceleration at 0.3, 10 and 30 Hz (PSA03, PSA10 and PSA30).

ESC2018-S15-728

TOWARD THE 2020 EUROPEAN SEISMIC HAZARD MODEL (ESHM20): STATUS UPDATE ON DATA COLLECTION, HARMONIZATION AND KEY ASPECTS OF MODEL DEVELOPMENT

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The 2020 update of the European Seismic Hazard Model (ESHM20) is already ongoing within the joint research activities (JRA2) in SERA Project (www.sera-eu.org). Starting with the SERA kick-off meeting, in April, 2017, the efforts have been focusing on compilation of new earthquake catalogues and new active faults, incorporating new ground motion models, using the crustal deformation models to reassess the earthquake activity rates, and ultimately improving the overall modeling uncertainties. Of great importance is the compilation of the recent national seismic hazard models and their integration with the ESHM20. We will update the seismogenic source models at the Euro-Mediterranean region, to reflect the newly and fully harmonized input datasets (earthquake catalogue, active faults, seismo-tectonic regionalization) in reconciliation with the national seismogenic sources. We will explore options to reduce the inherent epistemic uncertainties of both earthquake rate forecast and ground motion - based on retrospective testing and model's performance on new data. In this contribution, we also discuss the results of the re-assessed earthquake rate forecast of the pan Euro-Mediterranean region and some of their challenges. We summaries of the up-to-date datasets and finally, we conclude with an overview of the next steps and milestones toward the 2020 European Seismic Hazard Model (ESHM20).

ESC2018-S15-747

RECENT DEVELOPMENTS ON SEISMIC HAZARD ASSESSMENT IN SE SPAIN

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We present a summary of seismic hazard assessment studies developed in the Region of Murcia (southeastern Spain) during the last years. This is one of the region with the highest seismic activity in Spain, as evidenced by the seismic catalog and historical documents, and with the highest seismic hazard, according to the seismic hazard maps of the Spanish seismic code. Different studies show that some of the most active faults of Spain, as indicated by the estimated deformation rates, are located in this region. Additionally, the last damaging earthquakes affecting the Spanish territory occurred in this area, including the magnitude 5.1, EMS intensity VII 2011 Lorca earthquake, which caused nine fatalities and the demolition of hundreds of buildings. The reference seismic hazard map of Spain is the seismic hazard map of the Spanish building code NCSE. The current map of 2002 is an update of the former map of 1994. They are based on an area-source model, that does not present any difference specifically for the study region. According to this map, horizontal acceleration values expected for the 500-year return period on hard soil conditions (so-called basic acceleration) are around 0.06-0.16 g for this area. The seismic risk study of the region of Murcia, SISMIMUR, was presented in 2005-2006. The seismic action for this study was based on a logic tree with different area-source models, including one that mimicked the most important fault systems of the study area. Expected peak ground accelerations for rock conditions of 0.04-0.13 g are estimated for the region of Murcia. The seismic hazard maps of Spain were updated in 2012. These maps are intended to constitute the basis for the future revision seismic code. They are constructed considering an updated logic tree with nodes for different area-source models and combinations of ground motion prediction equations. Fault data are used to estimate the maximum magnitude that is expected in each area-source. Expected peak ground acceleration values for the 475-year return period are in the range 0.08-0.23 g. These results will be also incorporated in the Spanish national annex of Eurocode 8. A new seismic of the region of Murcia

was developed taking into account active faults as independent sources. The seismic potential of fault sources was estimated using fault slip rates derived from paleoseismic fault data. The seismicity that could not be associated to specific faults was included in an area-source of uniform seismic characteristics. The seismic potential of faults and area-sources was estimated assuming a modified Gutenberg-Richter recurrence model and distributed between the different types of sources within the range in which the seismicity rates and moment rates could be considered complete (unbiased by catalog incompleteness). Thus, double counting of seismic potential between faults and area-sources was prevented. Results of this model give expected peak ground accelerations of 0.08-0.30 g in the region of Murcia for the 475-year return period. The highest PGA values are found along main fault traces. More recently, a characteristic earthquake recurrence model was applied to fault sources. The expected peak ground acceleration values obtained considering the characteristic earthquake rates derived from paleoseismic data are in the range 0.08-0.18 g, with maximum values along fault traces. These last two studies were updated considering fault slip rate estimates derived from geodetic measurements for some fault systems (which are significantly higher than slip rates derived from paleoseismic data). Results indicate a significant increase on hazard estimates considering geodetically derived slip rates along fault traces, in correspondence with the significant rise of slip rate values. The present study illustrates how the subsequent updates of seismic hazard maps result in different hazard estimates. The variations between the different maps may be significant, depending on different choices of source models, ground motion prediction equations and the slip rates used to represent fault activity. The progressive availability of data and models should help in capturing and reducing the epistemic uncertainty observed in seismic hazard models. A part of this contribution is included in the MERISUR project (Metodología para la Evaluación Efectiva del Riesgo Sísmico Urbano) funded by the Spanish Ministry of Economy and Competitiveness (ref. CGL2013-40492-R).

ESC2018-S15-767

METHODOLOGICAL COMPARISON OF MACROSEISMIC MAGNITUDE ESTIMATES FOR EVENTS ALONG THE FRENCH-ITALIAN BORDER

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Magnitude estimates of earthquakes occurred before the instrumental period are a key issue in seismic hazard assessment. For such earthquakes, the only information available is provided by historical sources. These are first translated into macroseismic intensity by means of intensity scales and then intensities are used to estimate earthquake parameters such as epicentral intensity, magnitude and sometimes depth. Methods for computing earthquake parameters from intensity data differ within and between countries, leading to the long-lasting discussions about the reference earthquake catalogue that should be used for seismic hazard assessment. Within the SHARE project (http://www.share-eu.org/), the SHEEC 1000-1899 catalogue (https://www.emidius.eu/SHEEC/; Stucchi et al., 2013) first attempted at homogenizing data and procedures for the assessment of the parameters of historical earthquakes. However some issues remained open, including the way depth is taken into account in the methodology and the way uncertainty is quantified. We compare two methods, Boxer (Gasperini et al 2010) and IRSN (Provost and Scotti, 2017) applied to a set of 62 events located along the French-Italian border using the same macroseismic data (SisFrance database, http://www.sisfrance.net) and epicentral location. In Boxer parameter estimates result from the application of a single intensity prediction equation (IPE) to each isoseismal. The final estimate is the mean of the magnitudes associated to each isoseismal. The standard deviation of the mean depends on the weight given to each isoseismal, which in turn, depends on the number of data for the given event as well as the number of data used in the IPE calibration procedure for the given intensity class and its associated standard deviation. In the IRSN method, on the other hand, several IPEs are calibrated in order to fit the intensity decrease with distance and applied through a least-squares procedure that results in a solution for each IPE with an associated standard deviation. A space of

acceptable solutions is then defined for each IPE by rejecting magnitude-depth solutions that are incompatible with the allowed epicentral intensity values and the given IPE. The sum of the acceptable solutions quantifies the epistemic uncertainty of the earthquake parameters in the Magnitude-Depth-Epicentral Intensity space. We show that the treatment of depth has a major impact on magnitude estimates. We compared the barycenter of the IRSN space of solutions and Boxer magnitude estimates. Boxer does not assess depth; whereas in the IRSN method depth is inverted. In order to quantify differences between the two methods we run a first test assuming that depth is fixed at 10 km depth. In this case, application of the two methods to the 62 macroseismic data sets lead to differences between magnitude estimates characterized by a mean of 0.02 and a standard deviation of 0.26 with only 6% of the events presenting a difference in magnitude estimates greater than 0.5. We then ran a second test for the IRSN methodology, where depth can be inverted for and is allowed to range between 1 and 25 km. In this case differences in magnitude estimates are characterized by a mean of 0.05 and a standard deviation of 0.4. In order to understand the statistical significance of such differences, we compared quantified uncertainties using both methodologies. The space of acceptable solutions resulting from the IRSN method can be quite large compared to the uncertainty estimates proposed by Boxer. For the first test case we show that 92% Boxer mean magnitude estimates fall within the space of solutions proposed by the IRSN methodology. For the second test case, comparing only magnitude estimates, 84 % of Boxer estimates fall within the IRSN magnitude uncertainties. This work underlines the importance of quantifying uncertainties in parametric earthquake catalogues and the need to propagate such uncertainties in seismic hazard assessments, be it probabilistic or deterministic.

ESC2018-S15-770

PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR THE MALTESE ARCHIPELAGO THROUGH THE USE OF DIFFERENT APPROACHES

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In the present study we attempt to construct seismic hazard model and produce probabilistic seismic-hazard assessments for the Maltese Islands in terms of Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) at different periods. Assessing the seismic hazard for the region is currently of prime interest for the near-future development of industrial and touristic facilities as well as for urban expansion and so far very few investigations have been carried out on seismicity around the Maltese islands and no maps of seismic hazard for the archipelago are available. Although recent constructions of a certain structural and strategic importance have been built according to high engineering standards, the same probably cannot be said for all residential buildings, many higher than 3 storeys, which have mushroomed rapidly in recent years. Such buildings are mostly of unreinforced masonry, with heavy concrete floor slabs, which are known to be highly vulnerable to even moderate ground shaking. Seismic hazard has been computed using the two earthquake source models relying on different assumptions and providing full description of earthquake activity. The first one is the zonation model: seismotectonic and geological data are used coupled with earthquake catalogues to identify seismogenic zones within which earthquakes occur at certain rates. In this study we used several seismogenic zones and include in computation few seismogenic area close to the Maltese islands never considered before. In order to determine the ground motion parameters related to a specified probability of exceedance, the earthquake source models are combined with ground motion prediction equations and one of them is based on the results of the high-freqeuncy ground motion scaling study recently performed in the area. The second one is the spatially smoothed seismicity approach based on the instrumental seismicity using adaptive smoothed approach originally described by Helmstetter et al., (2007). We analyze the instrumental background seismicity, compute the rate of earthquakes on a grid, and smooth these rates to account for uncertainty in the spatial distribution of future earthquakes. The smoothed seismicity is obtained by counting the number of earthquakes

with magnitude greater than 3.0 in each cell of a grid with spacing 0.1° in latitude and 0.1° in longitude. The seismicity rates are calculated on a spatial grid platform using the Catalog of Italian seismicity 1981-2016 (Gasperini et al., 2013). The optimized adaptive neighbor number, N=2, is obtained by choosing the value that maximized the likelihood that the forecast rate models gave rise to the spatial distribution of the earthquakes in the testing catalog. Finally, the annual rate of exceeding a specified ground motion at a site is calculated from a double summation over distance and magnitude, using suitable ground motion relationships. For hazard calculations, we choose a low cutoff magnitude of Mmin =4.5 and the upper limit Mmax =7.5 is a relatively arbitrary choice in the definition of background seismicity. We adopted only one GMPE for the active shallow crustal regions to assess the ground shaking hazard as defined by Bindi et al., (2011) for rock conditions. A first attempt to combine also the influence of local site is presented.

ESC2018-S15-783

GROUND MOTION PREDICTION EQUATIONS (GMPE) FOR MINING INDUCED SEISMICITY IN LEGNICA GLOGOW COPPER DISTRICT IN POLAND

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Although seismic events induced by human technological activity are weak to moderate compared to the tectonic earthquakes, due to their shallowness, they can result in significant ground motion. At the same time, the specific features of such seismic sources lead to ground effects which do not follow the ground motion propagation rules obtained by observations of tectonic earthquakes. In particular, the conditions of ground vibration propagation due to dominant short distance (up to 10km) and the amplifying site effects are related to geological conditions of the study area. Therefore, in order to obtain an accurate tool for predicting the ground motion for such areas, the identification of a GMPE should be done locally. Another factor that influences GMPE in induced seismicity case studies is the dominant type of induced events focal mechanism which often contains a significant non-Double Couple (DC) component. Therefore different classification of source mechanism should be used than faulting mechanism classes used in case of tectonic earthquakes. We present here a new GMPE for the mining seismic activity in underground copper mines in Legnica-Glogow Copper District (LGCD) in Poland, which have been worked out accounting for the above remarks. The ground motion database comprises 4533 records which were triggered by 1605 seismic events from three seismically active mines. The database consist of ground motion parameters such as Peak Ground Acceleration (PGA); source parameters of mining events such as local magnitude, hypocentral coordinates and some full moment tensor mechanism solutions; registration parameters such as station coordinates and site class. The study has shown that when dealing with ground motion caused by shallow and weak seismic sources, like in the analysed case of mining induced seismicity, local geological conditions and their variability have significant influence on surface effects, even over a relatively small area. The amplitude of the ground motion also depends significantly on the source mechanism type. The investigation of the new 'site and mechanism specific' GMPE for the LGCD region can be used for a more accurate estimation of Probabilistic Hazard Assessment (PHA) in this region. This work was partially supported within statutory activities No 3841/E-41/S/2018 of the Ministry of Science and Higher Education of Poland.

ESC2018-S15-821

SITE-SPECIFIC PROBABILISTIC SEISMIC HAZARD ASSESSMENT ANALYSES IN ZEYTINBURNU, ISTANBUL

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The first step in estimation of seismic losses in urban areas is the assessment of regional seismic hazard. The source and local site parameters determine the accuracy of the hazard model. Using locally derived input parameters in site response modeling and hazard analyses, the earthquake potential of Zeytinburnu region in Istanbul is investigated in detail. In this study, two alternative source models including area and fault (line) sources are considered in the hazard computations. Analyses are initially performed

using generic rock and soil conditions considering return periods of 475, 975 and 2475 years. Then, site-specific seismic hazard analyses are made using available local soil conditions. Probabilistic seismic hazard analyses with line sources and local soil models yield significantly different results than area sources and a generic soil model for all return periods. This observation points out the fact that detailed local source and site parameters should be employed in hazard analyses. In summary, numerical results obtained with locally derived input parameters indicate that Istanbul has significant potential for hazard in terms of both local earthquake occurrence and site amplifications.

ESC2018-S15-823

HYBRID BROADBAND GROUND-MOTION SIMULATIONS FOR THE 2016 AMATRICE EARTHQUAKE, CENTRAL ITALY, AND SENSITIVITY OF GROUND-MOTION TO EARTHQUAKE SOURCE PARAMETERS

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On 24th August 2016 at 01:36 UTC a MW 6.0 earthquake struck several villages in central Italy, among which Accumoli, Amatrice and Arquata del Tronto. It caused 299 fatalities, major destruction and extensive damage in the surrounding area (up to 11 intensity degree). The earthquake was recorded by 350 digital accelerometers belonging to the National Accelerometric Network (RAN) of the Italian Department of Civil Protection, to the National Seismic Network (Rete Sismica Nazionale, RSN) of the Istituto Nazionale di Geofisica e Vulcanologia (INGV), and to other local networks. This earthquake ruptured a NW–SE oriented normal fault, according the prevailing extensional tectonics of the area. The maximum acceleration was observed at Amatrice station (AMT) with epicentral distance of 15 km, reaching 916 cm/s2 and 445.6 cm/s2 on E-W and N-S components, respectively. Motivated by the high levels of observed ground motion and damage, we have computed synthetics broadband time series for engineering purposes. To produce high-frequency seismograms, we have used a stochastic finite-fault model approach based on dynamic corner-frequency. Whereas to infer the low frequency seismograms, we have considered two heterogeneous kinematic slip models (Tinti et al. (2016) and Cirella & Piatanesi (2016)) obtained through the inversion of strong ground motions. In order to retrieve broadband synthetic time series, high frequency seismograms were merged to low frequency ones. Using the wide available waveform database we have also tested the likelihood of the physical parameters adopted in simulations. We have adopted the region-specific attenuation and source scaling parameters derived by Malagnini et al., (2011) for the area. Simulated hybrid ground motions are then validated with the observed ground motions, and then compared with Italian ground-motion prediction equation (GMPE) ITA10 (Bindi et al., 2010). In the near field we have found that, rather than the use of GMPEs, hybrid simulations have a higher capability to detect near source effects and to reproduce the source complexity as well as the slight bilateral rupture observed by several authors (e.g., Tinti et la., 2016; Lanzano et al., 2016; Calderoni et al., 2016; Pischiutta et al., 2016). Moreover, the general good consistency found between synthetic and observed ground motion (both in the time and frequency domain), suggests that the use of regional-specific source scaling and attenuation parameters in hybrid simulations improves ground motion estimations. Finally, the use of site-specific amplification curves (at stations were the velocity profile was available) rather than the site-classes as prescribed by NTC-08 seismic code, led to a further reduction of residuals between observed and simulated.

ESC2018-S15-832

EFFECTS OF ALTERNATIVE SOURCE MODELLING AND PARAMETERISATION APPROACHES ON THE RESULTING PROBABILISTIC SEISMIC HAZARD ESTIMATES IN TURKEY

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Recent practice in the probabilistic seismic hazard involves, with an increasing rate, source modelling based on the so-called linear sources, derived from active faulting data. As opposed to the more traditional areal sources for which the computed hazard is more or less uniform over the entire source, linear sources bring a higher level of precision to the geographic distribution of the

resulting ground motion estimations. On the other hand, including faults in the probabilistic hazard models brings an increased degree of uncertainties due to a large number of parameters required for modelling. Chartier et al. (2016) indicate that this is especially the case in the low to moderate seismicity regions, such as greater part of Europe, where slow slipping faults are difficult to characterize. Nevertheless, in its preferred weighting scheme, the European Seismic Hazard Model (Woessner et al., 2014) assigned a 20% weight to the fault source and background (FSBG) model developed for Europe, for return periods ranging from 475 years to 2475 years. With the experience gained in the European Seismic Hazard Model and therefore with an increasing confidence on the fault source models, its counterpart in the east, the Earthquake Model of Middle East (Danciu et al., 2017, Sesetyan et al., 2018) assigned a 40% weight. Following and benefiting from these two major efforts, the recent project on the update of the probabilistic seismic hazard in Turkey developed two source models, one based on an area source model (Sesetyan et al., 2016) and second on a fault source complemented with a smoothed seismicity model (Demircioglu et al., 2017), assigning 50% weights to each in the final source model logic tree. For the Turkey case, a comparison of ground motion distributions resulting from the two source models reveals that, especially for low seismicity regions, fault source and area source models may in one respect compensate for each other, as in regions where we don't have adequate faulting data, the area source model may yield more conservative results, or in regions lacking recent seismicity but where geologic evidence of active faulting is available the fault source model may have a similar effect. In additions to these, the present study concentrates on challenges and uncertainties associated with the modelling of high seismicity/high hazard zones, where we observed two kinds of discrepancies, the first resulting from the source modelling approaches, i.e. large differences in the maximum ground motions estimated from the area and fault source models; and second, differences in the maximum ground motion values obtained in an individual model (here the fault source model) for two highly seismic regions yielding comparable levels of ground motions in another model (here the area source model). The effects of alternative source models, magnitude frequency distributions, partitioning of the total seismic moment between fault and background sources, as well as the effects of fault geometry in connection with the ground motion models used are discussed for the two highest hazard zones in Turkey, i.e. the North Anatolian and Aegean regions.

ESC2018-S15-835

GROUND MOTION PREDICTION EQUATIONS: A REVIEW OF EQUATIONS FOR THE VOLCANIC REGION OF MT. ETNA (SICILY).

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Ground motion prediction equations (GMPE) typically involve statistical estimation procedures for regression analysis on selected sets of instrumental data. The explanatory variables usually include the earthquake magnitude (M), a measure of the source-to-site distance (R), a parameter describing the site categories, the faulting mechanism, and other independent variables such as hanging-wall factor and sediment depth. The uncertainty of the prediction is reflected in the standard deviation (?? of the ground-motion residual distribution. Commonly refers to as the uncertainty of the ground motion due to the genuine randomness of the process under consideration (aleatoric uncertainty) as well as the deficiencies of the model (epistemic uncertainty). Efforts aiming at reducing the uncertainty regard in particular the epistemic part of the error. Improvements with respect to this can be achieved by the choice of models having more degrees of freedom, allowing, for instance, a better modelling of the magnitude dependence of ground motion or distance dependence of attenuation. From an ANOVA analysis, Tusa and Langer (2016) concluded that a major part of the prediction error of GMPE calibrated for the volcanic area of Mount Etna can be attributed to the improper treatment of site response. In the present study we start from the results of Tusa and Langer (2016) who recently derived a set of GMPEs for PGA, PGV and 5% damped spectral acceleration at several frequencies, by using different functional forms. The data set consisted of seismic events covering a magnitude range of $3.0 \leq ML \leq 4.8$ and an epicentral distance from 0.5

to 100 km. The data was used to calibrate two distinct GMPEs for shallow (focal depth 5 km). The shallow earthquakes occur in a very specific seismotectonic setting, and their peculiar location at hypocentral depths lesser than 5 km has effects on both the seismic scaling laws and wave propagation phenomena. This kind of events, with magnitude reaching ~5 and epicentral intensities up to degree IX EMS, represents the main source of hazard for the densely urbanized flanks of the volcano (Azzaro et al., 2016). In this study, we propose a more accurate definition of GMPEs for PGA, focusing our attention on the shallow earthquakes since they are of primary engineering interest for the studied area. We updated the data set, and reprocessed all data using both a random effects approach and the non-linear Marquardt-Levenberg inversion scheme. In particular, we compare models with various degree of freedom, and focus on the correction for site effects. In principal increasing the degrees of freedom of a model leads to lower misfits. This, however, comes with the cost of losing in significance of the predictions. We therefore calculate several goodness-of-fit statistics, such as Nash-Sutcliffe model efficiency coefficient (E) (Nash and Sutcliffe, 1970), the LH value (Scherbaum et al., 2004), the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). Besides we propose cross-validation tests as these do not depend on any a-priori information on the statistical behavior of the data. The above mentioned problem of soil classes is tackled by adopting a site classification based on EC08- site classification is also presented. In alternative, we use a classification with four classes defined by the dominant site period. We refer to the empirical site classification method by Zhao et al. (2006), which uses the mean H/V spectral ratio amplitudes across a range of periods.

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ESC2018-S15-860

A KINEMATIC SOURCE MODEL FOR THE RAUW FAULT, NE BELGIUM

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The Rauw fault is a 55-km-long normal fault in NE Belgium and part of the southwestern border of the Lower Rhine Graben. It features the largest Neogene offset west of the Roer Valley Graben. While the fault experienced several meters of Quaternary displacement, there is no evidence of activity in the last ~40,000 years. Its current state is therefore unclear. The Rauw fault is nevertheless capable of accommodating large earthquakes. This makes it a possible source of seismic hazard for the nearby nuclear site of Mol-Dessel and a future geological disposal for long-lived and/or high-level radioactive waste which might be sited in the region. We developed a kinematic source model for the Rauw fault to generate possible future rupture scenarios. To ensure we obtain the full range of realistic ruptures we consider multiple modelling strategies and empirical scaling relationships. Slip distributions are calculated using a spatial random field or a summation of subevents with a fractal distribution of sizes. In either case, we enforce a roughly wavenumber-squared fall-off in the spectral domain. The obtained slip distributions are combined with multiple published slip rate functions that were found to be compatible with dynamic modelling. Rupture velocity is not constant but varies with depth, is correlated with the slip distribution and randomly perturbated. The rupture propagation is then calculated with a numerical method. To analyze the set of ruptures generated with our model, we performed simplistic ground motion simulations with a hybrid approach, involving wave propagation that is

deterministic at low frequencies and stochastic at high frequencies. We use only a simple layered crustal model to minimize the effects of wave propagation. In a next step we will combine our kinematic source model for the Rauw fault with realistic wave propagation. We can then quantify the variation of near-field ground motions and correlate this to the rupture histories. We will also be able to provide engineers with physics-based ground motion time series that can be used in seismic analysis for complex structures like geological disposals.

ESC2018-S15-873

GROUND-MOTION SCENARIOS FOR THE CITY OF SULMONA (ITALY): FIRST APPROACHES FOR THE ASSESSMENT OF BUILDING BEHAVIOR

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The city of Sulmona (AQ, Italy) lies above a deep sediment-filled active intramontane basin, known as Sulmona Basin, flanked by steep uplifted carbonate blocks. The basin develops in the more external portion of the Abruzzi central Apennines, with a NW-SE trend and it is limited to the east by the Mt. Morrone active normal faults system (e.g., Vittori et al., 1995; Gori et al., 2014). The basin is characterized by a series of complex geological, geomorphological and tectonic features which may be responsible for important effects of seismic site amplification. In fact, during past earthquakes the city of Sulmona had often suffered more heavy damage than observed in the surrounding localities (Pizzi et al., 2014). The Mt. Morrone fault, also known as Sulmona fault , is considered as earthquake seismogenic source (Valentini et al., 2017) capable of producing M~6.7 earthquakes (e.g., Peruzza et al., 2011). According to the Italian Database of Individual Seismogenetic Sources (DISS Working Group 2010), the last strong shock associated to this fault is the M6 1315 earthquake (CPTI Working Group 2004), which determined a degree X MCS at Sulmona. In this study, we consider both instrumental records as well as synthetic simulations to obtain earthquake scenarios relevant for the city of Sulmona, incorporating both site effects and building response. In particular, besides the conventional response spectra, we have carried out first tests on the building response (non-structural or structural damage) calculating the generalized inter-story drift spectrum following the approach by Miranda and Akkar (2006). The method provides an estimate of maximum inter-story drift in multistory buildings and allows a first assessment of the deformation a building undergoes during an earthquake. The effects of peak ground acceleration, rupture distance and local site conditions on maximum inter-story drift spectra, are also evaluated. As representatives of damaging earthquakes for the area of Sulmona, we used the instrumental records relative to M>5 events. Data have been recorded by four stations (station SUL with soil class A; SULA and SULC with soil class C; SULP with soil class B); real time histories were downloaded from ITACA – the Italian Accelerometric Archive - and cover an epicenter distance range from 40 to 100 km. In order to extend our analysis to larger events, we carried out numerical simulations by the code EXSIM, assuming an M6.7 earthquake along the Sulmona fault.

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ESC2018-S15-877

EFFECT OF EARTHQUAKE CATALOGS DECLUSTERING ON THE SEISMIC HAZARD ASSESSMENT

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The effect of various preliminary processing methods of seismic catalogues on seismic hazard assessment is studied. The impact of declustering, i.e. the removal of dependent events, and the choice of the completeness magnitude was investigated. The catalogues of the Kamchatka and Caucasus regions were used for the analysis, because synthetic catalogues may not show the real features of regional seismicity. The declustering impact on seismic hazard calculations is illustrated by the examples of Kamchatka and Caucasus regions, where probe sites were selected. Three methods of declustering are considered: there is a different number of events in the catalogues after their application. The plotted hazard curves indicate a complex "interaction" of catalogue declustering with the choice of the completeness magnitude, since both of them affect the b-value, and it is not always possible to predict in advance whether this leads to an increase or a decrease in the estimate of b-value. The method of declustering, which leaves most events in the catalogue, does not always give the highest hazard estimate. In this regard, it is necessary to note again that it should be treated with special care and attention to declustering of catalogues. At least, it should be taken into account that this procedure can affect the final result unpredictably.

ESC2018-S15-891

RAP-RESIF GROUND MOTION DATASET

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Ground motions recorded at both, accelerometric and broad-band stations from the RAP (Reseau Accelerometrique Permanent) and RESIF (Reseau sismologique & geodesique français) French seismic networks have been collected, over the period 1996-2016. The collected waveforms have been visually inspected, non-standard errors have been removed, P and S-wave arrivals have been manually picked. For each record, noise, P-wave, S-wave and coda windows are defined following the Perron et al (2017) algorithm. The raw data is then processed following the Boore et al. (2012) procedure. As a result, the dataset includes about 7000 three-component recordings from 300 seismic stations, 74% being accelerometers and 26% being broad-band sensors. The data covers earthquake magnitudes Ml from 2.5 to 5.6, recorded at epicentral distances from 1 to several hundred km. The aim of this high-quality dataset of seismic-motions and associated meta-data is to be used in several applications of engineering seismology and earthquake engineering, such as:

- integrating these data to active region datasets for ground motion model development;
- testing of ground motion models predictions against data;
- testing of seismic hazard models against data;
- generalized inversions of ground motion;
- seismic wave attenuation mapping;
- high frequency attenuation analyses, particularly for rock sites;
- weak motion dynamic site-response and site-effect analyses.

ESC2018-S15-895

REGIONAL DEPENDENCE IN STRONG GROUND MOTION: COMPARISON TO PREDICTIVE MODELS FOR WESTERN TURKEY

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The regional difference in earthquake ground motion amplitudes has been the subject of ground motion prediction related studies for more than a decade. Various studies showed the influence of region specific parameters such as focal depth, stress drop, high frequency attenuation characteristics, and shallow soil properties on ground motion amplitudes. In this study regional differences in ground-motion amplitudes are investigated by using the conventional residual analyses of strong-motion and broad-band data compiled from the Marmara and Aegean regions in Turkey. A ground-motion dataset compiled from the earthquakes occurred between 1976 and 2017 is used for this purpose. The lower magnitude limit of the dataset is ML 3.5 whereas epicentral distances of the recordings are within 300 km. The events are shallow crustal having hypocentral depths less than 30km. The 2017 M6+ earthquakes in the Aegean Region (Izmir earthquake, Mw6.4 and Bodrum-Kos earthquake, Mw6.6) significantly improve the pertaining data distribution in terms of magnitude and source-to-site distance. Indeed, the Bodrum-Kos Earthquake draws the upper bound magnitude for the Aegean SM database. The only distinguishable recent large-magnitude event in the Marmara region is the 2004 Gökçeada earthquake (Mw6.9). Geometric means of horizontal peak accelerations (PGA) as well as 5% damped linear elastic response accelerations (Sa) at various structural periods are calculated and are used together with the most recent local ground-motion predictive models by Kale et al.(2015), Gülerce et al (2015) and Boore et al (2014) which are applicable to entire Turkey. The between-event and within-event residuals are computed separately for Marmara and Aegean Regions, which feature two distinct seismotectonic regimes, and they suggest biased ground-motion estimates in terms of source and path. Different behavior of between-event and within-event trends apparently advocates a regional variation in which GMPEs cannot capture. The results of this study will serve to develop a region-dependent ground-motion predictive model for Turkey that will be a product of the "Updating and Extending the European Seismic Hazard Model" task in SERA project (Horizon 2020 - Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe).

ESC2018-S15-929

INCREASING EARTHQUAKE FORECAST TESTABILITY - CSEP FUTURE DEVELOPMENTS

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The Collaboratory for the Study of Earthquake Predictability (CSEP) has expanded over the years to many different testing areas hosted at multiple testing centers. Hundreds of earthquake forecast models have been submitted to CSEP and are being tested. New testing metrics were developed and implemented and a lot of progress was made to establish CSEP as an institution that cannot be ignored when issuing earthquake forecasts. Its rigor and independence became the standard in evaluating earthquake forecasts and in reporting on the results. In the framework of the testing activities of the Global Earthquake Model, one line of expanding the capabilities of CSEP was developed at GFZ Potsdam. The group there applied the mechanisms that CSEP introduced to earthquake forecast models to the area of intensity prediction equations (IPEs) and ground-motion prediction equations (GMPEs). The first truly prospective tests were carried out on IPEs for Italy and also on GMPEs for Japan and New Zealand. This new set of tests helped CSEP move into the hazard domain and increase the relevance of its results to the hazard community. Finally, the

group at GFZ Potsdam has also conducted the first prospective test of the US national seismic hazard maps. Although these tests have been successful and well-received, they have also shown the limitations of the CSEP approach. Many aspects of seismic hazard or earthquake forecasting remain inherently untestable if only the model forecasts are tested and not the model ingredients. We propose to continue along the lines of the GFZ Potsdam developments and create new areas of activity for CSEP, namely targeted experiments that cannot be conducted with the current CSEP software system. As part of the eGSIM (European Ground Shaking Intensity Models) service, we will introduce permanent testing of IPEs and GMPEs to the testing center to establish strong performance records to be used in hazard models. Further targeted experiments include the predictive power of b-values, discrimination of foreshocks for short-term forecasting, as well as a deeper look into precursory phenomena applying CSEP-style rigorous testing. We support including testability in future hazard models or their components to move to better testable seismic hazard models. Finally, to expand into the risk domain, we will test exposure models against new and independent data.

ESC2018-S15-932

SEISMIC HAZARD ASSESSMENT USING MACROSEISMIC INTENSITY DATA - APPLICATION TO THE FRENCH TERRITORY

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The Probabilistic Seismic Hazard Analysis (PSHA) is currently performed using the well-known and "standard" Cornell-McGuire approach (Cornell 1968; McGuire 1978). Instead its large application around the word, this standard methodology presents several disadvantages regarding its strong sensitivity to some not well defined parameters, such as: geometry of the sources, attenuation of ground motion with distance from the source, completeness of available seismic catalogue, etc. In many countries (mainly in the French territory) most seismic database is constituted by historical macroseismic data thus the application of standard PSHA approach requires the conversion of macroseismic intensities into para instrumental parameters (ex. magnitude). In order to better exploit the macroseismic intensities, probabilistic hazard evaluations based on observed intensities are more and more performed in Europe. D'Amico and Albarello 2008 implemented the computer program SASHA (Site Approach to Seismic Hazard Assessment) to apply a PSHA procedure based in intensity. This procedure relies on local information concerning effects of past earthquakes documented at the site where hazard is computed, and no reference model of seismogenes sources is required. The approach allows to exploit the large amount of macroseismic information available at the site in the frame of a formally coherent and complete treatment of intensity data, by taking into account the relevant uncertainty and the inherently bounded, ordinal and discrete character of intensity values. We present the results of probabilistic seismic hazard assessment for the French territory using macroseismic intensities data and following the SASHA procedure. For areas with lack of observed intensities for past earthquakes, local seismic histories were built using indirect macroseismic estimates deduced from epicentral information through several empirical attenuation relationship considering several homogenous tectonics zones. The assessment of seismic hazard is performed in three main steps: 1) building the local history of seismic effects (site seismic history) by considering uncertainties affecting available intensity data, 2) evaluating its reliability (completeness and representativeness), and 3) computing the seismic hazard at several sites of the French territory. Due to the strict link between macroseismic intensity and damage, seismic hazard estimates in terms in intensity as ground-shaking measure must be an important task for futures researches.

ESC2018-S15-948

SEISMIC HAZARD ASSESSMENT IN TERMS OF MACROSEISMIC INTENSITY USING A SITE APPROACH: AN APPLICATION TO ITALY

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Probabilistic seismic hazard estimates in terms of peak ground motion and response spectra are essential in design of earthquake-resistant

structures, but these parameters correlate poorly with damage thus generally providing a bad estimate of seismic risk. On the contrary, the use of macroseismic intensity, which includes description of damage to buildings, to parameterize earthquakes effects allows a direct link of hazard assessment with risk estimates in urban areas. Moreover, in many parts of the world, macroseismic information is more abundant and readily available than instrumental ground-motion measures, such as in most of European countries, where long-lasting documentary history is available about the effects of past earthquakes. The so-called "site approach" to PSHA (Albarello and Mucciarelli, 2002), implemented in the SASHA computational code (D'Amico and Albarello, 2008), provides hazard estimates in terms of macroseismic intensity by basically relying on local information about documented effects of past events (site seismic histories) and allowing full exploitation of macroseismic data available at the site in the framework of a formally coherent and complete treatment of intensity values by taking into account the specific nature of intensity (ordinal, discrete, finite in range) and relevant uncertainty (completeness, ill-definition of the oldest earthquakes, etc.). As in the standard Cornell-McGuire approach, the seismogenic process is assumed to be stationary, but no reference model of seismogenic sources is required. Seismic hazard is assessed in two main steps. First, the local seismic history is built up integrating seismic effects observed at the site during past earthquakes with "virtual" intensities deduced from epicentral data (via probabilistic intensity attenuation relationships) and, possibly, "simulated" intensities deduced via physically constrained stochastic simulations; each intensity estimate is considered affected by a measurable uncertainty depending on the available information. Then, completeness and representativeness of the site seismic history is evaluated following Albarello et al. (2001). The seismic recurrence at the site is parameterised for each intensity threshold Is using a fully distribution-free approach that does not require any pre-processing (e.g., aftershock removal, selection of mainshocks, etc.). Results are given in terms of hazard curves probability, for each threshold Is, that at least one earthquake with intensity not less than Is will occur at the site during a given exposure time), reference intensity (determined from the hazard curve at a given probability, e.g., 0.1), and deaggregation analysis (magnitude/distance pairs more representative of the reference ground motion, and identification of the past earthquakes that are most important for the hazard). Several PSHA studies were performed over the last decade in Italy and elsewhere using the site approach (e.g., Galea, 2007; D'Amico and Albarello, 2008; Bindi et al., 2012; Azzaro et al., 2016; Carvalho and Albarello, 2016; D'Amico et al., 2016; Jiménez et al., 2016). Here we present the hazard estimates computed for Italy using the last available release of the Italian macroseismic database (Locati et al., 2016) and related parametric earthquake catalogue (Rovida et al., 2016).

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ESC2018-S15-951

PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR ITALY USING ADAPTIVE SMOOTHED SEISMICITY INCLUDING FORESHOCKS AND AFTERSHOCKS

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The goal of this work is to construct a seismic hazard model and produce probabilistic seismic-hazard assessments for the Italy in terms of Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) at different periods using spatially smoothed seismicity approaches along with the updated seismic catalogs. In the present study the seismic hazard is evaluated based on the instrumental seismicity using adaptive smoothed approach originally described by Helmstetter et al., (2007). We also attempt to incorporate foreshocks and aftershocks into the time-independent seismic hazard analysis considering that not only the mainshock but also its associated shocks have an opportunity to exceed a given amount of ground motion at a site (Marzocchi & Taroni, 2014). The seismicity rates are calculated on a spatial grid platform using the Catalog of Italian seismicity 1981-2017 (Gasperini et al., 2013) from magnitude Mw 3.0. Smoothing the location of each earthquake by a 2D kernel is it possible to obtain the spatial distribution of the earthquakes. The adaptive smoothed seismicity approach differs from the fixed one because the value of the smoothing distance depends on the density of the observed seismicity: bigger the density smaller the distance and vice-versa. In order to incorporate clustered events (foreshocks and aftershocks) into time-independent PSHA we use two different procedures, one proposed by Marzocchi & Taroni (2014) and other new one developed for the future Italian seismic hazard model. The first one uses a gamma factor to correct for the missing rate due to de-clustering in the catalogs, and also modifies the slope of the Gutenberg-Richter law (clustered seismicity usually have bigger b-values respect to the declustered one).The other procedure modifies the incremental rate according to a function that counts in each magnitude bin which is the percentage of mainshocks respect to the total number of events. Both procedures assume that each cell of the grid has similar clustering properties, and use the Le Cam's theorem (Le Cam, 1960) to obtain poissonian exceedances from non-poissonian seismicity rates. Finally, the annual rate of exceeding a specified ground motion at a site is calculated using suitable ground motion relationships in the framework of Cornell (1968) approach. For hazard calculations, we choose a low cutoff magnitude of Mmin =4.5 and the tapered Gutenberg-Richter law with a corner magnitude equal to 7.1 (estimated using the historical catalog); the maximum value for the magnitude bin is fixed to 7.5. We adopted a GMPE for the active shallow crustal regions to assess the ground shaking hazard as defined by Bindi et al., (2011) for rock conditions. The results obtained are maps of horizontal PGA with 10% and 2% probability of exceedance in 50 years (return period of 475 and 2475 years). We present the differences between the forecast seismicity rates and calculated seismic hazard obtained using declustered and clustered instrumental catalogs as the expected number of Mw>4.5 events per year in each cell, respectively. Hazard calculated using the non-declustered catalog leads to increase ground motions in PGA at probability levels of 10% and 2% probability of exceedance in 50 years. This difference is larger in the case of the 10% in 50 year probability level reaches up to 50% change in PGA when we use the new approach, but this difference is much smaller when we use the Marzocchi & Taroni (2014) approach. So the choose of the proper method to include foreshocks and aftershock is critical. However, in both approach, the percentage change in the ground motion gets less pronounced at the larger periods of ground motion (2 sec) respect to that of PGA values.

ESC2018-S15-954

RETROSPECTIVE TESTING OF ITALIAN SEISMICITY MODELS FOR THE NEW ITALIAN SEISMIC HAZARD MODEL

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Testing the consistency of a model with data is a fundamental part of the scientific process. The gold standard for such a kind of testing is through prospective tests, i.e. using data independent from the ones that are used to build the model. Unfortunately, this gold standard is not always achievable in a reasonable amount of time, but we can still learn something about the model from retrospective consistency tests; for example, one model that is not able to describe satisfactorily the data used to calibrate it, it may be deemed as unreliable. In this presentation we show the results of retrospective tests applied to a set of Italian seismicity models, which have been built to define the new national seismic hazard model. These models have been built by independent groups of researchers and are based on different kinds of information, such as the historical catalogue of earthquakes, seismotectonics models of Italy, geodetics-deformation observations and active faults database. Specifically, we show the results of the consistency tests, which aim at comparing the observed number and spatial location of target earthquakes with the forecasts of the models in time windows of interest for the long-term seismic hazard analysis. We stress that, to our knowledge, this testing phase makes the new Italian seismic hazard model among the best (retrospectively) tested hazard models globally. The results of the tests show a good agreement between observations and forecasts of the models. Worthy of note, also a model entirely based on geodetic data has good spatial forecasting performances. Afterward, we score statistically the forecasting skill of each model using two different metrics: the loglikelihood and the parimutuel gambling score. We translate these tests and scores into weights to build an ensemble seismic hazard model for Italy, which describes in a proper probabilistic framework both aleatory variability and epistemic uncertainty.

ESC2018-S15-974

NEW SEISMIC HAZARD MAP FOR SLOVAKIA IN TERMS OF MACROSEISMIC INTENSITY

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Probabilistic seismic hazard analysis on local and regional scales is an important part of the seismological research with direct implications towards the society. Territory of Slovakia is characterized as a region with the low-to-moderate earthquake activity. There are clear evidences of several damaging historical earthquakes (e.g., 1443, 1763, 1858, 1906) with epicenters on the territory of Slovakia. The recent seismic hazard map for the territory of Slovakia in terms of macroseismic intensity was prepared within the GSHAP Project (Schenk et al., 2000) two decades ago. Due to new seismological, geological and geophysical data, and methodological progress in PSHA, we prepared a new national seismic hazard map for Slovakia in terms of macroseimic intensity for a return period of 475 years (probability of exceedance of 10 % in 50 years). We followed the classical Cornell–McGuire approach. The area of interest includes the territory of Slovakia and neighbouring parts of Austria, Hungary, Czech Republic, Poland and Romania. We compiled a new homogeneous earthquake catalogue for the area covered by the seismotectonic model of the territory of Slovakia (Hók et al., 2016). The catalogue consists of 3720 events in the time 350 AD - 2011. For each seismic source zone we determined the magnitude-frequency relation, intensity-frequency relation and the maximum possible earthquake. For attenuation models we selected the combination of regional intensity prediction equations and the intensity prediction equation based on local data (Labák, 2000). The final seismic hazard map was calculated using the logic-tree approach.

ESC2018-S15-991

SCALABLE WORKFLOW FOR DEVELOPING REGIONALIZED GROUND MOTION PREDICTION EQUATIONS

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Ground motion prediction equations (GMPEs) are critical elements of probabalistic seismic hazard analysis (PSHA), the backbone of hazard maps, as well as for site-specific hazard analysis. With the increasing availability of data, the ability to combine multiple datasets into a virtual network creates opportunities to develop regionally appropriate GMPEs. As a case study, we computed a new regional GMPE suitable for Southern California. This GMPE was enabled by the San Jacinto Fault Zone (SJFZ) project. The SJFZ project includes a real time virtual seismic network, which uses the Antelope Real Time System created from the ANZA seismic network, along with SJFZ PASSCAL stations and select stations from the Southern California Seismic Network, Plate Boundary Observatory, and UC Santa Barbara. The 2013 waveform data, using approximately 160 stations, were used to calculate peak ground accelerations from more than 10,000 earthquakes (0.5≤M≤4.5), yielding ~120,000 recordings with hypocentral distances ranging between 5 km and 180 km. The 2013 dataset is a subset of the complete SJFZ dataset (2008-present) and was used to prototype and test processes. These processes can now be utilized on other years of the SJFZ project as well as on large datasets acquired in different regions. With the regional GMPE developed from the 2013 test dataset, we can set up a framework for estimating path-specific geophysical attenuation functions to improve the accuracy and precision of ground-motion predictions.

ESC2018-S15-1000

SEISMIC RISK ASSESSMENT FOR SOUTH OF PORTUGAL: A CRITICAL OVERVIEW

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The seismic history of Portugal shows that the country was struck by a large number of earthquakes, some of with great magnitude, which produced large material losses and high human losses. The memorable earthquake of November 1, 1755, was one of the most powerful earthquakes that affected Portugal. It results in the almost complete destruction of the city of Lisbon, especially in downtown area (the Baixa), and it also strongly affected the coastal municipalities of Algarve region (in the south of Portugal). Besides, it was felt in the whole country and also caused damage and causalities in Morocco and Spain. Earthquakes are often seen as inevitable natural disasters. However, these should be considered natural phenomena and the adverse effects of which can be minimized by effective seismic risk management. For this reason, it is important to realize how these phenomena act, what are their sources, implications and in what way we can mitigate its effects. In 2006, a model with eleven seismogenic zones was considered to re-evaluate the seismic hazard for Portugal mainland, to contribute for supporting decisions for the actualization of the seismic zonation map presented in the Portuguese Annex of Eurocode 8. Between 2008 and 2009, in the aim of projects ERSTA and SHARE, alternative area source models were proposed, together with the estimated activity rates parameters and magnitude distribution. SHARE proposal (together with ground motion prediction equations assumptions) resulted in quite different seismic hazard levels when compared to the seismic zonation presented in EC8, leading to a need, among decision makers, to understand the origin of such differences. With this objective, hazard maps were assessed, using OpenQuake software, for the three different source models and using different ground motion prediction equations, and a comparison analysis was carried out. Large differences between models results were observed in the seismic source zones south of Portugal. In fact, the different assumptions used had a major impact in the recurrence period of large seismic events and in seismic hazard values for Portugal mainland. The study of the impact in seismic risk is, of course, the following step, that is the aim of this work. The seismic risk was assessed for the south of Portugal, using LNECLoss software, which is a computer tool for seismic loss modelling. LNECLoss comprises several modules to perform seismic risk analysis including bedrock seismic input, local soil effects, vulnerability analysis, fragility analysis, human losses and economic losses. The last two were not considered in this study. The Portuguese 2011 Census, the last survey performed in Portugal, is a valuable input, which allowed, in previous studies, to identify 49 typologies and the most

representative and frequent building types by parish. For each building type capacity and fragility curves were proposed by different authors. Being so, building response was assessed, accounting for the seismic hazard obtained using the different models mentioned above, for five damage states: no damage, slight, moderate, severe and complete damage. Seismic hazard maps show differences between models, considering the same ground motion prediction equation and when considering a model, applying different sets of ground motion prediction equations. However, independently of ground motion prediction equations and recurrence period considered, the differences are always more significant between models. Consequently, major differences are also observed in the seismic risk maps, which are more significant between the models, mainly for the states of slight and moderate damage. Higher damage percentage values are noticed for longer recurrence periods and the differences between the models are observed in all damage states. Regions that may suffer higher damages are the south and south-west of the Algarve, a tourist region, where large urban centres are located. Therefore, it is possible to infer that the observed differences lie in the options initially taken by the authors of the three models. Seismic hazard models have direct implications for seismic risk and the observed differences show that the definition of seismogenic zones and their characterization play an important role in seismic risk analysis. Further studies on seismic hazard are needed, particularly concerning the definition of the parameters of seismogenic zones (number, location, magnitude, etc.). This requires a more in-depth knowledge of seismic faults and all tectonic structures, onshore and offshore and a more comprehensive study of the seismic catalogue. All these factors will have a direct impact on region seismic risk assessment.

ESC2018-S15-1020

EFFECT OF THE NEW PSHA MAPS ON THE URBAN RENEWAL APPLICATIONS IN TURKEY

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The rapid migration from the rural to urbanized areas since 1950's in Turkey, had caused severe circumstances in terms of vulnerability in every aspect of the life. It was only 25-per-cent of the entire population was living in urban areas in 1950. However, this ratio has reached to 75-per-cent in 2017. The new residents of the metropolitan cities demanded housing in very large numbers. Nature of the earthquake is erratic in time and location. The general forces acting on the houses were only the gravity loads those are excessively resisted by the low-standard structural members. Controversially, the earthquake loads are sudden and not resisted by the low-standard structural members. Having experiences from 1999 Marmara Earthquakes, the law makers in Turkey decided to diminish the vulnerable housing building stock to mitigate the seismic risks. The Law of "Transformation of Areas under the Disaster Risks" (No:6306) has entered into force in 2012. For the time being, 131,715 building was demolished according to the rules given in the law. However, the lateral force values in the assessment was based on the seismic hazard map dated 1995 where the recent major earthquakes were not accounted. The first national seismic hazard map was prepared in 1945. Since then, there have been 7 different seismic hazard maps with different approaches, in the order of the years 1945, 1947, 1948, 1963, 1972, 1994 and more recently, March 2018. The new probabilistic seismic hazard map provides better resolution compared to the previous map. The recent map is based on probabilistic analysis of the geodetic location cells with small size whereas the previous maps have always based on regions. During the development of the 2018 map, several data sources from various institutions and organizations combined. More recently (March 18th, 2018), an updated seismic hazard map has been enacted as part of the updated national seismic design code. This study aims to explain the fundamentals of the updated Turkish probabilistic seismic hazard map and provide an understanding for the effects on the urban renewal applications in Turkey.

ESC2018-S15-1028

3D PHYSICS-BASED NUMERICAL MODELLING OF THE 30TH OCTOBER 2016 NORCIA EARTHQUAKE

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Ever since the probabilistic seismic hazard analysis (PSHA) was proposed in the late 1960s, it has become a key tool to determine seismic-design loads for engineering purposes. Since then, progress in science and technology has made and the methodology of PSHA is in continuous evolution, both in terms of seismic source characterisation and ground motion characterisation. The latter is usually based on ground motion prediction equations (GMPEs). However, observed data in the near field of sources are still sparse and GMPEs may not appropriately capture the near-field ground motion. An appealing alternative is represented by the injection of the results of numerical simulations of the source and wave propagation into the seismic hazard analysis. Prior to the use of any numerical code, verification against actual observations is mandatory. The 30th October 2016 earthquake with magnitude MW of 6.5 which struck a mountainous region in Central Italy and was recorded by several accelerograph stations in the epicentral area, provides a valuable opportunity to perform a comprehensive verification study on numerical methods In particular, the 3D physics-based numerical modelling SPEED (Mazzieri et al. 2013) with results reliable up to a maximum frequency of 1.5 Hz is used in this study. The 3D model for the earthquake was constructed including the surface topography, an approximate 3D shape of the Norcia basin and a suitable kinematic representation of the causative fault. Belonging to the group of the intermontane basins present within the Central Apennines, Norcia basin is filled up by Pleistocene to Holocene age deposits and the bedrock units consist of limestone and pelagic marls of Jurassic to Miocene age (Aringoli et al., 2014). The interface between the younger deposits and the lithologic bedrock shows a complex nature (Blumetti et al., 1993). For the 3D modelling of the basin, 3D velocity-depth model of Norcia basin was constructed by using an extensive set of data consisting of: H/V measurements at more than 80 points from literature and ongoing studies, Vs-profiles measured at approximately 40 locations and 9 profiles from literature (Regione Umbria, 2004; Böhm et al. 2011; Aringoli et al. 2014). The October 2016 earthquake was a normal fault event striking northwest–southeast. The hypocentre was located by the Italian National Institute of Geophysics and Volcanology (INGV) at 42.83° N, 13.11° E at a depth of 9.2 km. Several studies were carried out to provide kinematic parameters of the fault. Among the preliminary fault solutions, three studies were investigated: Chiaraluce et al. (2017), Liu et al. (2017), and Pizzi et al. (2018). Preliminary simulations were therefore performed using the analytical method of Hisada (1994), based on the asymptotic integration of dynamic Green's functions for 3D fault sources in a linear visco-elastic layered half-space. In these simulations, the basin and surface geology were not included and the crustal model defined by Evangelista et al. (2017) was adopted. Comparisons of the simulated waveforms with the observations at several stations showed that the fault solution by Pizzi et al. (2018) provided a better fit with the observations. This fault solution was therefore selected for the 3D numerical simulations. Preliminary results of 3D simulations showed good agreement with the strong ground motion registrations in terms of displacement and velocity waveforms with some discrepancies at a few stations especially in the north-south component of the ground motions. This is reflected in the comparison of the permanent displacements obtained through the numerical results with those from SAR measurements. To better understand the differences, a comparison with numerical results obtained through 1D simulations (using SHAKE91, Idriss and Sun, 1992) and 2D simulations (using FLAC, Itasca, 2016) was performed in terms of amplification functions at two strong ground motion stations, NOR and NRC. As expected. the amplification calculated through 2D and 3D numerical models is more irregular and narrow-banded than that calculated through the 1D approach; however, all show agreement in terms of frequencies and amplitude of resonance. The numerical amplification functions are in good agreement with those computed from the records at NRC and NOR and fall within the 16th and the 50th percentiles of the observations.

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SESSION 16

ESC2018-S16-54

GLOBAL SEISMIC NOISE SYNCHRONIZATION AND SEISMIC DANGER INCREASING IN CONNECTION TO IRREGULARITY OF EARTH'S ROTATION

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Starting from Sumatra mega-earthquake on December 26, 2004, M=9.1, the intensity of strongest earthquakes in the world was increased dramatically. The data of low-frequency seismic noise from global and some regional broadband seismic networks are available starting from 1997. We can estimate daily median values of some non-linear statistics of seismic noise from all operable stations of these networks. Such estimates show that seismic noise properties have explicit trends. In particular wavelet-based multiscale entropy, index of linear predictability and wavelet-based smoothness index of seismic noise are increasing whereas singularity spectrum support width and spectral exponent are decreasing. At the same time coherence of daily median seismic noise properties from different parts of networks is increasing. These facts are interpreted as increasing of global seismic danger. We can try to connect such trends of the seismic noise with time series of the Earth's rotation irregularity (LOD - length of day) which has been freely available since 1962. Since 1997, this series contains a statistically significant high-frequency component with periods from 2 to 300 days, which is associated with the transition to high-precision measurements using space geodesy. Evaluation of the properties of the LOD series in a sliding time window of 1 year length identified a significant anomaly of increased entropy of the high-frequency component of the LOD time series in 2000. A comparison of the anomalies of the averaged properties of seismic noise on global broadband seismic networks and on network in Japan allows us to propose the hypothesis that the irregularity of the Earth's rotation is reflected in the synchronization of the properties of seismic noise and can be a trigger for the intensification of the strongest earthquakes since the end of 2004.

ESC2018-S16-150

THE NATURE OF DOUBLE EARTHQUAKES AND THEIR FORECAST BY THE METHOD OF SEISMIC ENTROPY

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Double earthquakes (DE) are strong earthquakes close in time, place and magnitude. This is quite rare and difficult to explain events. Elucidation of the nature of their occurrence is important for forecasting. The method of seismic entropy, involving the results of studies of processes in the sources of strong earthquakes, allows to identify the nature of DE, determine them as independent earthquakes with a specific tectonic relationship, allows to distinguish them from other cases of close but independent earthquakes, as well as to allocate them against foreshocks and aftershocks. DE are allocated based on track and energy diagrams arise in seismic systems, when the trajectory evolves over decades with a deficit of cumulative energy of earthquake indicators. DE are detected in seismic systems located in different seismotectonic situations in the Altai, Italy, the Kurils, in the Central US, but truly their "homeland" is Iraq. The characteristic features on which their classification is carried out are studied.

ESC2018-S16-164

FRACTO-EMISSIONS AS SEISMIC PRECURSORS: THE CRACK-SIZE EVOLUTION IN THE EARTHQUAKE PREPARATION ZONE

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Fracture experiments on different type of rocks have demonstrated that high-frequency pressure waves (up to TeraHertz, 10^12 Hz), produced by mechanical instabilities at the nano-scale, can induce low energy fission reactions on medium weight elements with neutron and/or alpha particle emissions [1, 2]. Similarly, pressure waves with lower frequency, i.e. MegaHertz and kiloHertz frequency bands, may trigger the emission of electromagnetic and acoustic signals, respectively [1]. The same phenomenon can take place during the early stages of an earthquake. At the tectonic scale, cracking is a multi-scale phenomenon, as well as the frequencies of pressure waves cover a broad spectrum, from THz for fracture at the nanoscale up to the simple Hz at the kilometre scale [1]. In this framework, the use of the fracto-emission signals (Acoustic

Emission AE, Electro-Magnetic Emission EME, and Neutron Emission NE) can represent a promising tool in seismology, not only for their monitoring capabilities during the earthquake, but also for their forecasting potentialities before the event [3]. On the other hand, another very important aspect of seismic prevention is the assessment of the so-called "earthquake preparation zone". As a matter of fact, before the quake occurrence, a very wide area of cracking rocks extending even up to millions of square kilometers is active and in a critical condition around the future earthquake focal zone under the influence of tectonic stresses [4]. An innovative assumption could be that, in addition to being proportional to the magnitude of the incoming earthquake [4], the nature of the preparation zone could also depend on the crack-size forming in the Earth's crust before the seismic event. In particular, approaching the earthquake occurrence, this area would shrink because of the closure of the pre-existing smaller cracks, resulting in a new zone where the remaining small cracks coalesce to form larger ones. As a consequence, an evolution of the crack-size, from the nano- up to the macro-scale occurs. Thus, the first precursive phenomenon, temporally more distant from the quake epicentre, will be the neutron emission (when the crack-size is of the order of nanometre and the preparation zone extension is maximum). Then, the electromagnetic emission in the GHz-MHz frequency bands will take place, and lastly the ultrasonic acoustic emission (up to several hundreds of kHz), is expected. Finally, the day of the earthquake, the preparation area will collapse into the earthquake epicentre, macro-cracks along the seismic faults will coalesce and the quake will propagate. From the experimental point of view, since July 2013, an in-situ monitoring campaign has been started at a gypsum mine located in Northern Italy. By using dedicated instrumentation installed at about 100 metres below the ground level, the seismic risk assessment of the area is carried out. The underground position of the monitoring station provides a significant reduction in the acoustic and electromagnetic noise, as well as an extremely low neutron environmental background. The novelty of this investigation consists in the simultaneous acquisition of the three forms of fracto-emission and in their temporal correlation with the incoming seismic event by means of an appropriate multi-modal statistical analysis [3]. The preliminary experimental data, obtained during a period of nine semesters (July 2013 - December 2017), evidenced a strong correlation between acoustic, electromagnetic, neutron peaks and the seismic swarms occurring in the surrounding area of the mine. In particular, 444 earthquakes of magnitude M greater than or equal to 1.8, within a radius of 100 km, were recorded. For lower magnitude, no significant variation in the neutron flux was observed. Thus, 1.8 is considered to be a sort of seismic threshold. The multi-modal statistics applied to the 444 quakes identified 52 seismic swarms with a magnitude M between 2.5 and 4.7. Similarly, the same number of fracto-emission peaks were obtained. Therefore, the temporal correlation between the distributions of seismic activity and each fracto-emission shows how AE, EME, and NE tend to anticipate the next seismic swarm peak with an evident and chronologically ordered shifting of about one day, three-four days, and one week, respectively [3]. Hence, fracto-emissions should be considered as precursors of the next main earthquake rather than aftershocks of the previous one. Finally, a power-law correlation seems to exist between the fracto-emission rate peak and the local magnitude of the swarm: by increasing the magnitude, also AE, EME, and NE increase.

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ESC2018-S16-210

METHODS, TECHNOLOGY AND SYSTEM FOR AUTOMATIC PREDICTION OF EARTHQUAKES

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We propose an approach to automatic prediction of earthquakes. The forecast is based on a new

one-class classification method named the method of minimum area of alarm. It was designed to detect rare anomalous objects. The idea of the algorithm is as follows. At the first step, the algorithm builds for each training sample of anomalies objects (precedent) a set of objects classified by it as abnormal. Next, for a given number N*, the algorithm selects the maximal number of the precedents for which the cardinality of the union of these sets is not exceed a predetermined number N*. The decision rule classifies the objects using only the selected precedents. For other precedents, we should look for new distinctive properties and add them to the feature space. The algorithm is greatly simplified if it selects not the maximal but close to it number of precedents. The technology combines two levels of data analysis. The first level supports automatic data processing and understandable methods of analysis for a wide class of users. The system transforms all types of input data in uniform spatial and spatio-temporal grid-based feature fields. The fields are designed so that the precursors of strong earthquakes are timed to their maximum values. The data model assumes that the field values exceeding or equal to earthquake precursors found during training can also be precursors of earthquakes. The quality of the forecast is determined by the probability of detecting earthquakes and the volume of the alarm area. The method of minimum area of alarm has two options for optimizing the forecast on the training material: (1) as the probability of event detection increases, the volume of the alarm area increases by the minimum value; (2) for a given volume of the alarm area, the number of detected events is maximized. The second level is designed for detailed analysis of hypotheses, which the expert can formulate at the first level. The idea of the technology was tested in our Web-based GIS platforms for monitoring and analysis of seismic fields (http://distcomp.ru/geo/2/, http://distcomp.ru/geo/3/) and for monitoring and analysis of natural and anthropogenic processes in Arctic (http://distcomp.ru/geo/arctic/). The first version of the forecasting platform is available at http://distcomp.ru/geo/prognosis/. The platform consists of two GISs: GeoPrognosis and GeoTime 3. GIS GeoPrognosis is built in client-server architecture with a thin client. It provides analytical tools that suggest intuitively understandable operations with a simplified interface and supports the mapping of parameters of spatio-temporal processes in the geographic context of the Google Maps API. GIS GeoPrognosis processes data with a constant time step systematically. There are two temporal intervals: the training interval from the date of beginning the observations to time t and the testing (prediction) interval from time t to t + T, where T is the alarm time interval. At the training interval in each time step a new data is downloaded from the remote servers, then it is transformed into standardized feature fields, alarm area is being constructed, and a GIS project for launching GIS GeoTime 3 is compiled. In the testing interval GIS GeoPrognosis determines whether the alarm area covers an epicenter of the earthquake with a predictable magnitude and calculates the statistics of the forecast. GIS GeoTime 3 has a client-server architecture with a thick Java-client (http://www.geo.iitp.ru/GT3/). It is designed to process and analyze geographic information on spatio-temporal processes. It has advanced functionality, high interactivity, platform and browser independence, the ability to work with distributed information and computing resources and flexible customization of the functionality to the user's task. GIS GeoTime 3 is launched from the GIS GeoPrognosis page with the same data that was previously analyzed in it. In this case, GeoTime 3 tools allow the user to supplement the GIS project with tile maps and 2D, 3D, 4D point, vector and grid-based data from remote and local servers. GIS supports the joint processing of all the above types of data. The approach has been tested using the data from ISC and NEIC earthquake catalogs for the Mediterranean, Japan and California regions. The results have demonstrated the effectiveness of the approach, methods and the automatic system for prediction of earthquakes. In testing we used well-known characteristics of the earthquake catalogs. The study of the possibility to improve the quality of the forecast by using a wider set of the earthquake catalog characteristics or by adding other sources of input data was beyond the scope of current stage of our work.

ESC2018-S16-253

LONG-RANGE DEPENDENCE IN THE SEISMIC PROCESS AND IMPLICATIONS FOR EARTHQUAKE FORECASTING

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Since the beginning of the 1980s, when Mandelbrot (1983) observed that earthquakes occur on fractal self-similar sets, many studies have investigated the dynamical mechanisms that lead to self-similarities in the earthquake process. Interpreting seismicity as a self-similar process is undoubtedly convenient to bypass the physical complexities related to the actual process. Self-similar processes are indeed governed by power laws as a consequence of scale invariance. One of the fundamental scaling laws in seismology describes the magnitude-frequency distribution of earthquakes (Gutenberg and Richter, 1944). This law arises from the self-similarity in the fracturing process (Mandelbrot, 1983; King, 1983; Scholz, 1991). Along with the space-time clustering of seismicity (e.g., Kagan and Jackson, 1991) and the mechanics of earthquake interaction (e.g., Stein, 1999; Scholz, 2002), this property implies that the process of accumulation and release of seismic strain has memory effects (e.g., Lomnitz, 1994). Periods of high release of seismic deformation will most likely be followed by years of higher-than-average seismic strain release. Conversely, seismically quiet periods will tend to be followed by quiet years.In this work, we examine series of seismic moment release in Italy and worldwide through Hurst's rescaled range (R/S) analysis (Hurst, 1951) in order to determine whether and how the degree of correlation among the earthquakes in the series varies both spatially and temporally. This is accomplished by examining the space-time variations of the so-called Hurst exponent (H), which measures the level of correlation (i.e., memory) in time series. It takes values between 0 and 1 and indicates a persistent behavior if $H > 0.5$, and an anti-persistent behavior if $H < 0.5$. A value close to 0.5 indicates a random process with no correlation and no dependence within the time series.Our analysis shows that long-range dependence (or long-memory) is an inherent feature of the seismic process, and is universal. Indeed, we found that seismicity is a memory process with a Hurst exponent $H \approx 0.87$ and that H is substantially space- and time-invariant, except in cases of catalog incompleteness. Following the results of the R/S analysis, we present a new probability model for earthquake occurrence that allows for persistency in the seismic process. Unlike the Poisson model, dependent events are allowed. The model is based on an empirical power law that relate the storage capacity of a seismic source (expressed in terms of scalar moment) to time. Its effectiveness is evaluated through a retrospective test. Specifically, we developed 10-year and 30-year forecast maps for the Italian Central Apennines that show the probability of exceeding a magnitude 5.5 earthquake. The comparison of the average number of expected events with those actually observed shows a good agreement (7.4 expected events vs. 8 for the 30-year forecast). Moreover, our forecasts are consistent with those presented in the work of Marzocchi et al. (2012), where the authors analyze the performance of alternative forecasting models in Italy.An application to ground-motion hazard analysis will be presented in Session S15 of this assembly.For further details on this research, interested readers may refer to Barani et al. (2018).

ESC2018-S16-287

INTERDISCIPLINARY ANALYSIS OF PRE-EARTHQUAKE PROCESSES IN SUPPORT OF EARTHQUAKE PREDICTION STUDIES

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We summarize a multi-year research effort on wide-ranging observations of pre-earthquake processes. Based on space and ground data we present new results relevant to the existence of pre-earthquake signals. Recent large magnitude earthquakes in Asia, Central America and Europe have shown the importance of these various studies in the search for earthquake precursors either for forecasting or predictions. Some new results were obtained from modeling of the atmosphere-ionosphere connection and analyses of seismic records (foreshocks /aftershocks), geochemical, electromagnetic, and

thermodynamic processes related to stress changes in the lithosphere, along with their statistical and physical validation. This cross - disciplinary approach could make an impact on our further understanding of the physics of earthquakes and the phenomena that precedes their energy release. For recent events, we present results of synergistic observations of pre-earthquake activates related to the 2015 Nepal M7.8, 2015 Chilean M8.5 and 2017 Mexican M8.2 earthquakes and the potential impact of these interdisciplinary studies to earthquake predictability. A detail summary of our approach will be subsequently published in a new volume as part of the AGU Geophysical Monograph series and is intended to show the variety of parameters seismic, atmospheric, and geochemical and the historical perspective of this research and could bring this topic to a broader geosciences community.

ESC2018-S16-398

DETECTION AND ANALYSIS OF THE SEISMIC QUIESCENCE BEFORE 2017 MW 7.3 IRAN EARTHQUAKE BY RTL METHOD

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A major earthquake (Mw=7.3) occurred in the Kermanshah province of Iran on November 12, 2017, causing extended damage and casualties. The region belongs to the Zagros mountain range, one of the youngest and most seismically active belts on Earth, originated by the Arabia-Eurasia collision since Late Paleogene, and extending from South-East Turkey to the south of Iran. The seismic data used in this study were extracted from the regional catalog of the Iranian Seismological Center (IGTU catalog), which is available since 2006. We explored seismicity preceding this earthquake using the Region Time Length (RTL) algorithm, a method that has been applied in several regions worldwide (e.g. Gentili et al. 2017 PEPI 272, 27-33 and references therein) and for which several improvements have been developed in the last years. The RTL analyzes declustered catalogs and is sensitive to anomalies in background seismicity, which may precede a large seismic event. In order to decluster the earthquake catalog, we used an innovative statistical approach, based on the nearest-neighbours distances between events in the space-time energy domain. The retrospective application of RTL algorithm in the area surrounding the mainshock epicenter highlights two significant quiescences: one preceding the 12 November 2017 Mw 7.3 earthquake, and the other occurring before a Mw 5.7 earthquake occurred in the same region on November 2013. The RTL map in Northwestern Iran (Lat=30-38°N, Lon=43-53°E), calculated for a time interval between June 2017 and the occurrence of the Mw 7.3 earthquake, evidences a seismic quiescence anomaly extended throughout a broad NW-SE oriented region, corresponding to northern Zagros mountains.

ESC2018-S16-409

ESTIMATING MAGNITUDE OF THE FOLLOWING LARGEST AFTERSHOCKS

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We consider the problem of forecasting the magnitude of the future, starting from a certain moment, the largest aftershock. This task is relevant, because later large aftershocks, occuring at rapidly decreasing rate of tremors, are less expected and therefore represent an independent danger. At the same time the magnitude of largest aftershock gradually decrease with increasing time after the main shock. Here the forecast is based on the use of information about aftershocks, which have already occurred to this point. Using informative priors for parameters of the Gutenberg-Richter and Omori-Utsu laws, we obtain Bayesian posterior distribution of the maximal magnitude of the following aftershocks. This makes it possible to approximately triple the probability gain in comparison with estimates obtained only on the basis of the magnitude of the main shock. The research was partially supported by Russian Science Foundation (Project 16-17-00093).

ESC2018-S16-564

A NEW PROPOSAL FOR STOCHASTIC MODELING OF EARTHQUAKE OCCURRENCE THROUGH A COMPOUND MODEL

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Earthquakes are natural phenomena that affect multiple time-space scales and of which we only have indirect measurements strongly affected by uncertainty. These phenomena may be investigated on different, coherent time-space-magnitude scales where they show different critical aspects and are related to different goals. In this work our objective is to consider the time evolution of disastrous earthquakes, that means to move in medium-large scales, and to model their occurrence in forecasting perspective by combining knowledge gained at different levels. In the past, phenomenological analyses of the seismicity led mainly to two patterns: time-stationary point processes on regional and long time scales, and self-exciting models to describe typically the increase of seismic activity on short space-time scales immediately after large earthquakes. Later it was noted that even catalogs deprived of secondary shocks show clusters. These observations and the need to consider jointly the previous patterns to provide a better description of the phenomenon have brought to hybrid models which widely require measurements of geodetic and geologic quantities. Some of the model components are smoothed seismicity background model, renewal models, EEPAS model, aftershock models (e.g. ETAS), tectonic model based on a strain-rate map converted into earthquake rates. On the other hand self-correcting models are the only ones that attempt, on large space-time scales, to incorporate physical conjecture into the probabilistic framework. They are inspired to the elastic rebound theory by Reid, which was transposed into the framework of stochastic point processes by Vere-ones in 1978. Hence we can say that most of the probability models used in earthquake forecasting belong to the two classes of self-exciting and self-correcting models, which are conflicting from the point of view of the hazard function: piecewise decreasing function in case of self-exciting models, piecewise increasing function in case of self-correcting models. Attempts for conciliating this dissent were done i) by Schoenberg and Bolt (2000) by simply putting together the conditional intensity functions of two point processes, one from each class, ii) by Varini (2008) by employing a state-space model for estimating the different phases of a seismic cycle, and iii) by Votsi (2014) by considering a discrete-time hidden semi-Markov model whose states are associated with different levels of the stress field. In all these proposals the results were not completely satisfactory. We present a new stochastic model for earthquake occurrences which takes into account the need to consider jointly the opposite trends which characterize self-exciting and self-correcting models, and the idea to superimpose (not simply combine) behaviors characteristic of different time-scales in a single hierarchical model. We consider all the earthquakes that are associated with a seismogenic source and exceed the magnitude threshold Mw 4.45 so that the time period in which the data set can be considered as complete includes a sufficient number of strong earthquakes with Mw not smaller than 5.3. These events are responsible for most of the release of seismic energy; we put them on the first level of our model and assume that these leaders events follow the stress release model. At the second level there are the subordinate events, that is, those that occur between two consecutive leaders and show the tendency to cluster in closeness to them. We consider the occurrence times of these events as ordered failure times in the time interval limited by the two leaders and we model them through a generalized Weibull distribution with a bathtub-shaped hazard function so as to match the clustering trend close to the extremes of the interval. The model has been examined following the Bayesian paradigm; in particular, to assign prior distributions of the model parameters we have adopted an objective Bayesian perspective which combines the empirical Bayes method and the use of vague-proper prior distributions, whereas estimation of the model parameters was performed by applying Markov chain Monte Carlo methods which allow to obtain not only the parameter estimates (typically as their posterior means), but also a measure of their uncertainty, as expressed through the simulated posterior distribution of each parameter. The proposed model is applied to the sequence of earthquakes associated with one of the most active composite seismogenic sources of the Italian Database of Individual Seismogenic Sources (DISS, version

3.0.2), which is located in the Central Apennines and includes some of the most recent destructive earthquakes in Italy. We report the performance of the model in terms of marginal likelihood; moreover, we compare our model with the stress release and ETAS models respectively, on the basis of two validation criteria: the Bayes factor and the information criterion by Ando and Tsay. The Bayes factor aims at the model comparison by looking for the model that best fits the data, whereas the Ando-Tsay criterion chooses which model gives the best predictions of future observations generated by the same process as the original data.

ESC2018-S16-627

NEW FEATURES OF CACCAMO'S "DELTA/SIGMA" METHOD FOR EARTHQUAKE REPLICA FORECASTING

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In 2006 Domenico Caccamo has developed the method for the prediction of the major replicas of earthquakes, called "Delta/Sigma". This method is based on the study of anomalies in the main-aftershock sequences (Caccamo et al., 2006b). and it is derived from some problems encountered in the statistical analysis of temporal series of seismic data (Caccamo et al., 2002). The first version of "Delta/Sigma" algorithm was implemented in Matlab environment by Caterina Laganà and Fabio Massimiliano Barbieri (Caccamo et al., 2006b). The method was tested on several aftershock sequences as: the sequence of November 16, 2000 in Papua New Guinea (Caccamo et al., 2007ba); the sequence of December 27, 2003 in Loyalty Islands (Caccamo et al., 2007b) and the sequence of September 26, 1997 in central Italy: Umbria-Marche (Caccamo et al., 2007c). In the study of Chile earthquake of February 27, 2010, with magnitude M = 8.8, "Delta/Sigma" method has permitted to obtain the forecasting of all replicas with magnitude M > 6.2 with a success percentage of 100% (Caccamo et al., 2013). Recently the method has been further improved, thanks to the collaboration of new researchers such as: Vincenza Pirrone physics, Luigia Puccio numerical analyst, Roberto Lotronto expert in computer science, and the graduating student in mathematics Andrea Calderone. Indeed for the same earthquake of Chile we have obtained the forecasting of all replicas with magnitude M > 5.8 with a success percentage of 100% (Caccamo et al., 2017). In this paper we describe the new version of "Delta/Sigma" method that allows us real-time forecasting of earthquake replicas with magnitude M < 5.5. We present the new features and the experimentation done on the data sets of the latest earthquakes of 2017 in Mexico, Russia and Iran. We will show the obtained results and also a table summarizing the real-time forecasts for the 2011 earthquake in Japan, confirming the goodness of the method for all those earthquakes that have the same characteristics of the earthquake in Chile.

ESC2018-S16-646

STUDY THE PREPARATORY PHASE OF STRONG EARTHQUAKES BY MEANS OF A MULTI-PARAMETRIC CLIMATOLOGICAL APPROACH

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Based on pre-earthquake observations, some recent theoretical considerations predicts that some geophysical quantities reveal abnormal changes just prior moderate and strong earthquakes, within a defined spatial area (the so-called Dobrovolsky area) according to a Lithosphere-Atmosphere-Ionosphere coupling (LAIC) model. One of the possible pre-earthquake effects could be some climatological anomalies in the epicentral region, weeks/months before the major earthquakes. In a previous study an algorithm, called CAPRI (Climatological Analysis for PRecursors Identification), for searching of anomalies in some climatological parameters by a statistical analysis, was introduced and successfully applied to Central Italy earthquake sequences in the last 30 years. The simultaneous analysis of the climatological parameters related to the seismic sequences showed the presence of persistent contemporary anomalies in most of them. An ESA-funded project, SAFE (Swarm for Earthquake study) and an ASI-funded project, LIMADOU were dedicated to investigate the LAIC

from ground to satellite. In this work most of the earthquakes considered in those projects, was analyzed in terms of climatological parameters. The analysis involves some land/atmospheric parameters collected from meteo/climate big data archive starting from a date preceding the mainshock by at least four months. The simultaneous analysis of the different climatological parameters related to the strong world earthquakes showed the presence of chronological sequence of anomalies, thus reinforcing the idea of considering such behaviour as an effective tool for an integrated system of future earthquake prediction.

ESC2018-S16-647

PRE-EARTHQUAKE ANOMALY DETECTION BY SWARM SATELLITES

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In the framework of SAFE ("Swarm for Earthquake study") project, funded by ESA within the initiative "STSE Swarm+Innovation", we analyse Swarm three-satellite magnetic and electron density data for almost four years, 2014-2017, to look for possible earthquake related anomalies. After defining the potential pre-earthquake anomalies statistically and in the frequency content, we apply the search of satellite anomalies in the whole space-time interval of interest, avoiding high magnetic latitudes (1 Jan 2014-31 Aug. 2017, |geomagnetic latitude|<=50 degrees) and then we correlate them with earthquakes by means of a superposed epoch approach. Results are also compared with analogous random simulations in order to assess their robustness. In general, our results point to a significant statistical correlation of the magnetic field signal and the electron density with seismicity. Both are superior with respect to random anomaly distributions with largest concentration 3-4 times the corresponding of random simulations, corresponding to a deviation from the random mean by more than 40-50 sigma, confirming a lithosphere-atmosphere-ionosphere coupling in the preparation phase of earthquakes.

ESC2018-S16-694

THE POSSIBILITY OF EARTHQUAKE FORECASTING: LEARNING FROM NATURE.

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We present approach based on physically substantiated short-term precursor's selection to provide the real-time multiparameter monitoring having as a purpose the short-term forecast of earthquakes. Three main principles should be fulfilled: 1. We register natural phenomena for which we have multi-year experience demonstrating their connection with the earthquake preparation process; 2. All these phenomena have very high statistical confidence in relation to post-phenomena earthquake occurrence; 3. We have the physical explanation of these anomalous phenomena generation and their interrelation within the framework of earthquake preparation process. It is important to note that precursors are registered in different geospheres (lithosphere, atmosphere, ionosphere and magnetosphere) what confirms the fact of geospheres coupling during the earthquake preparation period. For the first time we included in consideration the role of triggers and their relationship with precursors. One of the well confirmed triggers is the Space weather evens changing the global atmospheric circulation. The arising large-scale irregularities of atmospheric pressure may serve as earthquake triggers while their linear borders coincide with the active tectonic fault. Another recently revealed effect is existence of earthquake retarders when earthquake happens later (up to month) in comparison with our procedure of earthquake time determination. Complications created by triggers and retarders in developed procedure of short-term earthquake forecast should be resolved in future development of our research. All these ideas will be presented in the book which will be subsequently published by Institute of Physics (IOP) which will have the same title as abstract.

ESC2018-S16-761

A TIME-DEPENDENT ASSESSMENT OF THE UNIFIED SCALING LAW FOR EARTHQUAKES IN NORTHEASTERN ITALY

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The temporal variations of the parameters of the United Scaling Law for Earthquakes (USLE) in the Friuli Venezia Giulia Region are analyzed, to get new insights on space-time patterns of seismicity in Northeastern Italy. For this purpose, the revised OGS bulletins, compiled at the National Institute of Oceanography and Experimental Geophysics, are used, considering all magnitude 1.5 or larger earthquakes, which occurred in the time span 1994-2015 and within the territory of homogeneous completeness identified for the OGS data (Peresan and Gentili, 2018). Two possible variants of the magnitude estimates are considered, which are recomputed from original magnitude Md, using two different relations, in order to improve homogeneity of magnitude estimates for small (i.e. Md lower than 3.5) and moderate size events (Gentili et al., 2011). The parameters A, B and C of the USLE are computed, at different spatial resolution, by the algorithm of Scaling Coefficients Estimation (Nekrasova et al. 2015), where the count of earthquakes is performed in a set of cascading squares (i.e. a telescope). Specifically the USLE coefficients are evaluated at each of about 300 seismically active cells of a regular grid 1/16°×1/16° (Hierarchy I), as well as at each of about 80 seismically active cells of 1/8°×1/8° size (Hierarchy II). The obtained estimates of A, B and C are cross-compared to highlight correlations and the effect of averaging at lower spatial resolution. The parameter A, which corresponds to the logarithmic estimate of seismic activity at magnitude M=3.5, normalized to a unit area of 1°×1° and unit time of one year, ranges between -0.9 to 0.2. The coefficient of magnitude balance, B (analogous to the b-value of the GR law) concentrates in the range from 0.5 to 1.0, while the fractal dimension of the earthquake epicenters C varies from 0.6 to 1.3. In addition, the temporal changes of the USLE parameters for the more robust Hierarchy 2 (1/8°×1/8° grid size), are analyzed computing A, B and C for moving time windows of 6-year. The performed analysis shows that:

- The USLE coefficients in Northeastern Italy are time-dependent, as observed in several regions worldwide.
- The obtained dynamical change of USLE attractor in the (A,B,C) domain is robust with respect to the considered magnitude estimates, and evidences significant transformations at the intermediate-term scale of years.
- The spatial scale of USLE analysis is of importance and should account for practical needs, though limited by the seismic data available.
- Temporal changes of the USLE coefficients expose correlated, though complex behaviours in dynamics of the Earth hierarchical system.

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ESC2018-S16-1074

THE RESULTS OF THE DISTANCE, OPERATIONAL SEISMIC FORECASTING, WHICH WAS MADE IN AZERBAIJAN FOR THE DIFFERENT REGIONS OF THE WORLD, ON THE BASIS OF YEAR-ROUND FLUIDS'S MONITORING IN AZERBAIJAN

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Researches in the field seismic forecasting always were relevant, but small successful. Until 2014, the world was not developed reliable mathematical methods and the software for forecasting the main parameters of the earthquake. In Azerbaijan are conducted seismic forecasting researches in the year-round rejime by the seismofluidodynamic (CFD) methods already 39 years (1979- 2018). It is presented by the seismogeochemical and seismogeodynamical directions. After the realization the strong earthquakes in Azerbaijan (Lerik-1998) and on the Caspian sea (2000), in RCSS at ANAS were intensified researches on the development of

methods for operational and short-term earthquake forecast. As a result, for the period 1998-2014 by us were developed, tested and implemented mathematical and softwares to solve the main problems of the operational and short-term forecast of the earthquakes only on the basis of year-round SFD monitoring in Azerbaijan. These are 2 (two) essentially different, autonomous "Automated technologies N.1 and N.2, which are used only on the basis of the monitoring of seismic fluid regime (SFD) in Azerbaijan". They are used for the different purposes: a) express-method assessment of the seismic situation (ml>=3.0) in a concrete region; b) distance, operational seismic forecast (mb>=6.0) in any region of the world. These technologies daily solve the following important problems: a) daily identification of the informative parameters in the stream data year-round SFD monitoring (for 1 day:305 values for the 14 parameters from the 23 objects of the observation); b) simultaneously, for the different azimuths of the projected foci of earthquakes on the final stage of their training (for 1:16 days before the earthquake's realization) are calculated main parameters of the earthquake: "diapazon-intervals" for the coordinates of foci; its magnitude; and time which remains before the earthquake's realization. The software is presented by algorithms which are developed on the basis of the automated express-methods (Keramova, 2004-2011) for the operational assessment of a seismic situation in the region only on anomalies of the year-round SFD monitoring in Azerbaijan: 1. the express-method calculating (formulas) for the daily detection SFD anomalies in the data of monitoring for their next processing; 2. the express-method for calculating on the formulas "diapazon-interval" of the magnitude future earthquake; 3. the express-method detection coordinates of the future hypocenter on the basis identification the created "portrait" of the seismic foci on the SFD anomalies; 4. the express-method for the daily calculating the "diapazon-interval" of the realization1's date of the predicted earthquake on 1:16 days. Currently, we are performing distance, operational seismic forecasting for the following regions: 1. Caucasus-Caspian: a) Caspian sea and Azerbaijan (ml>=3.0; h>=0 km); b) neigh-bouring countries (mb>=4.0; h>=0 km: Russia (Dagestan and Chechnya); Georgia; border with Armenia. 2. Anatolian-Iranian tectonic block (mb>=5.0; h>=0 km: Turkey; Iran). 3. Countries of the deep-focus Hindu Kush seismogenic zone (mb>=6.0; h>=90 km: Tajikistan; Afghanistan; Pakistan). 4. Countries of the catastrophic planetary earthquakes (mb>=6.5; h>=33 km: Italy; Indonesia; Japan; Philippines, Chile, etc.). Geography of these regions will be expanded in the future. This work is performed daily and duplicated by two different methods whith conditional name: 1) "Automated technology N.1" ("Identfire"), which presented by 5 programs, but the end result carries out manually, in the format of a report and a map. 2) "Automated technology N.2" ("Autolog") consists from only of one program and the end result is presented automatically in tabular and cartographic formats. One of the concrete examples of our distance, operational seismic forecasting is a strong earthquake (mb=6.3) in the Aegean sea (16.06.2017), on which was made a synchronous forecast for 6 days before its realization by both "Automated technologies N.1 and N.2 ... " in the "Report N.101". This foci was located at a distance of more than 1500 km from the observation objects in Azerbaijan. Our errors were in the coordinates (Δ=150-240 km), and in the magnitude (mb=5.0-5.9). Acknowledgement for this forecast is on e-mail of our organization's management. We have official verification's document from Russia (Republic Dagestan) on distance, operational seismic forecast, which was made by us in Azerbaijan for the territory of Russia (Dagestan) on the period 01.01.2017-31.08.1017. It was reflected in the document on the awarding of the leadership of the Ministry of Emergency Situations of Dagestan in October 2017, the employee of RCSS at ANAS (R.Keramova). The reliability of all the results of the seismic forecasting for territory Dagestan and adjacent Caspian sea water area was equal to 80-85%. However, despite the fact that our research in the field of the distance, operational seismic forecast in Azerbaijan are highly reliable, these works have not been completed yet.

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SESSION 17

ESC2018-S17-117

MACROSEISMIC PRACTICES AT THE U.S. GEOLOGICAL SURVEY

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The U.S. Geological Survey (USGS) "Did You Feel It?" (DYFI) system is an automated approach for rapidly collecting macroseismic intensity data from Internet users' shaking and damage reports, and for generating intensity maps immediately following earthquakes. DYFI has been operating continuously in California since 1999 and has operated globally since 2004. DYFI-based intensity maps are made more quickly than traditional intensity maps, provide more complete coverage at higher spatial resolution, offer citizen input and interaction, and allow data collection at rates and quantities never before possible. After two decades of operational experience with the DYFI system and its users, we document refinements to the processing and algorithmic procedures. We also describe a number of post-processing tools, applications, and research directions that utilize the extensive DYFI intensity database. DYFI calculates intensities to decimal precision, and geocoding allows for alternative methods for spatial averaging; both of these strategies simplify quantitative data analysis. For recent induced earthquakes in Oklahoma and Kansas alone, DYFI has provided more than 200,000 observations including 22,000+ at distances less than 20 km. This dataset has been used to study the unique characteristics of induced earthquakes; to evaluate the extent of felt area, shaking, and damage; to compare intensity and ground motion metrics; and as constraints for ShakeMaps used by utilities, insurers, and others. New DYFI developments described include a reimplementation of the DYFI codebase using open source tools and development; a self-contained compilation of the DYFI data archive for induced events in the Eastern US; a prototype voice-activated DYFI questionnaire using Amazon's Alexa platform; and tools for users to replicate, filter, and aggregate custom DYFI datasets in their own area of interest via USGS web services. We have found that transitioning from the conventional, scientist-vetted method of macroseismic intensity data collection to an internet-based citizen science approach requires flexibility; we concur with Sbarra et al.'s (2011) statement: "We believe that macroseismic scales are not static, but they instead should be updated on the basis of new experimental observations." Therefore, the USGS is pursuing common solutions to harmonize the collection and processing of modern macroseismic observations and assuring quality results. Coordinating DYFI intensity assignments with those made in other countries and with the European Macroseismic Scale is a sound goal, as is progress towards an International Macroseismic Scale (IMS). DYFI can be found online at the website https://earthquake.usgs.gov/dyfi/.

ESC2018-S17-125

CORRECTIVE PARAMETERS TO MERGE MULTIPLE-SOURCED ONLINE MACROSEISMIC DATA

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The practice of macroseismic investigation through internet inquiries is well established among several seismological institutions around the world, thanks to wide citizen participation. Up to now each institution follows its own method and procedure in collecting, analyzing and showing felt earthquake data in the form of maps, graphs and intensity data. As consequence of these different approaches, seismologists have not found a common standardized method to obtain macroseismic intensity data. When an earthquake affects only one country, then these differences are not evident to detect. However, for medium-high magnitude earthquakes that occurred near the border and hence affect several countries, the national differences become more clear, with often the result that it is not possible to create a single, cross-border macroseismic map composed of homogeneous intensity data. Instead of proposing that we all use a common, standardized procedure/questionnaire to produce an homogeneous dataset, we test an alternative approach consisting of respecting the differences among various strategies used to collect and analyze data, and applying a statistical evaluation of differences and the implementation of corrective parameters. To demonstrate this procedure, we analyzed macroseismic data of

both European cross-border felt earthquakes , where intensity data sets are complementary, and of events that occurred in one country where intensity data is provided by different institutions (INGV-HIST, EMSC, USGS-DYFI). In this analysis we show the application of statistical methods in order to evaluate, in a quantitative way, the degree of agreement of different datasets, and the possibility to retrospectively merge data, in order to obtain more uniform and stable intensity data.

ESC2018-S17-126

RELIABILITY OF SINGLE QUESTIONNAIRES AND OF PRELIMINARY INTENSITY MAPS

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Internet macroseismology, based on voluntary collaboration of citizens, has been carried out at Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy, since 1997, currently "Hai sentito il terremoto" (HSIT) dataset includes nearly 1,000,000 questionnaires. The intensity assessment method is of expert-based type and it has been under evolution and refinement over time. Through a matrix of scores, made closely following the macroseismic scale, the answers of all questionnaires from a municipality contribute to the definition of intensity. An important initial step is the exclusion of potentially erroneous questionnaires. The identification of such reports is made on the base of three criteria (scarcity of information, contradictory answers, excessive intensity discrepancy from attenuation relation), however, some specific cases pose several doubts. For example, a very light shaking produces few effects and people tend to give little information, omitting to answer to the absence of specific diagnostics. A different situation occurs when the observer is located outdoors, where objects subject to shaking are less than indoors. In this case scarcity of information is normal and it doesn't represent an anomaly. The benefit of taking into account these particular cases is the inclusion of a greater amount of questionnaires data. The intensity discrepancy criterion presents some problems as well. It is useful in excluding excessively high intensities resulting from possible questionnaires sent in jest, but it can discard even interesting data and hide site or propagation effects. Here we show some cases of deep earthquakes in which the disabilitation of the filter has been crucial for highlighting peculiar propagation anomalies. Finally we analyzed how the reliability of macroseismic intensities depends on the number of questionnaires and thus on the time passed since the earthquake. Although after 24 hours since an earthquake occurrence we receive 70% of the final quantity of questionnaires, already after 8 hours we obtain a preliminary municipality intensity with a good correlation with the final one. A separate discussion is made for high magnitude events, where the near field area is subject to the doughnut effect. In fact the epicentral area has a time of completion longer than that of the far field.

ESC2018-S17-142

ON THE USE OF FRACTIONAL VALUES FOR MACROSEISMIC INTENSITIES AS INFERRED FROM THUMBNAIL-BASED QUESTIONNAIRES

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The Internet is becoming an increasingly useful resource of data for felt earthquakes since people adhere to the various platforms that are currently available to report ground shaking effects. Online questionnaires with different degrees of detail are made available by the national agencies that use them to estimate macroseismic intensities without resorting to field operations that can take a few days to a few weeks. In order to facilitate the citizen contributions and speed it up, some agencies have added thumbnail-image based questionnaires to their web services. One of these questionnaires is described by Bossu et al. (Seismological Research Letters, 2017). It presents a set of 12 images that aimed to obtain intensity values (Ithumb) with a one-to-one correspondence with the 12-degree EMS-98 intensity scale. Comparison with the similar Internet inquiry "Did You Feel It" intensities (DYFI) and a few EMS-98 earthquake data led Bossu et al. (2017) to propose an adjustment equation to Ithumb to make the two datasets analogous. As a result, each contribution is assigned an intensity corrected value that is fractional. For example, 3 is corrected to 3.2, 5 is corrected to 5.8 and 7 is

corrected to 8.3. We verify that there is no thumbnail image that corresponds to intensities 4 or 9 on the corrected scale. The collected data on recent events is now available at the CSEM/EMSC webpage (https://www.emsc-csem.org/#2) that links to the Seismic Portal of EPOS project under Web Services (http://www.seismicportal.eu/webservices.html. The data files that can be downloaded, once the event Id is known, comprise four columns, the coordinates of the point, original (raw) intensity (Ithumb) and adjusted intensity (Iadj). The use of fractional values to represent adjusted intensities gives a false sense of precision on an Intensity value that should keep integer values, half-integers being discouraged (Grünthal et al., 1998, European Macroseismic Scale (EMS-98), Cahier du Centre Européen de Géodynamique et de Séismologie, Vol. 15.). When deriving the adjustment equation, Bossu et al. (2017) use as distance reference the center of the binning interval, instead of the average distance for each bin that takes correctly into account the irregular distribution of distances for the reported values. Estimating the cumulated uncertainties in deriving the adjustment equation I estimate the prediction uncertainty to be larger than 1.0, much larger than the 0.1 precision inferred from the fractional values provided. The adjustment equation is non-linear, and it is applied to individual data points. However, the equation was derived from average sets of data points so that its average would fit DYFI and EMS98 measurements after correction. Given the non-linearity of the equation, its application on individual data points will result in an average value that differs from the deserved ones. I conclude that the adjustment of individual thumbnail intensity points and its replacement by fractional values, as it is done is some thumbnail-image questionnaires, has no additional value and may be misleading bringing a false sense of precision. However, if applied on statistically significant sets of data points it may provide relevant information for decision makers and researchers, but the uncertainties on the values estimated must also be accounted and better communicated. This publication is supported by FCT- project UID/GEO/50019/2013 – IDL

ESC2018-S17-205

DETERMINATION OF THE EARTHQUAKE EPICENTER FROM THE GEOGRAPHIC PROFILING OF THE DIGITAL FOOTPRINTS LEFT BY EYEWITNESSES

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When an earthquake is felt, eyewitnesses digitally manifest themselves thanks to the various collect methods developed by the European-Mediterranean Seismological Centre. Those observations are mostly collected through the websites' traffic analysis (desktop site, mobile site), a Twitter earthquake detection bot, the Lastquake mobile application and/or a dedicated questionnaire... The idea developed here consists in considering the pattern printed by the entirety of these observations (which can be considered the digital footprint left by the eyewitnesses) as being the signature of an earthquake. Through several examples, a method for fusioning and combining all eyewitness observations collected is presented. Especially, in the framework of the statistical method of the Geographic Profiling (GP), this approach leads to fast determination of a seismic epicenter. And, because the propagation of the information on the Internet network is faster than the propagation of the seismic waves, this approach leads also to compare the GP solution to that obtained from conventional geophysical procedures (detection / location of the seismic waves).

ESC2018-S17-294

QUANTIFICATION OF THE INCREASE IN SHAKING WITH THE FLOOR LEVEL BASED ON MACROSEISMIC DATA COLLECTED BY THE BCSF-RENASS IN FRANCE.

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Since 2000, the BCSF-RENASS collects, through Internet, testimonies of earthquake effects in France. They consist of answers to various questions that provide us numerous observations. Also, the witness selects a thumbnail that summarizes at best the individual observations. The questioner and each thumbnail have been

built to exhibit the main characteristics related to an intensity level of EMS98 but without the statistical approach as it is based on a single observation. Therefore we call it SQI (single questionnaire intensity, Lesueur et al. 2012). We use this information to provide rapidly, from few minutes after the shaking, an online macroseismic map with preliminary intensity estimation for each city based on the average value of SQI. Regarding the size of the city, the estimation is based on few testimonies and up to several hundreds for the large cities. Nevertheless, we need before to correct the SQI from the impact of the floor level to retrieve the ground shaking level for intensity assessment. Indeed, the seismologists and building designers know that the ground motion is amplified on the floors above of buildings, but in practice it is quite complex and depends on the observation floor and the total height of the building as specified in the EMS98 scale. If the recommended practice in EMS98 is to discount all reports from observers located higher than the fifth floor when assigning intensity, there is no clear recommendation to take into account the possible amplification at first floors (1 to 5). At BCSF-RENASS, the questionnaire allows the witness to select between 5 classes: “underground”, “ ground floor”, “1 or 2”, “3 or 4” and “5 and more”. We used up to now a flat correction of 1 degree for the SQI if the observation was at floor levels 3 or 4, no correction for floors 1 and 2 and we exclude the fifth floor and more for our preliminary intensity estimation. Our purpose here is to review this flat correction and to identify, from our numerous testimonies in France at various floors, the real effect of the floor level on the SQI, as it has been done in Italy (Sbarra et al. 2012 and 2015). We worked on the residual between average value of SQI at ground floor and SQI at floors above. We used four floor-level classes, ground, 1st and 2, 3 and 4, and 5 and more. We based our study on 4 representative earthquakes in France affecting large cities with high buildings. To avoid multiple origin of amplified shaking, as site effects, we analyzed separately the observations at rock from those at sediments for large city. Our previous flat correction appears to be for most cases too strong. We observe an average amplification of about a half-degree of intensity, nevertheless some SQI show a much stronger difference with the average shaking level. The average amplification of floors 1 and 2 is observed but is very small. The average amplification of floors 3 and 4 is confirmed and is lower than for floors 5 and more. Despite these few events studied cannot be representative of all cases in Europe, due to the small magnitude range and to the limited number and types of building considered, the results are nevertheless homogeneous, and average floor amplification stable. This shows clearly that SQI at high floor, from floors 3, are not characteristic of the ground shaking, and it must be corrected to not overestimate the Intensity, especially for large cities that have numerous tall buildings.

ESC2018-S17-362

EVOLUTION OF MACROSEISMIC PROCEDURES AT PORTUGUESE SEISMIC NETWORK

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After 12 years gathering macroseismic data through the web-questionaire it became evident for us the need to evolve toward a new version to overcome some hardware problems. This was the spark to start a major upgrade of the questionnaire, and consequently the algorithm that analyses the answers (WebMInt), in order to make all the process more operationally effective and more robust. The work is in progress at this moment. Some problems related with geographic location are being reviewed since the existing method was dependent on dated conditions. All the questionnaire and the algorithm is being revised and more questions and more detail are being considered, as well, one easier interaction with the algorithm from outside to make possible fine adjustments. The algorithm uses easily understandable terms that are going to make easier the work of non-Portuguese speaking persons who wants to test or use it. A completely new group of questions, related with damage on buildings, is now being considered. One question related with a new behaviour observed on people in recent felt earthquakes, appears for the first time. Several languages are available to fullfil the questionaire as Portugal becomes more and more internationalized. Most of the work related with

questionnaire implementation is being carried out on a XAMPP environment integrated with LimeSurvey program. SQL will be used to handle the new macroseismic database. ShakeMap and MIDOP software packages, as well the core operational software of the Portuguese seismic network, will be fully inter-operational with the new questionnaire and WebMInt algorithm.

ESC2018-S17-363

EVALUATION OF 12 YEARS OF DATA FROM WEB MACROSEISMIC QUESTIONNARIE AT PORTUGUESE SEISMOLOGICAL SERVICE

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The Portuguese seismological service uses the Internet to collect macroseismic data directly from witnesses, that report their experiences at their geographical locations by filling an online questionnaire, since 2006. This questionnaire is available to anyone at the webpage of Portuguese Institute for Sea and Atmosphere (IPMA), is called "Did you feel an Earthquake?" and can be accessed by the link: https://www.ipma.pt/pt/geofisica/informe/. The macroseismic questionnaire was designed based on EMS-98 scale and consists on simple questions, most with multiple choice answers. The answers are received as an e-mail at Operational Centre of Seismology (COS) at the IPMA. The questionnaire is well known by the IPMA web users. For instance, just after the occurrence of December 17, 2009 earthquake (SW C.S. Vicente, ML = 6.0) 3667 answers were available in few hours. The urgent need to provide seismic information to civil protection and the great number of responses received, after felt earthquakes with impact on the population, led to develop an automatic process for evaluation of questionnaire answers. In order to implement the algorithm for automatic macroseismic evaluation, it was developed a computer application, named WebMInt, written in C programming language. This tool is integrated at Portuguese seismological service, since 2010, and interact with other computational tools of operational seismic monitoring and surveillance routine, in particular with the earthquake analysis software SEISAN, the program W_Emap and software ShakeMap. The reported effects are analysed, filtered and converted into degrees of seismic intensity in very few minutes. On the other hand, since 2011, the Portuguese seismological service has implemented the ShakeMap (V3.5) software package provided by U.S. Geological Survey (USGS), in order to obtain reliable shakemaps for Portugal mainland. It accepts observed macroseismic intensity as input data, together with peak ground motions measurements from seismic stations. The good performance of the developed macroseismic evaluation process, providing quantitative and qualitative information about seismic intensities for recently felt earthquakes that occurred in Portugal region, led to a fully integration at the seismic processing routine of Portuguese seismological service and became an important step of it. The process is stable, it was tested and is coherent with other methods (manual, ShakeMap) and provides a rapid and vast source of information to feed the IPMA´s Macroseismic Intensity Data Base. In addition, this information combined with specific attenuation laws and site corrections is used as an important constraint to shakemaps produced for Portugal mainland and Madeira Archipelago. This is a process in permanent evolution with improvement of some small aspects or addition of new developments in order to get better results and more complete information. The improvements made did not affect de Data Base structure. Finally, although the good performance, some aspects must be improved specially what concerns with hardware support, damages on buildings and indicators for intensities exceeding V. The results of macroseismic evaluation process are published, since 2014, at IPMA shakemap webpage and can be accessed by the link: http://shakemap.ipma.pt/. Some examples of application to earthquakes that occurred in Portugal region are presented.

ESC2018-S17-508

FIRST ONLINE MACROSEISMIC DATABASE FOR THE REPUBLIC OF GEORGIA (SAKARTVELO)

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Several international projects like GEM, HARE, NERA, and EMME, have been recently carried out in order to harmonize seismic hazard and risk maps. The focus is on creating homogenous databases of seismogenic faults, earthquake catalogues, strong motion data, ground shaking models, and develop open softwares for hazard and risk calculation, such as OQ (Open Quake) or ELER. However, in several countries where there are few available data of strong ground motion, estimation of macroseismic intensity is of paramount importance. Different macroseismic scales have been used to describe earthquakes in different countries, thus a harmonization towards European macroseismic standard for the creation of homogeneus data of macroseismic intensity is of basic importance. In the present work, we describe the first online macroseismic database of the Republic of Georgia. A total of 111 earthquakes with related 3944 Intensity Data Points (IDPs), comprising 348 IDPs of the pre-instrumental period (pre-1900 AD) and 3596 IDPs of the instrumental period (post-1900 AD), were revised and reported. Each single IDP has been re-evaluated and intensity values have been homogenized to the MSK scale. Detailed descriptions of each event in the database allow to use these data for conversion from the MSK scale to the European macroseismic intensity. The archive of the Institute of Geophysics of TSU contains further 200 earthquakes that occurred in other regions of Caucasus, and need a revision and systematization in the near future.

ESC2018-S17-512

NEW MACROSEISMIC INTENSITY ASSESSMENT METHOD FOR NEW ZEALAND WEB QUESTIONNAIRES

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This paper presents the implementation of an expert-based method to calculate "Community Modified Mercalli intensities" (CMMI) for New Zealand earthquakes, using GeoNet's "Felt Classic" (2004-2016) online felt reports. The method has been implemented and tested for c. 43,000 felt reports from nine recent moderate-to-large (Mw 5.7 to 7.8) New Zealand earthquakes, including the damaging M7.1 4/9/10 Darfield, M6.2 22/2/11 Christchurch and M7.8 14/11/16 Kaikoura earthquakes. Results from this method ("matrix method") have been compared for the nine earthquakes using three independent approaches: a) traditional method (only for the M5.7 14/2/2016 Christchurch and M7.8 Kaikoura earthquakes); b) community intensities from New Zealand's latest Ground Motion to Intensity Conversion Equation (GMICE); and c) community intensities from a recent GMICE using California data. Results show a good consistency in community intensities between the matrix, traditional and California GMICE methods. However, CMMI derived using the New Zealand GMICE shows a tendency to overestimate the intensities by about 2-3 intensity levels in comparison to the CMMI and traditional MMI, showing the need to review the current New Zealand GMICE. The matrix method provides a useful way to obtain geographical damage distribution following an earthquake, being the first of its kind using New Zealand felt report data. Its future use in ShakeMapNZ and GeoNet website will provide local authorities, emergency planners, decision makers and the public with a fast and easy tool to understand the damage distribution following an earthquake. The first database of CMMI for New Zealand felt reports has been generated, comprising 914,000 felt reports from 27,688 different earthquakes during the 2004-2016 period. The database has generated more than 57,000 community intensity values for communities with five or more felt reports. Analysis of uncertainties using a bootstrapping method are currently being undertaken. In addition, further quality testing is currently being carried out to improve the quality and robustness of the CMMI method. This large dataset of community intensities is currently being used to update New Zealand's Intensity Prediction equation and Ground Motion to Intensity Conversion equation.

ESC2018-S17-655

MACROSEISMIC DATA COLLECTION AND PROCESSING IN SLOVAKIA USING WEB-BASED QUESTIONNAIRE

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Web-based macroseismic questionnaire of the Earth Science Institute of Slovak Academy of Sciences is constantly improved and redesigned to achieve even better clarity and ease of use by respondents on computers, laptops, tablets and mobile phones. We are able to collect and analyse responses faster - almost in real time - and take advantage of wide response from public with growing proportion of responses from mobile phones. After discussing with colleagues from other European institutions working in the field of internet macroseismology (meeting in Ljublana, 2017) we decided to amend formulations, change the order of multiple questions and to improve questionnaire processing algorithms in order to include effect of the floor of observation inside a building. We also added images of the intensity degrees to the end of the questionnaire – this European initiative introduces common element to all questionnaires of local institutions and complements data gathered by the questionnaire itself, and its aim is to have available a simple way how to merge data for cross-border events and also to contribute to building of comprehensive European macroseismic catalogues. In our web environment, created for this purpose, a seismologist can create summary from the questionnaire data saved on servers at any time and visualize it on the map of the observations. Collected data can be filtered and after a complete database for an event is gathered, macroseismic intensity per location can be calculated using an automatic algorithm, and preliminary intensities can be exported for visualization on a map after review of a seismologist.
Acknowledgement:
The authors have been supported by the Slovak Foundation Grant VEGA 2/0188/15.

ESC2018-S17-838

INTERNET MACROSEISMOLOGY IN FINLAND: CURRENT OBSERVATORY PRACTICE AND FUTURE PLANS

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The designing and dissemination of macroseismic questionnaires constitute the core of macroseismic surveys in Finland since 1882. Field surveys are not conducted routinely, because local earthquakes are seldom damaging. The history shows how new technologies have an immediate effect on the surveys. Thus, placing the macroseismic questionnaire on the Internet at the turn of the 2000s was a logical step to take. The current questionnaire design is aimed at assessing intensity on the European Macroseismic Scale. The classification factors of the different intensity degrees are emphasized. Besides local and regional earthquakes, other phenomena such as explosions, quarry blasts, frost shocks and passing supersonic aircrafts trigger seismic waves that are noticed and reported on the questionnaire. They may cause concern among the general public and are sometimes interesting to the media, so a correct identification of the source is needed. Data collection over the Internet has substantially shortened the time span of attention given to interesting earthquakes. Some 80-90% of the total number of observations can be obtained within the first 24 hours following an earthquake. They are strongly biased in favour of positive responses. The presentation outlines how macroseismic observations are currently processed in Finland. The questionnaire has been shifted to the e-questionnaire service provided by the University of Helsinki and is no longer maintained by seismologists. The responses are stored as tables that are easily handled with the help of Excel for example. The data are processed using an ArcMap model. It computes the intensity according to the number of hits found on each questionnaire. The results are stored as spatial data. The respective file is read into an established GeoServer from where it can be published as an embedded map using a map portal. There are a number of options for the level of visualization.

ESC2018-S17-885

INTERNET MACROSEISMOLOGY IN ROMANIA: ISSUES AND SOLUTIONS

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In the last decades, many efforts were done in Romania to gather macroseismic intensities in case of felt Vrancea earthquakes using classical questionnaires sent by post mail and additionally an online environment was developed for the automatic approximation of the intensity from people answers and feedback. Besides the extended scientific studies, the near real time estimation of the macroseismic intensity recently became mandatory for the insurance companies to cover some of the losses and damage that earthquakes might cause to houses, belongings, and other buildings. The procedure proposed in this paper was applied for rapid macroseismic estimation and loss assessment for the recent intermediate-depth medium sized Vrancea earthquakes, by using the online (PC based and "INFP" mobile application) macroseismic questionnaires, and the automatic intensity estimation code recently improved. Besides the automatic estimation, we have also used the classical approach to assess the intensity data points and the results have been compared. Using the internet macroseismic data collected during the last five years and the recorded accelerations, there have been realised conversion equations of peak ground motion parameters (acceleration and velocity) in macroseismic intensity for earthquakes with magnitudes between 4.5 and 6.0 Mw. The results were compared with the proposed by the Romanian Macroseismic Intensity Standard. Acknowledgements:
This paper was carried out within Nucleu 2018 Program CIRRUS PN 1815 01 01 Project supported by ANCSI, Romania

ESC2018-S17-1010

SOME CASE STUDIES OF MACROSEISMIC INTENSITY DATA-POINTS RECOMPILATION IN CENTRAL AMERICA: THE CONTRIBUTION OF RIESCA PROJECT TO THE MARCA-GEHN PROTOTYPAL DATABASE

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In the frame of the activities of RIESCA Project ("Proyecto de formación aplicada a los Escenarios de Riesgo con la vigilancia y monitoreo de los fenómenos volcánicos, sismicos e hidrogeologicos en América Central", funded by the Agenzia Italiana per la Cooperazione allo Sviluppo, and coordinated by the University of Palermo) we agreed to build up a prototypal archive of macroseismic data points for the Central America countries involved in the project, namely, El Salvador, Guatemala, Honduras and Nicaragua. The objective of this collection is to establish a common, quality controlled seismological dataset, for checking, validating, and eventually updating the earthquake parameters for some damaging and destructive events. They will be integrated into new fault/area source characterization for seismic hazard purposes as well as into site-specific characterization of metropolitan areas. With collaborative efforts, a google form for inputting the data into a repository has been realized and tested in 2017. During the 3rd training period in Central America in 2018 (http://proyectoriesca.agronomia.ues.edu.sv/), the seismological working group has uploaded about 750 intensity data-points of 23 earthquakes in the prototypal archive named MARCA-GEHN (Macroseismic Archive of Central América - Guatemala, El Salvador, Honduras, Nicaragua). At ESC General Assembly we will present the general features of the database and some interesting case studies among the earthquakes already collected.

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SESSION 18

ESC2018-S18-52

HOW EYEWITNESSES OBSERVATIONS CAN CONSTRAIN EARTHQUAKE IMPACT ASSESMENT

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Except in the few regions of the world covered by dense accelerometric networks, rapid earthquake impact assessments are intrinsically uncertain. Reasons are well identified. Earthquake ground motion is highly variable for similar magnitude and distances (even in the same geographical region), building vulnerability is often poorly constrained and, unforeseeable specific circumstances, or, especially for moderate earthquakes, individual accidents may dominate the overall impact. Individual eyewitnesses' observations may dramatically reduce rapid earthquake assessment by excluding some or many of the potential scenarios. For example, during the 2015 Ghorka, Nepal earthquake, many, if not all impact assessment tools in operations overestimated its human tolls, simply because Kathmandu was expected to have suffered major damage which, fortunately, proved wrong, due to the frequency content of ground motion that was only identified after the earthquake. However, within five minutes of the earthquake, significant website traffic originating from the city was observed, excluding the possibility that it had been flattened and indicating that our assessment had been overestimated. This essential information was confirmed by felt reports collected in the following tens of minutes. Beyond such a specific case, this talk aims at demonstrating the importance of eyewitnesses' observations in rapid earthquake impact assessment and explores potential ways forward. The first

ESC2018-S18-66

DETECTION AND LOCATION OF LOCAL EARTHQUAKES BY MEANS OF AMPLITUDE MEASUREMENTS IN THE AUSTRIAN SEISMIC NETWORK.

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This study focuses on testing the robust method to detect and locate earthquakes by means of amplitude measurements with data from the Austrian seismic network (ZAMG – Zentralanstalt für Meteorologie und Geodynamik). In addition, an intermediate objective is to determine a direct relationship between the intensity of vibration (ShakeMap) and vibration velocities (SourceMap) with the final goal of giving a rapid, robust and reliable assessment of source characteristics of moderate to large earthquakes, which is extremely advantageous for hazard assessment. The proposed localization method is based on the minimization of maximum resultant ground velocities in sliding time windows covering the whole registered event. The basic idea is that any small seismic source can produce large amplitudes, as long as it is located close enough to the seismic station sensor. The developed method is based on an empirical model of the ground shaking obtained from amplitude data of earthquakes in the area of interest, which were located using traditional methods. Using the Back-Projection approach, we can rapidly determine an event location and its magnitude without picking phases. The maximum resultant ground velocities are back-projected to every grid point of the study area applying the empirical amplitude – distance relation. We refer to these back-projection values as Back-Projected Ground Velocities (BPGV) or pseudoMagnitudes. The number of operating seismic stations in the network equals the number of pseudoMagnitudes at each grid-point. The method introduces the new idea of selecting the minimum BPGV at each grid-point for further analysis. If no detectable earthquake (earthquake strong enough to exceed the detection threshold) occurred, the spatial distribution of the minimum pseudoMagnitudes constrains the magnitude of weakest earthquakes hidden in the ambient noise. In case of a strong enough earthquake, the spatial distribution of the minimum pseudoMagnitudes shows a significant maximum at the grid-point nearest to the actual epicentre. The application of this method is restricted to the area confined by the convex hull defined by the seismic station network. Additionally, one must ensure that there are no dead traces involved in the processing. This new approach is almost wholly insensitive to outliers (data from locally disturbed seismic stations). The idea of obtaining and storing a Back-Projected Matrix (BPM), independent of the registered amplitude, for each seismic station has the advantage of saving computational time for the calculation of the final maximum

pseudoMagnitude, at every grid-point. The improved method is applied to a new data set obtained from the national Austrian seismic network (ZAMG). The method has been tested for a larger data set and for an extensive seismic network.

ESC2018-S18-88

REAL-TIME EARTHQUAKE DAMAGE ASSESSMENT TOOL FOR ALGERIAN BUILDING

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Algeria is one of the countries that have experienced several strong to moderate earthquakes during the last decades. The experience of these events showed that the elaboration of adequate intervention measures was done after the first in situ inspections, which may take long time to provide information and therefore decreases the chance to find survivors. This delay is due to the lack of different means to locate quickly, at the early hours, the affected areas and due also to the uncertain alarm level to be given. In order to enhance the rapid response and emergency operation, disaster mitigation measures can be done. The present work consists on a development of an integrated rapid earthquake loss assessment tool. The main motivation through this development is the ability to estimate the probable seismic damage and their spatial distribution in an affected area by a potential earthquake, according to the existing building context in Algeria. This framework based on the Algerian building seismic damage assessment approach is integrated in a data-processing code developed for this purpose. In the implementation of this framework, a Geographical Information System (GIS) is used. The elaborated concept allows the automation of calculation and the quick data treatment with the generation of the seismic damage maps. It is used, in one hand, to make a predictive estimating of the earthquake damage which can occur in an urban area subjected to the seismic risk, through a probable earthquake scenario, enabling to take the adequate preventive measures. In the other hand, it can be used to give in real time, an estimating of the post-seismic damage, after a disaster occurrence, once the epicentre localised and the magnitude known, as it allows a quick survey of the disaster extends in the more affected areas, which would help to know the level of alarm to be given and the necessary emergency facilities to be mobilised. This tool arises as a decision-making tool which constitutes a contribution in the urban planning field and crisis management in Algeria. A case study of the implementation of the developed tool in the urban centre of Blida city is presented.

ESC2018-S18-107

AN EARTHQUAKE ALERT PROTOCOL MERGING THE USGS PAGER AND FEMA'S HAZUS SYSTEMS

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The USGS's PAGER automated alert system provides rapid (10-20 min) loss estimates in terms of ranges of fatalities and economic impact for significant earthquakes around the globe. In contrast, FEMA's Hazus software, which is currently operated manually by FEMA personnel internally within several hours of any large domestic (United States) earthquake, provides more detailed loss information quantified in terms of physical damage to the building stock, as well as a broad range of social and economic consequences estimated at a much higher spatial resolution (the population census-tract level). Hazus was originally designed for FEMA's mitigation planning, but has been used of late for post-earthquake situational awareness. While the quick alerts generated automatically by the PAGER system are a great way to initially identify consequences for earthquakes, there remains a need to provide detailed loss information for a wider, better-informed post-earthquake response. To this end, we have developed a prototype summary product that takes advantage of the benefits of both these loss models to be used for significant domestic earthquakes. The signature product, a new twoPAGER report, will serve as a supplement to the widely-deployed standard onePAGER product for all significant

omestic earthquakes. Page one is the standard, automated PAGER alert content, with summary alert levels for overall fatality and economic loss estimates, as well as summary content on recent earthquakes, structure vulnerability, and historical secondary hazards. As soon as the Hazus run using the most up-to-date version of the USGS ShakeMap is completed and reviewed by both agencies, the second alert page will be generated and delivered via the USGS website as an update. This second page will contain a summary of the more comprehensive Hazus model results, including spatially-distributed estimates of: affected population, economic impact, non-fatal injuries, displaced households, and the number and level of damage (including potential building safety evaluation requirements) to structures. This enhancement does not affect the timeliness and the importance of the initial (onePAGER) alerting content for significant earthquakes; however, the twoPAGER report will provide more detailed, damage and loss/impact content for the US in the critical hours following a damaging earthquake. The twoPAGER summary-alert content could be readily replicated with loss estimates generated in other nations, including Hazus (implemented in Israel, Taiwan, among others), or similar mechanistic loss modeling approaches.

ESC2018-S18-154

IMPLEMENTATION OF NEW GENERATION TOOLS INTO THE GNSS PERMANENT NETWORK DATA PROCESSING FOR A MORE ACCURATE ASSESSMENT OF THE IMPACT OF VRANCEA EARTHQUAKES, ROMANIA

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National Institute for Earth Physics (NIEP) operates a regional GNSS reference network for monitoring the Carpathian-Danubian-Pontic area deformations and the impact of local earthquakes. With a focus on Vrancea seismic area and the Carpathian Bending Zone (Romania), the network consists of 27 operational stations and another 5 to be installed in 2018. This will provide observations of the crustal motions in order to better understand the surface-to-depth interconnections for intermediate deep earthquakes, improved, reliable and high-accuracy environmental measurements for global weather forecasts, climate monitoring, earthquake precursors (ionospheric studies), coseismic studies, GNSS positioning and navigation, and other types of complementary research. Nowadays, advances in GNSS receivers technology and computational algorithms such as 20 Hz acquisition rate (and even more), that are commonly available, make us search worldwide for systems & algorithms that would make possible a real-time estimation of waveforms and coseismic displacements. Thus, we could support, improve and further analyse the results from the collocated velocity & accelerometers' seismic sensors, particularly atmospheric, magnetic, infrasound, tilt and/or seismic array sensors. So-called VADASE (Variometric Approach for Displacements Analysis Stand-alone Engine) does not require either additional technological complexity or a centralized data analysis. Basically, it can be embedded into GNSS receiver firmware, thereby providing a significant contribution to tsunami warning and other hazard assessment systems. With the help and support of Leica Geosystem and Topgeocart Company, 5 demo licences were installed on our Leica GR10 & 30 receivers and the system is fully operational now, in 2018. The approach is based on time single-differences of carrier phase observations collected at a high-rate (1 Hz or more) using a stand-alone receiver and on standard GPS broadcast products (orbits and clocks), which are ancillary information routinely available in real time. In this approach, we primarily estimated the time series of epoch-by-epoch displacements. The involvement in EPOS – IP project as member of GNSS Data and Products Working Group helps us evolve in the same direction, test and implement GLASS software package for the dissemination of GNSS data & dedicated products (time-series, velocities and strain-rates - to be created using state-of-the-art methodologies) for a better understanding of different Solid Earth processes in European region. The present paper highlights the results obtained in 2018 following the implementation of the new generation of tools into GNSS permanent reference network data processing in help for a more accurate assessment of the Vrancea earthquakes impact.

Keywords: GNSS, high-frequencies, VADASE, GLASS

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Acknowledgments:
This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS/CCCDI—UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0266, Contract No. 16PCCDI/2018, Nucleu Program, project no. PN 18150203, project number PN-III-P2-2.1.PED-2016-1014, Contract No. 86/01.07.2014 and European Union's Horizon 2020 research and innovation program under grant agreement No.676564.

ESC2018-S18-172

SHAKEMAPEU: AN INTEGRATED EUROPEAN SHAKEMAP SYSTEM

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The last few years have witnessed impressive improvements in strong-motion data curation and dissemination in the Euro-Mediterranean region. Two new modern strong-motion portals were developed within the EC-funded project NERA, mainly based on the European Integrated Waveform Data Archive (EIDA; https://www.orfeus-eu.org/data/eida/), namely: (a) an automatic peak-motion database (RRSM; http://www.orfeus-eu.org/opencms/rrsm/information/) that delivers earthquake and peak-motion information within minutes of any event with M >= 3.5 and; (b) a manually revised strong-motion (M >= 4.0) database tailored to engineering applications (ESM; http://esm.mi.ingv.it/). Within ongoing projects EPOS-IP and SERA, the content of the two databases has been made accessible via event, station, peak-motion and waveform webservices, thus considerably improving users' access to strong-motion data and automation of downstream products, like ShakeMap. We present in this contribution the key elements of a novel European ShakeMap system, ShakeMapEU, which uses the USGS ShakeMap codes and input from the RRSM and ESM to deliver maps of expected and recorded ground shaking within minutes of any event with M >= 4.0 in the Euro-Mediterranean region. The predicted maps are initially constrained by the earthquake locations and magnitudes provided by Euro-Mediterranean Seismological Centre (EMSC) together with the recordings of the RRSM and subsequently updated as soon as manually revised ESM ground-motion estimates are available. The system uses ground-motion prediction tools suitable for the European context and adopts the seismo-tectonic regionalisation of project SHARE (http://www.share-eu.org/) to identify subduction, volcanic, shallow active crustal and stable continental seismicity. The system uses the authoritative configuration for Switzerland and Italy and will in the future include any other regional configuration as adopted by other European Institutions running USGS ShakeMap. The system, presently accessible at http://shakemap-eu.ethz.ch/, is based on ShakeMap 3.5. A transition to ShakeMap 4.0, including new developments concerning map and web rendering, is planned in the future. The main goals of ShakeMapEU are: (i) to provide a single source for ShakeMaps at the European scale that builds on ORFEUS and EPOS-IP services and modern future-proof community software and tools; (ii) to serve as a backup to local authoritative ShakeMap implementations and; (iii) to deliver ShakeMaps for regions where no local capability is yet available. Finally, the ShakeMapEU can act as a platform for testing novel methodologies aimed at improving the temporal and spatial prediction and mapping of the experienced ground shaking.

ESC2018-S18-207

REAL-TIME MONITORING AND GROUND MOTION PARAMETERS FOR THE M8.1 AND M7.1 MEXICO EARTHQUAKES IN SEPTEMBER 2017

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In September 2017, the strong M8.1 earthquake off-coast Mexico and the M7.1 earthquake near Mexico City have caused strong ground motions and have left populated areas severely damaged.

The seaquake additionally caused considerable tsunami wave heights along the Mexican coast. We have observed both events and computed the earthquake and ground motion parameters by a real-time earthquake monitoring system based on SeisComP3 and integrated modules provided by gempa GmbH. The locations and the focal mechanisms were automatically available within 5 and 20 minutes, respectively, allowing immediate and reliable estimation of PGA, PGV, macroseismic intensities and other ground motion parameters. The ground motion parameters where determined based on different GMPEs and the Vs30 model as provided by the OpenQuake Hazard Library and USGS, respectively. We calculate MMI of up to XII at the epicentre and significant values event for Mexico City explaining the significant destructions of buildings and structures. By comparison with the observed ground motion the different GMPEs are validated and the best-performing one can be selected. The tsunami potential due to the seaquake was estimated by efficient on-the-fly tsunami simulation which allows the comparison of difference source scenarios considering the estimated location, the magnitude and the mechanism. The predicted waveheights of up to 1 m along the Mexican coast agree well with observations.

ESC2018-S18-225

SLIPNEAR: AN AUTOMATED COSEISMIC SLIP INVERSION FOR NEAR REAL-TIME IMPLEMENTATION

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SLIPNEAR is an evolution of the FMNEAR method (Delouis 2014) which inverts the local to regional seismic records for focal mechanisms and which is running in near real-time in different seismological observatories. In SLIPNEAR, the same kind of records are used, strong-motion and broadband velocimeters at epicentral distance ranging from 0 to about 1000 km, to invert for the slip distribution on the two nodal planes of focal mechanisms. The method aims at discriminating the actual rupture plane and providing the first order properties of the slip distribution: rupture directivity and rupture extent, location and value of maximum slip, source time function... Several of these source parameters can have a strong influence on the impact assessment of earthquakes. The slip model is rectangular, scaled with an initial input magnitude, and initially large enough to allow for unilateral, bi-lateral, or along-dip propagations of rupture. Model discretization is chosen so as to limit the number of parameters but allowing enough flexibility to represent a great variability of seismic ruptures. The approach is calibrated using a number of earthquakes of magnitude larger than 6 which have been well-studied and whose slip distributions have been published. During the processing of an earthquake, several inversions are carried out both in sequence and in parallel so has to converge towards a best solution and provide an assessment of the robustness of the solution. Criteria depicting the uncertainty in the solution are built to help the user assessing the confidence one can have in the solution. The SLIPNEAR method is developed in the frame of the European H2020 project SERA.

ESC2018-S18-304

PERFORMANCE OF THE GFZ DECENTRALIZED ON-SITE EARTHQUAKE EARLY WARNING SOFTWARE (GFZ-SENTRY): APPLICATION TO K-NET AND KIK-NET RECORDINGS, JAPAN

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In study, we report on the application of GFZ-Sentry software for decentralized on-site earthquake early warnings to a large data set of recordings collected by the Japanese K-NETand KiK-net seismic networks. The data set is composed of 3,225 three-component recordings from 24 seismic events. The magnitudes of the selected earthquakes fall into a range of MJMA 6.0–7.3 (Mw 5.7–6.9) and cover hypocentral (epicentral) distances between 5 and 107 km (2 and 103 km, respectively). The data have been coordinated in real time with velocity and displacement; in this manner, the peak ground displacement (Pd) within the first few seconds (to a maximum of 3 s) after the P-wave arrival in the vertical component is determined. This value is used to estimate the peak ground velocity (the median, along with the associated 16% and 84%

confidence intervals) on the horizontal components using empirical relationships. Based on these values, the traffic light status (green, orange, red) is then determined following the methodology introduced by Parolai et al. (2015), which uses three matrices to show the relationship between the expected ground motion and the possible damage (in terms of seismic intensity) that may arise. The performance of the software was evaluated without making ad hoc calibrations for the area or the selected thresholds and was found to be quite reliable. For example, in 90% of cases, assignment of the "red" status is followed by shaking that leads to a seismic intensity equal to or greater than V (very light potential damage). Additionally, all of the recordings leading to an intensity greater than VII (moderate to heavy damage) were correctly classified by a red status. Similarly, when considering all the declared green statuses, it is remarkable that only in 10% of cases was there a "missed alarm" (i.e., a green status is determined, but due to the level of observed shaking, it is later seen that the status should have been red).

Parolai, S., D. Bindi, T. Boxberger, C. Milkereit, K. Fleming, and M. Pittore (2015). On-site early warning and rapid damage forecasting using single stations: Outcomes from the REAKT project, Seismol. Res. Lett. 86, no. 5, 1393–1404, doi:10.1785/0220140205.

ESC2018-S18-316

A RAPID RESPONSE MAGNITUDE SCALE FOR TIMELY ASSESSMENT OF THE HIGH FREQUENCY SEISMIC RADIATION

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In this work the scaling of seismic moment (Mo) and radiated energy (Er) is investigated for almost 800 earthquakes of the 2016-17 Amatrice-Norcia sequences in Italy, ranging in moment magnitude (Mw) from 2.5 to 6.5. The analysis of the Mo-to-Er scaling highlights a breaking of the source self-similarity, with higher stress drops for larger events. Our results show the limitation of using Mo, and in turn Mw, to capture the variability of the high frequency ground motion. Since the observed seismicity does not agree with the assumptions on stress drop in the definition of Mw, we exploit the availability of both Er and Mo to modify the definition of Mw and introduce a rapid response magnitude (Mr), which accounts for the dynamic properties of rupture. The new Mr scale allows us to improve the prediction of the earthquake shaking potential, as shown by the reduction of the between-event residuals computed for the peak ground velocity. The procedure we propose is therefore a significant step towards a quick assessment of earthquakes damage potential and timely implementation of emergency plans

ESC2018-S18-329

IMPROVING SEISMIC NETWORKS PERFORMANCES BY CROWDSOURCED DETECTIONS

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Fast earthquake information is deemed to contribute to seismic risk reduction. To this end, significant and costly efforts are currently being deployed around the world to increasing the density of seismic networks, improving data transmission robustness and timeliness as well as implement earthquake early warning algorithm. Alternatively we propose to use the crowdsourced detection to trigger a seismic location and improve the time performance for an existent seismic network. Crowdsourced detections are based on the detection of the rapid eyewitnesses' online reaction caused by widely felt earthquakes. Eyewitnesses routinely turn to social media within seconds of ground shaking to find out information or share their experience. The EMSC (European-Mediterranean Seismological Centre) routinely monitors the traffic on its websites, one of the top global earthquake information source, the number of launches of its smartphone app LastQuake and finally, the number of tweet (i.e. messages published on the micro-blogging site Twitter) containing the keyword "earthquake" in

various languages to detect increases and identify the geographical origin of the eyewitnesses. Crowdsourced detections are independent of seismic data and generally occur within 15 to 90s of the earthquake occurrence. In this study we associate the crowdsourced detection to the seismic data, using the crowdsourced as initial location if a seismic event. In practice, automatic picks close in space and time to the crowdsourced detections are automatically selected, outliers are filtered out and a seismic location computed using Iloc software. The whole process takes a couple of seconds, allowing an improved delay of time for the event publication. The results of this approach applied on the GEOFON network will be presented in this study, to describe its methodology and illustrate its performances for local and large earthquakes.

ESC2018-S18-480

REAL-TIME PREDICTION OF GROUND SHAKING WITHOUT SOURCE PARAMETERS: TOWARD NEXT GENERATION OF EARTHQUAKE EARLY WARNING

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Earthquake Early Warning (EEW) is an alert of strong shaking before its arrival. Many of the present EEW systems quickly determine the hypocenter and magnitude (source parameters), and then predict strength of ground motions (Peak Ground Acceleration, Peak Ground Velocity, and/or Seismic Intensity) using ground motion prediction equations (GMPE). In this strategy, the source parameters are regarded as the causes of future strong shaking. EEW system of Japan Meteorological Agency (JMA) also had been based on the above source-parameters strategy. The 2011 Tohoku earthquake (Mw9.0), however, revealed some technical issues with such methods: under-prediction at large distances due to the large extent of the fault rupture, and over-prediction because the system was confused by multiple aftershocks that occurred simultaneously. To address these issues, we have proposed a new strategy for EEW (Hoshiba and Aoki, 2015, BSSA), in which the distribution of the present wavefield is estimated precisely in real time (real-time shake mapping) by applying a data assimilation technique, and then the future wavefield is predicted time-evolutionally by simulation of seismic wave propagation Here, we can directly monitor the propagation of ongoing ground shaking, and information on the hypocenter location and magnitude are not necessarily required. In this method, ground shaking itself is regarded as the cause of future ground shaking. We call this method, in which physical processes are simulated from the precisely estimated present condition, “numerical shake prediction” by analogy to “numerical weather prediction” in meteorology, in which present atmospheric condition (i.e., distribution of pressure, temperature, wind strength, wind direction and so on) are precisely estimated by data assimilation and then future is predicted from the time evolution of the atmosphere dynamics. In the presentation, I will show the performances of the numerical shake prediction applied to waveform data of M6 class crustal earthquakes, the 2016 Kumamoto earthquake (Mw 7.0), and the 2011 Tohoku earthquake (Mw9.0). GMPE usually leads the prediction of concentric distribution. However, actual ground shaking is not always concentric, even when site amplification is corrected. The strength of shaking may be much different among earthquakes even when their hypocentral distances and magnitudes are almost the same, as shown in examples of M 6 crustal earthquakes occurred at central Japan. For some cases, PGA differs more than 10 times, which leads to imprecise prediction in source parameter-based EEW. In numerical shake prediction method, because future is predicted from the present condition estimated by data assimilation technique, it is possible to address the issue of the non-concentric distribution. Once the heterogeneous distribution is actually monitored in ongoing wavefield, future distribution is predicted accordingly to be non-concentric. We will indicate examples of the M 6 crustal earthquakes occurred at central Japan. We will also show the case of the numerical shake prediction for the 2016 Kumamoto earthquake (Mw 7.0), during which M 6 class earthquake was remotely triggered apart from 70 km from the epicenter. Many authors estimated that rupture duration of the 2011 Tohoku earthquake (Mw9.0) was more than 130 s. The numerical shake prediction predicts well the ground shaking from the late rupture which caused the under-prediction in source parameter-based algorithm. A simplified version of the “numerical shake prediction” is called PLUM (Propagation of Local

Undamped Motion) method. In PLUM, strength of shaking at target station is predicted from real-time monitor of shakings at its neighbor stations assuming no attenuation of seismic wave propagation between the monitor stations and target station. Kodera et al. (2016, EPS) demonstrated that PLUM is capable of issuing warnings for destructive inland earthquakes more rapidly and precisely than the current JMA system. The PLUM method also leads to reduce the missed alarms because its prediction is based on monitor of actual ongoing shaking. JMA incorporated PLUM into its EEW system in March 2018 to address the under-prediction for large earthquakes with large fault rupture.

ESC2018-S18-507

REAL-TIME STRONG MOTION RESPONSE SPECTRA DETERMINATION IN SUPPORT OF RAPID DAMAGE ASSESSMENT FROM LARGE EARTHQUAKES

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We present the results of a seismic processing system that can produce near real-time traditional strong motion response spectra as an earthquake is occurring. The strong motion response spectra change in real-time as the seismic waveforms are acquired through a streaming implementation of the strong motion response spectra calculations. Alarm triggering algorithms can then be used, also in streaming implementations, to produce rapid determinations of likely structure shaking based on measured ground motion. We will show the results of such an alarm algorithm based upon specifications given by the United States Nuclear Regulatory Commission in which the measured response spectra are compared to structural design response spectra. We will demonstrate small processing latencies relative to the data availability. Such a system can be used to produce rapid damage assessment and should also be a valuable asset for earthquake early warning systems.

ESC2018-S18-587

MAGNITUDE SCALES, SOURCE PARAMETERS AND GROUND MOTION VARIABILITY IN CENTRAL ITALY

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We present the results of analysis on ground motion variability performed over 10 yrs of data in central Italy, including the 2009, Mw 6.3 L'Aquila earthquake and the 2016-17 sequence (Mw 6.2 Amatrice, Mw 6.1 Visso and Mw 6.5 Norcia earthquakes). We computed local, moment and energy magnitudes for about 1400 earthquakes in the range 2.5 <= Mw <= 6.5. A non-parametric spectral inversion technique is applied to isolate the source spectra from attenuation and site amplification effects. The source spectra are described in terms of Brune model and the stress drop is computed from the seismic moment and the corner frequency values. The stress drop varies over three orders of magnitude from about 0.1 to 10 MPa, the larger values associated to the mainshocks. The stress drop values describe a log-normal distribution with mean equal to 0.567 MPa, and with a 95% confidence spread from 0.079 to 4.789 MPa. The stress drop variability introduces a spread in the seismic energy versus moment distribution, with differences in energy up two orders of magnitudes for earthquakes with the same moment. The variability in the high frequency spectral levels is captured by the local magnitude which linearly scales with radiated energy. Since the peak ground velocity increases with increasing stress drop, local and energy magnitudes performs better than moment magnitude as predictors for the shaking potential. The availability of different magnitude scales and source parameters for a large earthquake population is used to characterize the between-event ground motion variability in central Italy. An ad-hoc Ground Motion Prediction Equation (GMPE) is developed in the Fourier domain and the overall residual distribution is partitioned into event, station and propagation components. The impact of using different magnitude scales for developing the GMPE is discussed in terms of reduction of the between-event variability. Non-stationarity in the between-event are discussed as well.

ESC2018-S18-789

NEW IMPLEMENTATION OF SHAKEMAP IN ITALY

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In Italy, INGV has been running Shakemap since 2006, to provide fast, quantitative description of earthquake ground shaking. The recent technological developments and research outcomes induce the need of revising Italian ShakeMap in terms of ground motion prediction equations (GMPEs) and site classifications, in order to improve the quality and overall accuracy of the ground shaking maps. The ground motion prediction equations are selected after statistical ranking of the most recent equations available in the literature. In particular, the GMPEs are used: i) Bindi et al (2011) for active shallow crustal regions and volcanic areas (depth greater than 5km); ii) Bindi et al.(2014) for events with focal depths greater than 35 km, occurring mainly in Northern Apennines; iii) Skarlatoudis et al (2013) for the subduction zone (inslab) in the southern Tyrrhenian sea and iv) Tusa and Langer (2016) for shallow volcanic areas (focal depth less than 5km). In the new release, we implement a new soil map developed using the topographic slope and the Italian geological map at 1:100,000 scale (ISPRA, http://www.isprambiente.gov.it/it/ispra), with an EC8 A-C classes mapped according to the different outcropping rock-types. In addition, the information on the soil condition of several recording sites has been updated in the past decade. We make several tests on the new and the old configuration for all the M >= 5.0 in the ShakeMap archive and, in particular, on the M6.5, October 30th, 2016 Norcia earthquake, finding an overall general improvement of accuracy in terms of ground shaking. Finally, a substantial improvement concerns the update of the M 4.5+ maps from the fully automatic, real-time data processing of strong motion data to the reviewed, quality checked data available at the Engineering Strong Motion database (ESM).

ESC2018-S18-830

TOWARDS EEW IN CENTRAL AMERICA

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Central America has a very high exposure to seismic risk. In particular, moderate on-shore and tsunamegenic off-shore seismicity can induce strong motions along the heavily populated Central American Pacific coast. Though improving the building stock is the best way to mitigate the earthquake hazard, earthquake early warning has the potential to provide some warning of impending strong motion, and can be part of wider program to reduce losses during future earthquakes. At minimum, accurate estimates of ground motions provided contemporaneously with shaking can also provide invaluable information to authorities and populations if cascading failures in communications and power occur. Following an initial feasibility study with INETER in Nicaragua, that included developing a prototype system which has been providing alerts to INETER since 2016, the SED is collaborating with monitoring agencies across the region to develop the capacity for EEW. Central America has is a long-standing tradition of sharing data and best practice across borders, and most networks already operate well-configured SeisComP3 automated processing systems. This means that it is relatively easy to setup demonstration systems using the Virtual Seismologist and Finite-Fault Rupture Detector algorithms that the SED has been developing over the last decade. Limited resources and challenging operational conditions mean that target alerts times under 10s that can be reached in other countries are currently not realistic in this region. However, for earthquakes occurring near the shore, alerts with accurate locations and magnitudes are routinely obtained within 20s of origin time, and this can be improved. In this presentation we present the project and describe how we propose to build EEW capacity. In particular, the seismic networks need to implement a medium term strategy that prioritises EEW – hardening infrastructure and reducing latency. Most importantly, densification of the network with appropriate strong motion sensors in key areas is required. Key features for new instrumentation are low cost and robustness. We will also show how we are testing candidate sensors, and estimating their EEW potential, in order to build thedensest effective EEW infrastructure with limited funding.

ESC2018-S18-846

SUFFICIENT AND EFFICIENT IMS FOR EARLY PREDICTION OF BUILDING DAMAGE FOR THE

ASSESSMENT OF THE IMPACT OF AN EARTHQUAKE

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In seismic vulnerability assessment methods, the vulnerability of a building class can be studied by assessing fragility curves. By relating a probability of damage to a ground motion intensity measure (IM), these curves account for variability due to the building model definition, the threshold damage parameter and the IMs, considered as being the engineering demand parameters providing the best representation of ground motion severity. The relation between building response and IM can be linked to the damage prediction when associated with damage state thresholds. For example, Hancock et al. (2008) proposed an equation relating earthquake parameters (magnitude, epicentral distance) and damage prediction. Luco (2002) defined two natures of IM: (1) an efficient IM defined as providing small variability of the conditional probability of damage (DM) given IM P(DM|IM); and (2) a sufficient IM defined as providing conditionally independent DM of the magnitude and distance. Coupled with real-time estimates of seismic ground motion, Krishnan et al. (2012) estimated damage for tall buildings present in a wide area by coupling ground motion predictions with a numerical analysis of building models. Most of these studies use numerical methods to model building response, and a "building-specific" prediction for a given scenario can provide accurate estimation of damage. Perrault and Guéguen (2015) assessed the correlation between efficient IMs according to the definition of Luco (2002) and building response using experimental data from a database of strong motions recorded in Californian buildings. From this database, the variability of building response is assessed through the normalized relative roof displacement (NRRD) and a combination of IMs is proposed as predictive equations of the expected response of building. These equations can be considered as a tentative of providing a building damage prediction equation (BDPE). In addition, it can be shown that also the process of earthquakes causing structural failure is a Poisson process. By this way, the Poisson process is a model with one parameter that is the failure probability only depending on the failure rate. It is usually computed via P [f | IM] a function providing the failure probability conditional to the values of IM, that is, the fragility of the structure. Uncertainty of estimation in fragility assessment may arise from structural modeling, that may expect to be reduced using experimental data. This is the main objective of this abstract that aims at combining BDPE and failure pobability for developing loss prediction model at the urban scale. Sufficient and efficient IMs for building damage prediction models will be tested and analysed for impact assessment.

ESC2018-S18-896

SYNERGY OF ACCELEROMETRIC NETWORKS TOWARD AN EFFECTIVE EARLY WARNING SYSTEM FOR THE CITY OF THESSALONIKI

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The PRESTo (PRobabilistic and Evolutionary early warning SysTem) software for Earthquake Early Warning (EEW) has been under real-time testing and continuous calibration/evaluation for the city of Thessaloniki during the last three years. We present initial results from the incorporation of two existing strong motion networks in the broader area of the city: the strong motion network of the Aristotle University of Thessaloniki, including the EUROSEISTEST array and the strong motion network of the National Observatory of Athens. The synergy of the two networks initiated in July 2015 and since then PRESTo software has detected tens of earthquakes of local magnitude above 2.0. We present statistics regarding the efficiency of the EEW system operation and more specifically on the timeliness of the issued warnings and the accuracy in earthquake location and magnitude determination for the period July 2015 to March 2018. Furthermore, we use recorded data to develop local empirical equations to replace PRESTO built-in empirical functions and further improve the effectiveness of the system. Improvement capability is demonstrated through playback applications of the EEW system, i.e. in pseudo-real-time. Our results show that the synergetic networks are capable of providing prompt information about

imminent strong ground shaking in the city of Thessaloniki from earthquakes in close-by significant seismogenic sources of Northern Greece.

ESC2018-S18-899

QUICK DETERMINATION OF THE FAULT MECHANISM FROM INITIAL P-WAVE AMPLITUDE DISTRIBUTION

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When an earthquake occurs, there are only few seconds between the rupture beginning and its devastating effect on population and buildings. Having a reliable image of the seismic source in real-time is crucial for producing realistic strong motion shake maps, which are the most valuable piece of information to provide to the end-users, for an efficient planning of emergency operations. The focal mechanism (together with the rupture extent) represents a key parameter for a correct prediction of the ground shaking at target sites, since the source radiation pattern and directivity modulate the amplitude and frequency content of the radiated seismic wave field as a function of the azimuth with respect to the propagating rupture on the fault plane. While different methodologies have been proposed for the real-time magnitude estimation in EEWS, the problem of the rapid determination of the focal mechanism still lacks of a unique and validated solution. Currently, the real-time automatic determination of the focal mechanism takes advantage of a grid of pre-computed solutions and is generally available within minutes after the earthquake detection and location. Here we develop a straightforward and robust methodology for the real-time determination of the focal mechanism using the azimuthal distribution of initial P-wave amplitude and a-priori constraints based on the local tectonic information. In our methodology, as soon as a few seconds of P-wave signals are available at a set of recording stations, we measure the initial P-wave peak amplitudes as the maximum absolute amplitude values of displacement, velocity and acceleration (Pd, Pv and Pa, respectively). The three parameters are estimated on the vertical component of the ground motion in progressively expanding P-wave time windows, starting from the arrival of the P-wave and stopping at the expected arrival of the S-waves. To account for the path attenuation effect, both Pd, Pv and Pa are corrected using precomputed, empirical scaling relationships, and then normalized to their maximum value. An empirical combination of the three parameters is then used to compare the observed amplitude distribution (as a function of azimuth and take-off angle) to the theoretical amplitude variation (i.e., theoretical P-wave amplitude radiation pattern), for a set of potential fault geometries. The comparison, through a dedicated algorithm, provides a first-order identification of the best solution for the fault mechanism (in terms of strike, dip and rake angles). We account for the available tectonic information through a specific prior distribution for strike, dip and rake angles and used a probabilistic, Bayesian, evolutionary approach, where the solution at each time step is used as a prior information for later times. At each iteration, the convergence of the solution is evaluated by comparing the current solution with the most likely triplet of the previous step and the convergence of the solution is declared if the solution does not show significant variations for a given time window. We apply the methodology to a large dataset of earthquakes, with magnitude ranging between 4 and about 7, to understand the potential limitations of the proposed approach. We explore the optimal combination of the P-wave peak amplitudes parameters (Pd, Pv, Pa) and investigate the use of different prior distribution to better constrain the fault geometry and rapidly determine the source focal mechanism.

ESC2018-S18-912

ARRAY-BASED EARTHQUAKE LOCATION FOR REGIONAL EARTHQUAKE EARLY WARNING: CASE STUDIES FROM THE DEAD SEA TRANSFORM

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Retrieving robust earthquake locations with as few stations as possible is crucial for earthquake early warning. A new realtime array-based location algorithm was developed that consists of two consecutive modules. The first is a single standalone array module that monitors waveform slowness and backazimuth in a continuous

manner, and identifies P and S phase arrivals. The second is a multi-array module that intersects multiple backazimuth estimates and surfaces of equal differential arrivals of the P-phase. Initial location estimates are issued either by the standalone module, after the S-phase arrival to the first array, or by the multiple arrays module after the P-phase arrives to a second array. Location estimates are subsequently updated with data made available by additional arrays. This approach is validated with a series of earthquakes recorded by small-aperture arrays deployed along the Dead Sea Transform. Use of realtime array methodology is particularly suited to environments with sparse network and/or unfavorable source-stations configurations.

ESC2018-S18-931

MODELIZATIONS AND ANALYSIS OF SENSITIVITY IN THE INTEGRAL EVALUATION OF THE SEISMIC RISK AT URBAN SCALE. APPLICATION TO THE CITY OF LORCA.

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This work presents a methodology for the comprehensive assessment of the seismic risk in an urban environment with a high degree of resolution. A logic tree is incorporated into the methodology for the consideration of different vulnerability distributions that are stochastically simulated by the Montecarlo method and different analysis procedures for damage estimation, in order to quantify the uncertainties inherent in these two aspects. The proposed methodology is applied to the urban center of Lorca, Spain. A seismic hazard assessment is carried out with a probabilistic-deterministic approach, by means of two methods: classic area source method (MCZ) and an hybrid method (MH) considering zones and faults. From this assessment, two seismic scenarios are identified: 1) an Mw 5.2 earthquake at a short distance for a return period of RP 475 years and 2) an Mw 6.3 earthquake at 15 km for RP of 975 years. The first scenario coincides with the characteristics of the main earthquake of the seismic serie of Lorca in 2011. There is a simulation for the damage scenario taking into account the location and the plane of rupture of the Alhama de Murcia fault that generated the earthquake. It also considers different ground motion prediction equations (GMPEs). The sensitivity of the different models and methods in the hazards assessment results is analyzed, identifying the ones that reproduce the best the accelerations recorded in the 2011 earthquake. A sensitivity analysis was also performed with different vulnerability distributions and Montecarlo simulations with samples of 100, 1000, 2000 and 3000 buildings, in orden to assess the effect of vulnerability distributions on the damage results. This method is applied to the specific case of Lorca, with the quantification of damage for the vulnerability assessment of a detailed building stock sample obtained in a field campaign and for the vulnerability assigned to the entire building stock of Lorca comparing the theoretical results with the observed damage after the earthquake. The proposed methodology of seismic risk assessment has allowed to reproduce with enough precision the scenario of real damages observed after the Lorca earthquake. The physical damage in buildings and the real and estimated costs present differences less than 5%.The models and results of the calibration with the scenario of the 2011 Lorca earthquake are used to simulate the second scenario, corresponding to an extreme earthquake Mw 6.5, with a 5% probability of exceedance in 50 years. These results can be useful for the definition of emergency plans in Lorca.

ESC2018-S18-988

INTEGRATION OF DAMAGE ASSESSMENT FOR CRITICAL INFRASTRUCTURE TO THE ISTANBUL EARTHQUAKE RAPID RESPONSE SYSTEM

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Istanbul Earthquake Rapid Response System-IERRS (Erdik et al., 2003) consists of more than 200 strong motion stations and is currently operational for the production of ground shaking and building damage distribution maps immediately after an earthquake. This is achieved with ELER (Earthquake Loss Estimation Routine)

software that is triggered by the exceedance of specified magnitude and distance threshold values. Recorded strong motion data are simultaneously processed to obtain peak ground motion values and spectral accelerations at certain periods. This information is then incorporated with ground motion predictive models as well as local soil information in order to estimate spatial distributions of the selected ground motion parameters (e.g. PGA, PGV, instrumental intensity, spectral accelerations). Spectral acceleration-displacement based damage assessment methodology is implemented for the computation of number of damaged buildings at different damage states. Extension of the IERRS to damage assessment in critical infrastructure is being planned with the integration of new software, ELER-Lifelines, which is a standalone application coded in Matlab with a modular structure. Real-time or scenario based damage estimation with ELER-Lifelines can be realized at network and component levels for four critical lifeline networks, namely Water, Electric Power, Gas and Oil transmission and distribution systems. Expected damage and losses can be calculated with alternative vulnerability models and the resulting risk maps are presented for the following system elements: Water Networks: Wells, Water Treatment Plants, Pumping Stations, Tanks and Pipelines; Electric Power Networks: Low-, Medium- and High-Voltage Substations, Distribution Poles and Lines; Gas and Oil Networks: Refineries, Processing Plants, Pumping Stations, Tank Farms and Pipelines. Real-time damage analyses for sanitary and waste water, electric power and natural gas networks in Istanbul will be conducted based on the specifications of the inventory data.

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SESSION 19

ESC2018-S19-35

A CELLULAR-AUTOMATA KINEMATIC MODEL OF EARTHQUAKE RUPTURE REPRODUCING KEY PROPERTIES OF HIGH-FREQUENCY SEISMIC WAVES, INCLUDING SECOND CORNER FREQUENCY AND FLAT ACCELERATION SPECTRUM

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It is a common idea that high-frequency radiation from an earthquake source is noise-like and incoherent. However, how such radiation is formed remains unclear. Earlier Gusev (2013, 2014) proposed that incoherence results from highly convoluted, "lacy" geometry of the rupture front. Here a kinematic model is developed to emulate formation of such a complex front. Fault surface is represented as a grid of cells. Rupture evolution is simulated as a sequence of failures of these cells. A cell is treated as simple automaton. Transitions between states of automata are controlled by neighbor cells. Excited by a neighbor, an “intact” cell switches to “failing” state. After certain delay DT=DT0+DT1, this state converts to the final “broken” state. DT0 is a time needed for an ideal crack to cross a cell. Additional delay DT1 varies from a cell to a cell; its value is real number (“asynchronous automaton”). As a whole, the set of DT1 values forms sample random 2D field on the fault surface, with given correlation function and given distribution law. This set is generated in advance, then front evolution unfolds deterministically. Conceptually, local value of DT1 reflects local effective strength of the fault: the larger is strength, the longer is delay. From a primer cell, rupture front spreads over the grid of cells. Depending on the choice of the set of parameters that control the generation of DT1 field, the instant geometry of the front can be made more or less “lacy”

ESC2018-S19-119

DETECTION OF HIGH STRESS ANOMALY CAUSED BY INTERACTION OF FAULTS

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Analysis of observations of the 2008-2014 seismic activity in West Bohemia, Czech Republic, provides evidence of interaction of compressive fault steps which induced an anomalously strong earthquake. The studied focal zone is formed by two parallel strike-slip faults with a step and overlap of about 200 m. The fault segments were activated successively by the 2008 and 2011 earthquake swarms with magnitudes of the strongest events of 3.8 and 3.7, respectively. The separate fault segments were linked during the 2014 mainshock-aftershock activity. The strongest earthquake with magnitude of 4.2 occurred on a new fracture formed between the existing parallel fault segments. It displayed a high stress drop and a reverse focal mechanism inconsistent with the regional background stress. Inversion of focal mechanisms for stress revealed a local stress anomaly characterized by interchanging the σ2 and σ3 principal stress axes in the area of the fault interaction. The modeling of the Coulomb stress change confirmed that the stress anomaly can significantly alter or even completely disturb the regional background stress. The results indicate that breaking a barrier between fault segments under compressive stress regime can be particularly dangerous because it might generate an earthquake stronger than the strongest earthquakes observed at the individual fault segments. This finding is scale invariant and should be valid even for large earthquakes.

ESC2018-S19-120

THE STRUCTURE OF THE MOMENT TENSOR

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In this study the form of the moment tensors are derived for different kind of sources such as shear and tensile sources in isotropic focal region and shear source in anisotropic focal region. These forms are obtained by considering the space of moment tensors as an image space of the elasticity tensor which is regarded as a linear transformation between the six-dimensional vector spaces of source tensors and the moment tensors. The elasticity tensor can be considered as a linear transformation only if the corresponding tensors are expressed in Kelvin notation which is a norm-preserving map between the space of symmetric second-rank tensors and the six-

dimensional vector space. This is similar to the approach of representing Hooke's law by using Kelvin notation. Then the advantages of linear algebra are used to study the invariants of the elasticity tensor e.g. the shear source tensor lies in one of the eigenspaces of an isotropic elasticity tensor. Similarly, for tensile sources the isotropic and deviatoric parts of the source tensors lies in two different eigenspaces of isotropic elasticity tensor. Hence by decomposing the elasticity tensor into its eigenvectors, the form of the moment tensor is obtained as a weighted sum of the deviatoric and the isotropic parts where weights corresponds to the values of the eigenvalues of elasticity tensor. Moreover the invariants of the tensile moment tensor, such as its eigenvalues and trace, are related with the scalar moment magnitude and the angle between the slip and normal vector of the fault. For shear sources occurring in anisotropic focal regions the form of the moment tensor and its invariants depend on the angle between the fault normal and the symmetry axes of the elasticity tensor. The eigendecomposition of elasticity tensor is used for determining the unit slip and the unit fault normal vectors from a given moment tensor.

ESC2018-S19-152

SOURCE PARAMETERS ESTIMATED FROM THE AFTERSHOCK SEQUENCES OBSERVED IN KRONOTSKY GULF AND GULF OF KAMCHATKA DURING 2010-2017

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Kamchatka is one of the most active seismic regions with strong to moderate earthquakes, rich in aftershocks or with a few of them. Those two scenarios can be characterized by the number of aftershocks N of the relative magnitude M-2 (where M is the magnitude of a mainshock). N presumably does not depend on M. During 2010-2016 there were 7 sequences observed in Kronotsky Gulf and Gulf of Kamchatka (53–56 N, 160–163 E). Mainshocks (subduction thrust faults) are of M6 (with Mw ~6–6.5), and N of M4 events varies from none (sequence of November, 2016) to ~15 (sequences of February, 2011 and November, 2013). All these earthquakes are well-recorded by at least three stations with hypocentral distances of 150–300 km. The modernized Kamchatka seismic network (D0 in FDSN), deployed in 2006–2010, also provides the coverage of broad frequency range, what allowed mass estimation of source spectra for moderate earthquakes and its parameters (seismic moment, corner frequency, stress drop). To recover source spectra, observed spectra were corrected for geometrical spreading (1/r), attenuation (Q(f) and kappa), changing seismic impedance, and site effects. Source parameters were estimated for ~150 earthquakes (M4–M6). The static stress drop was estimated from the flat level of the displacement spectrum (the seismic moment), using the standard ω^2 model. No clear indication to spectral stress drop dependence on seismic moment is found. Stress drop estimates for individual earthquakes range from about 0.5 to 70 MPa. The median value is 4 MPa, what is slightly higher than median value of 2.98 MPa obtained in [Allmann, Shearer, 2009] for subduction zone's regime globally. Also, preliminary, the tendency is observed that sequences of this area starting with stress drops values close to the median one (as in November, 2016) are characterized by less N parameter, while higher stress drops values of the mainshock (as in February, 2011) lead to higher N parameter. The study was supported by Russian Science Foundation (project 16-17-00093).

ESC2018-S19-165

EVALUATION OF EARTHQUAKE STRESS PARAMETERS AND ITS SCALING DURING THE 2016 AMATRICE SEQUENCE.

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The source parameter scaling of earthquakes is still a controversial issue in the scientific community as the evaluation of seismic source scaling in a region requires the comparison between low and high-frequency measurements. In fact, most of energy of an earthquake is concentrated around the corner frequency, typically near the low-frequency bandwidth limit for large events and near the high-frequency limit for small earthquakes. As various authors have

stated (e.g., Ide and Beroza, 2001; Abercrombie et al., 2017) this requires significant path and site corrections over a wide frequency range and corrections to account for radiation pattern and directivity. In this study we focused on the Amatrice sequence started with the August 24th, 2016 Mw=5.97 mainshock. We analyzed 83 events of the sequence from August 24th to October 16th 2016, within a radius of 20 km from the mainshock and with an Mw ranging between 5.97 and 2.72 to evaluate the apparent stress scaling in order to improve our knowledge of processes that control small and large earthquakes within this active region of Italy. Taking advantage of the averaging nature of coda waves, we analyze coda-envelope-based spectral ratios (Mayeda et al. 2007) using equations proposed by Walter et al. 2017 who consider stable, low-frequency and high frequency spectral ratio levels (LFL and HFL respectively) to evaluate corner frequency and apparent stress ratios of the events within the sequence. The methodology developed by Mayeda et al. 2007 combines the stability of seismic coda waves and the EGF approach to cancel out the average propagation and site effects. Furthermore, compared to traditional EGF methods this approach allows for the inclusion of more Green's function events, thereby providing redundancy and lower variance estimates. The technique developed by Walter et al. (2017) has the advantage of directly relate stable low and high frequency spectral ratio levels to the ratio of moments and stress parameters, respectively, avoiding the need to assume a particular model. Furthermore, the error on apparent stress estimates is proportional to the 3/2 HFL instead of the cube of the corner frequency which occurs when fitting spectral ratios derived from the Brune (1970) source model over the entire observed frequency range. Coda spectral ratios were computed for all pairs with three target events: the mainshock (Mw=5.97) and the two largest aftershocks (Mw=5.29 and 4.46). For these events we have independent seismic moments (from R.B. Herrmann's web page) that we used as constraints for the LFL evaluation, while the HFL is estimated through a best-fit analysis on the observed data. The two frequency levels allowed us to evaluate both the apparent stress ratio and the corner frequency ratio (Walter et al. 2017). Using the target event's absolute apparent stress as tie point, together with the apparent stress ratios, we could obtain the apparent stresses for all the EGF events. Our results demonstrate non-self-similar behavior within the sequence suggesting a change in dynamics between the largest events and the smaller aftershocks. The apparent stress and corner frequencies resulting from our analysis were compared to those obtained by Malagnini and Munafò (2018) showing good consistency. This strengthen the hypothesis of a non-self-similar behavior of the events within this sequence as two different and independent methodologies were applied. Furthermore, a comparison with some Central Apennines source scaling models derived for various seismic sequences (1997-1998 Colfiorito, 2002 San Giuliano di Puglia, 2009 L'Aquila), showed that the Amatrice sequence source scaling is well represented by the model described by Malagnini et al. (2008) for the Colfiorito sequence and by Pacor et al. (2016) for L'Aquila sequence. A different behavior was instead observed for San Giuliano di Puglia sequence (Malagnini and Mayeda, 2008). The departure from the self-similarity observed in this study is clear for seismic moments lower than 1016 N*m (~Mw=4.7), while the behavior for larger events is not well defined because of the small number of large earthquakes. The trend does not seem to increase monotonically but probably there is a break at some magnitude as the two largest events have the same apparent stress (2MPa). It is necessary to include the data of the whole Amatrice-Norcia-Visso sequence characterized by a larger number of strong events to better define this point.

ESC2018-S19-170

IMAGING OF THE 2016 KUMAMOTO EARTHQUAKE BY BACK-PROJECTION OF STRONG MOTION RECORDS.

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The sequence of the earthquakes that occurred before and after the 2016 Kumamoto earthquake (hereafter, the Kumamoto earthquake) began with the M6.5 event on April 14 (foreshock) and the M7.3 event occurred on April 16 (mainshock). These two events caused strong ground shake with Japan Meteorological Agency Seismic Intensity Scale 7 and this became the first case in

which seismic intensity 7 was observed twice in a single earthquake sequence of Japan. In addition to the foreshock and the mainshock, strong ground motion with seismic intensity 6 lower and 6 upper were recorded three times and twice, respectively. The Kumamoto earthquake is also featured by its very active aftershock activities and number of aftershocks is the largest among the recent domestic inland earthquakes. The series of strong ground shaking severely devastated and damaged the area around the Futagawa and Hinagu faults. More than 200 people were directly and indirectly killed by the sequence of the Kumamoto earthquake. The mainshock was caused by the activity of two faults, the Hinagu and the Futagawa faults. About the mainshock, many studies and surveys such as field investigations, aftershock location, seismic waveform inversion, and geodetic data inversion have already been executed. Their results have revealed that the rupture started at the Hinagu fault and proceeded toward the Futagawa fault where their strikes and dips are different. As for the fault mechanism, the results of centroid moment tensor inversion say that dextral strike slip component is dominant and normal fault component is also contained. Waveform inversion results report the main rupture occurred on the Futagawa fault and field observations detected the coseismic surface rupture of around 40 km long and the maximum displacement of 2 m along the fault. Several waveform inversions were also performed and revealed the spatio-temporal slip distribution that varies dependent on the depth. Back-projection results also show complex rupture process, e.g. an abrupt acceleration of rupture velocity during the mainshock. Although such rupture heterogeneities strongly affect the ground motion, they have not been completely taken into account in the current framework of strong ground motion prediction. Slip velocity function and rupture velocity variable on fault planes are expected to be take into consideration in the future strong ground motion evaluation. Actually, some attempts to incorporate aforementioned heterogeneity in fault models for ground motion prediction are under way in the world. Hence, accumulation of information on actual fault rupture process is essential to constitute a heterogeneous source model. In this study, we applied back-projection technique to investigate the rupture history of the Kumamoto earthquake through spatio-temporal distribution of seismic wave radiation. In our analysis, strong motion records recorded at KiK-net underground stations were used. Waveforms were rotated according to seismometer orientation and offsets were removed. The fault plane was determined from distribution of aftershocks although no assumption for fault plane is necessary in back-projection method. We made a fault model comprised of two fault planes, the Hinagu fault and the Futagawa faults, and set their geometries so that they fit the aftershock distribution. The back-projection technique used in this study is similar to that by Kao and Shan (2004), and Ishii et al. (2005). Waveforms were stacked considering radiation coefficients for each pair of station and grid on the fault plane with using Hann window and N-th root stacking. Then the stacked waveforms were squared into seismic wave radiation strength. Traveltime data were processed in the similar way as Takenaka and Yamamoto (2004) to obtain seismic emission image with more precision in relative location. As a result of the back-projection, two ruptures, one propagated toward the southwest and the other propagated toward the northeast, were imaged. The rupture that headed for the northeast reached the Futagawa fault at the deeper part about 2.6 seconds after the rupture initiation and then propagated to the shallow portion of the fault. This agrees well with the rupture history got by waveform inversions. We also found the rupture speed did not exceed the shear wave velocity for 3.4s after the rupture nucleation. Acknowledgement: We would like to express our gratitude to NIED for providing us with KiK-net data.

ESC2018-S19-183

CHARACTERIZATION OF THE SPATIO-TEMPORAL DISTRIBUTION OF SEISMIC CLUSTERS IN CENTRAL CHILE.

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Central Chile has been characterized in the last decades by a persistent presence of localized clusters. Know episodes of cluster seismicity has occurred in form of seismic swarms and acted as precursors of large earthquakes, while in other cases they did not evolve into major seismic

activity. Localized seismicity along a subduction margin may reveal regions of aseismic slip. We identify two clusters of seismicity in Central Chile, at latitudes comprised between 33°S and 36°S. The clusters are spatially localized at the NE an SW termination of the 2010 Pichilemu earthquake rupture. The Northern cluster is located offshore the town of Navidad, approximately at 34°S and 72.4°W, while the second one is located onshore and at larger depth, approximately at 34.8°S and 71.8°W. In this study we characterize the cluster seismicity by means of hypocentral location, spatio-temporal evolution, magnitude distribution, inter-event times moment tensor inversion and waveforms cross-correlation. Thanks to the densified seismic network following the 2010 Maule earthquake, we could detect repeated seismic swarm episodes in the area offshore Navidad and found steady seismicity activity with earthquake repeaters in the second cluster. Both clusters are occur close to the subduction interface and are characterized by NS striking, low dip angle thrust mechanisms, compatible with mechanism expected at the Chilean plate interface. They happen to occur in zones of lower coupling, when compared to the overall coupling in Central Chile. The spatial distribution of the Navidad cluster is elongated in the EW direction; however, it remains so far unclear whether this geometry reveals structures observed in the Nazca plate, or whether it is due to location uncertainties for offshore seismicity. Cluster activity along subduction margins have been interpreted as indicators for aseismic slip, where the swarms occur in correspondence to localized roughnesses of the plate interface. Under such hypothesis, the low coupling Navidad swarm region and the Pichilemu cluster region, could act as barriers for the rupture propagation of large events.

ESC2018-S19-196

MASSIVE REGIONAL MOMENT TENSOR INVERSION REVEALS THE SEGMENTATION OF THE NORTHERN CHILE SUBDUCTION

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Northern Chile is characterized by an intense seismic activity, driven by the subduction of the oceanic Nazca plate beneath the Western margin of the Southamerican plate, with occurrence of large intraplate megathrust earthquakes in the past centuries. The so-called Northern Chile seismic gap, lasting since the 1877 M 8–8.8 earthquake, was partially broken by the Mw 8.2 Iquique earthquakes in April 2014. Hundreds of events with magnitude above Ml 3.5 are recorded yearly. Beside seismicity at the shallow section of the slab, intermediate and deep focus seismicity is also present. Shallow seismicity is also observed inland, both associated to tectonic activation of shallow faults, as well as induced by mining operations. Seismicity in Northern Chile can be nowadays investigated with unprecedent resolution, thanks to the outstanding seismic monitoring network of the Integrated Plate boundary Observatory (http://www.ipoc-network.org). In past years, seismic analysis have been performed for specific events or seismic sequences, neglecting periods between major earthquakes, seismicity occurring at some distance or larger depth from their rupture areas and moderate earthquakes. As a consequence, a broad view on the regional seismicity is still missing and hinders our understanding of seismic processes in this region. This work aims to fill this gap, by applying waveform based moment tensor inversion techniques to characterize the spatially distributed seismic activity. Taking advantage by the dense seismic network and automatized waveform based inversion tool, we can decrease the minimum magnitude of target seismicity and increase the size of our earthquake dataset. We focus on a region comprised between latitude 18°S and 25°S and longitude 67°W and 72°W, with focal depths down to 300 km. A regional centroid moment tensor inversion procedure is tested and run for earthquakes in the time period 2004-2017 down to magnitude Ml 3.5 (shallow earthquakes) or 4.5 (intermediate and deep earthquakes). Good quality moment tensor solutions are obtained for more than 1500 earthquakes, proofing the potential for an automated moment tensor inversion routine in Northern Chile. A clustering algorithm is used to classify moment tensors, detect the presence of spatial and temporal clusters, and characterize the most prominent and active seismogenic structures. Both the spatial clustering of seismicity, the cumulative moment release as well as the analysis of moment tensors reveal anomalies in the slab geometry along the margin as well as across different depths.

ESC2018-S19-215

EFFECTS OF EARTHQUAKE DATA-CLUSTERIZATION ON STRESS INVERSIONS

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One criterion of stress inversions is a homogeneous distribution of used focal mechanism solutions within the studied areas. Having a large number of earthquakes, the authors used and developed automatized clusterization algortihms and then analysed the reliability of stress inversions calculated for these groups. Clusters of earthquakes have been created based on their epicenters' longitude and latitude. The following methods have been applied: (a) k-means algorithm, (b) automatized, nearest neighbor – classification and (c) manual grouping based on the map of used focal mechanisms. Clusterizations were followed by authors a linear, iterative inversion method that takes the faults instability into account using the Mohr-Coulomb law. The estimations have been carried out in MATLAB environment (using the code STRESSINVERSE). Earthquake focal mechanism data were gathered from the Vrancea region located in the Southeastern Carpathian Bends. The altogether 80 focal mechanism solutions presented here generally indicate the presence of thrust faults.

ESC2018-S19-244

AUTOMATED STATION QUALITY CONTROL OF THE ALPARRAY NETWORK WITH REGARD TO AUTOMATED MOMENT TENSOR INVERSION

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With its dense seismological network of more than 600 broadband stations, the European AlpArray initiative provides excellent opportunities to perform research related to regional seismicity patterns and source processes. Within the scope of the AlpArray subproject "From Top to Bottom – Seismicity, Motion Patterns & Stress Distribution in the Alpine Crust" we investigate the geodynamic processes controlling the multi-scale seismicity of the Alps, which is predominantly characterized by weak to moderate magnitudes. Thanks to the outstanding network density and adoption of modern inversion tools we aim to lower the magnitude threshold for automatized moment tensor inversion and provide new information on seismic source processes and stress distribution in the Alps. While the large number of stations within the AlpArray enables detailed studies over a broad region, quality control for such a dataset remains a major challenge. In order to perform automated studies of source processes stations with erroneous transfer functions, gain factors or component orientations need to be identified in advance. Here, besides presenting the state of the art with respect to seismic source results, we want to introduce a new tool dedicated to automated station quality control: the AutoStatsQ toolbox (https://github.com/gesape/AutoStatsQ) is a python based toolbox, using the pyrocko environment for seismological data processing (Heimann et al., 2017). Requiring only a list of stations, the toolbox performs several tests using automatically downloaded data and metadata for teleseismic events with a uniform azimuthal coverage in a chosen time range. (a) Relative gain factors are calculated for all stations and events in time domain based on maximum P phase amplitudes. (b) In frequency domain, the amplitude spectra of all stations in a desired frequency range are compared among each other and to synthetic data. (c) A Rayleigh wave polarization analysis is performed to identify deviations of sensor orientations. The results of all steps are provided both as text files and figures that are straightforward to interpret. Given that only little input is needed and due to the flexible and fully automated workflow, the AutoStatsQ toolbox can easily be used for the evaluation of metadata and data quality of seismic arrays or networks. It can perform tests on hundreds of stations at once. In case of the AlpArray, several stations with significantly deviating gain factors were identified as well as stations with erroneous transfer functions at very low frequencies. The results are used to inform the network operators and to estimate correct gain factors for moment tensor inversion. We demonstrate for selected case studies how the automated station quality assessment substantially improves moment tensor inversion results. Heimann et al. (2017): Pyrocko - An open-source seismology toolbox and

library. V. 0.3. GFZ Data Services. http://doi.org/10.5880/GFZ.2.1.2017.001

ESC2018-S19-290

SOURCE CHARACTERISTICS OF THE CRUSTAL MODERATE EARTHQUAKES OCCURRED IN THE LAST 30 YEARS IN THE CARPATHIANS AREA, ROMANIA

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During the last 30 years crustal seismic activity in Romania has concentrated along the Carpathians orogeny and in the adjacent areas. A significant activity is observed close to the epicentral area of the Vrancea subcrustal earthquakes that can be interpreted as a consequence of the strain field originated in the mantle, beneath the South-Eastern Carpathians Arc bend. Here several earthquake-prone zones are defined, both overlapping the epicentral area of the Vrancea subcrustal earthquakes and following the tectonic contacts between the platforms in the foreland and Carpathians orogen. Frequently, the seismic energy is released in sequences, either as foreshock – main shock – aftershocks, or seismic swarms. The largest event recorded within the considered time interval (Mw 5.7) occurred on 22 November 2014 in the Carpathians foredeep area (close to Marasesti city), at the bottom of the crust (h = 40 km) followed by a significant increase of seismicity over the entire area lying in front of the Vrancea region. Significant sequences were recorded also in the South Carpathians in the eastern and western sides. The source parameters are evaluated using relative deconvolution techniques (empirical Green's functions and spectral ratios) and spectral source analysis. To identify appropriate pairs of main events and associated empirical Green's function events we used cross-correlation analysis. The hypocenters distribution and the available fault-plane solutions were interpreted in connection with the active faults as geotectonically defined. The results were integrated in a unified database which provided systematic investigations of source scaling properties in correlation with seismotectonics characteristics in the study region. Key words: crustal moderate earthquakes, source characteristics.

ESC2018-S19-394

CLASSIFICATION OF FOCAL MECHANISMS AND MOMENT TENSORS OF MICRO-EARTHQUAKES OCCURRING IN 2008-2014 IN WEST BOHEMIA, CZECH REPUBLIC

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We develop and test a new hybrid approach of the amplitude and waveform moment tensor inversions, which utilizes the principal component analysis of seismograms. The proposed inversion is less sensitive to noise in data, being thus more accurate and more robust than the amplitude inversion. It also suppresses other unmodeled phenomena, like a directivity of the source, errors caused by local site effects at individual stations, and by time shifts in arrivals of observed and synthetic signals due to an inaccurate velocity model. This inversion is computationally less demanding than the full waveform inversion and thus applicable to large sets of earthquakes. The approach is numerically tested on synthetic data with various station configurations and levels of noise. The applicability of the inversion is demonstrated on inverting several thousands of micro-earthquakes that occurred in the time period of 2008-2014 in the West Bohemia seismoactive area, Czech Republic. The area is characteristic for the occurrence of earthquakes swarms. The earthquake swarms are monitored by seismic network WEBNET which consist of 22 local stations (13 online and 9 offline) with a sampling frequency of 250 Hz. We processed about 3000 events of the 2008 swarm (maximum magnitude was ML=3.8), 2000 events of the 2011 swarm (maximum magnitude was ML=3.0) and about 800 of the seismic activity in 2014 (maximum magnitude was ML=4.2). The magnitude of all analyzed events was above 0.5. It is shown that the developed method working in a semi-automatic regime yields very accurate results, which are comparable or even better than those obtained by the inversion of P-wave

amplitudes picked manually. Applying a cluster analysis to retrieved moment tensors, we identify several distinct clusters in each earthquake swarm. We present a systematic classification of the moment tensors and of the focal mechanisms and discuss mutual differences between individual earthquake swarms.

ESC2018-S19-396

AUTOMATIC EVENT LOCATION METHOD BASED ON THE PRINCIPAL COMPONENT ANALYSIS

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Automatic event locations are essential for an effective processing of a large amount of continuous data produced by seismic monitoring networks. Currently used methods for automatic location use two different approaches. The first one is based on searching the phase onsets, association of phases and solving the inverse problem for location having the onset times. The second approach makes use of the coherence of backpropagated waveforms, which leads to a computationally demanding grid search through a set of testing hypocenters in a sufficiently fine grid. We propose a modified approach which is faster and more effective, in which the computational load of the method is significantly reduced by introducing a hierarchical two-step search. In the first step, the raw waveforms are backpropagated for testing hypocenters in a sparse grid. In the second step, we apply the Principal Component Analysis and cross-correlations of waveforms for determining additional fine time offsets between the observed waveforms and the waveforms predicted for the tested hypocenter. The residuals are used to find an optimum location in a fine grid of pre-calculated travel times. We apply the method to data observed in the West Bohemia/Vogtland earthquake swarm area, Czech Republic. The main focal zone is about 8 km long in depths between 6 and 10 km. The background seismicity and less prominent earthquake swarms cover, however, a broader area having a size of 20x30km. The swarms last typically from several days to several months and comprise thousands of earthquakes with magnitudes up to ML=4.5. The activity is continuously monitored by local seismic network WEBNET consisting of 23 stations with a sampling frequency of 250 Hz. The efficiency and accuracy of the proposed algorithm is checked by comparing automatic locations with locations of the WEBNET catalogue obtained by manual picking of events with magnitudes down to ML=0. The tests show that the automatic and manual locations have a similar accuracy and a comparable magnitude of completeness.

ESC2018-S19-411

THE ALLAND EARTHQUAKE SERIES: LOCATION, SOURCE MECHANISM AND IMPLICATIONS FOR THE REGIONAL STRESS REGIME

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The Vienna Basin is one of the seismically most active regions in Austria. Because of population density and sensitive infrastructure, seismic hazard assessment in the area is of critical importance. In probabilistic seismic hazard assessments, the region is classified with low to moderate seismic hazard and the maximum credible magnitude was estimated to be around 6. Paleoseismological studies suggest that the region may have suffered earthquakes of magnitude ~7 in pre-historical times. In 2015, an earthquake occurred ~20km west of Vienna (ML 4.2), near the town of Alland, in an area that has been relatively quiet seismically throughout the last centuries. According to the Austrian Earthquake Catalogue, there have only been 14 earthquakes within a radius of 15 km around the epicentre since 1200 before this event. Of the 11 instrumentally-recorded events, none have exceeded magnitude 2.5. While the economic impact of the Alland earthquake was small, it is a notable event in the regional context, due to its larger magnitude, and to its probable thrust-faulting type. It may thus shed light on the tectonic regime in the area, e.g. on the question which faults are active at present. Thrust faulting has been a prime feature throughout the Alpine orogeny, but so far it has seemed to not leave a strong mark in instrumental seismicity and ongoing deformation in the Alps. In this study, we present main- and aftershock

locations, the source mechanism of the main-shock from moment-tensor inversion, and to which degree it aligns with known geological features in the area. We will also discuss the implications for stress field and regional tectonics, and briefly touch the assessment of the regional seismic hazard.

ESC2018-S19-420

DYNAMIC SOURCE INVERSION FOR PHYSICAL PARAMETERS CONTROLLING THE 2017 LESVOS EARTHQUAKE

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We perform a Bayesian dynamic finite-extent source inversion to constrain the physical parameters and stress conditions that governed the Mw 6.3 2017 Lesvos earthquake. The mainshock occurred on 12 June, offshore the south-eastern coast of the Greek island of Lesvos in the north Aegean Sea. It caused 1 fatality, 10 injuries and extensive damage to the south-eastern part of the island. The location of the event is separated from the nearest plate boundary by several hundred kilometres, so it is classified as an intraplate event. Stress state in the area is characterized as transtensional, with minimum principal stress axis σ3 oriented in an almost north-south direction. The earthquake likely ruptured the eastern segment of the Lesvos Basin fault, oriented perpendicular to σ3 and dipping to the south-west at 42° with normal faulting mechanism (Kiratzi, 2018). We start with centroid moment tensor inversion, obtaining the south-west dipping nodal plane compatible with the hypocentre location. Considering this plane as the fault plane, we perform the dynamic finite-extent source inversion based on the elliptical asperity model (Twardzik & Madariaga, 2014). The forward problem (dynamic rupture simulation) is solved by a 3D fourth-order staggered-grid finite-difference method in a box assuming linear slip-weakening friction law on a planar fault (Madariaga et al., 1998). Coupling the obtained rupture evolution with Green's functions pre-calculated with the code AXITRA allows us to evaluate the misfit between synthetic and observed waveforms on 19 stations with fault distances of up to 100 km. The inverse problem is solved using the Parallel Tempering Monte Carlo algorithm (Sambridge, 2013), which samples the posterior probability density function of model parameters that determine frictional and stress conditions on the fault. This way we obtain not only the model that provides the best fit with the observed seismograms, but we also gain information about the uncertainty, stability and correlation of the inverted dynamic and kinematic source parameters.

ESC2018-S19-425

SEISMIC SOURCE PARAMETERS AND STRESS TENSOR IN THE MEDEA REGION (NORTH-CENTRAL ALGERIA)

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North of Algeria belong to the African plate which is collision with Eurasian plate. The shortening rate is about 5 mm/year. This collision is responsible of events (large and moderate) that occur in the offshore domain, Tell Atlas, High plateaus and Saharan Atlas on the northern part of Algeria. Since 1365 many historical events were reported by various authors, like the Algiers event on 1365 with Io=X and Oran event on 1790, Io=X. During the instrumental era, on 1980, a strong earthquake hit the El Asnam region on October, 10th , with Ms = 7.3, it was the strongest event recorded in the western part of the Mediterranean sea, a second strong event hit the north of Algeria in the cities of Boumerdes-Zemmouri on 21 May, 2003 with Mw=6.8. After these two events the CRAAG, install a broad band seismic network. The records of this network permit us to compute seismic source parameters of moderate earthquakes which occur in Algeria. In this work, we interested to two seismic sequences recorded in the Medea region (north-central of Algeria). We calculate seismic source of three moderate events using near-field waveform modeling. For the seismic sequence which occurred on May and August 2007, the calculated moment magnitude were 4.2, 3.9 and 4.6 with focal mechanisms oriented [strike, Dip, Rake : 155, 85, -160]; [Strike, Dip, Rake : 15, 65, -18], and

[Strike, Dip, rake: 310, 85, -164] respectively. The second seismic sequence occurred on 2014 and 2016. The moment magnitude of the most important events were 5.0 and 5.6 with focal mechanisms oriented [Strike, Dip, Rake: 175, 70,-4],[Strike, Dip, Rake: 60, 60,135] respectively. We calculate also the stress tensor in the region, and we find a maximum compressive stress tensor horizontal and oriented NW-SE.

ESC2018-S19-457

EARTHQUAKE SOURCE SPECTRUM HAS TWO CORNERS AND AN INTERMEDIATE SLOPE

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Using random vibration theory, we show that a double-corner source spectrum can reproduce the peak ground acceleration (PGA) and peak ground velocity (PGV) of the NGA West-2 data set for 5.3 ≤ MW ≤7.7. In an earlier paper–Archuleta and Ji, GRL 2016–we found an apparent moment rate function for MW ≤ 5.3 that reproduced PGA, PGV and PWA (peak Wood Anderson displacement). This apparent moment rate also had two-corner spectrum. For magnitudes less and greater than 5.3, the two corners scale with magnitude; however, the scaling is different for magnitudes above and below 5.3. Here we focus our analysis and conclusions for MW ≥ 5.3. The two corners fc1 and fc2 scale as Log(fc1) = 1.754 – 0.5MandLog(fc2) = 3.250 – 0.5M. Both corners are proportional to 0.5M_W indicating self-similar scaling with seismic moment. The lower corner fc1is within 18% of the corner one would observe from the global CMT catalog, i.e., it's inverse 1/πfc1 corresponds to the duration of earthquakes found worldwide. Thus, the lower corner would be consistent with the average stress drop found for global earthquakes. Between fc1 and fc2he acceleration spectrum is proportional tof. The acceleration spectral level at frequencies greater than fc2 is consistent with PGA and PGV for earthquakes in the NGA West-2 data. This high-frequency spectral level is proportional to the stress parameter used in time domain stochastic predictions of PGA and PGV. It is of interest to note that the predicted radiated energy and the apparent stress agree with global estimates of these parameters for the same magnitude range.

ESC2018-S19-459

A PROBABILISTIC MOMENT TENSOR ESTIMATION WITH HIGHLY FLEXIBLE SEARCH ALGORITHM

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We present a full-waveform probabilistic optimization method for moment tensor inversion (implemented as open source code in the seismic source optimization framework Grond, http://gitext.gfz-potsdam.de/heimann/grond/). The optimization algorithm is a Monte Carlo directed global search approach, with the non-standard ability to simultaneously and efficiently optimize an ensemble of perturbed objective functions. Perturbations are generated employing a Bayesian bootstrap methodology. Therefore, parameter trade-offs, uncertainties, and ambiguities on the retrieved results can be analysed. One point in parameter space defines one potential source model (including mechanism, location and origin time). During the optimization, iteratively new candidate models are generated and evaluated according to a flexible, user-specified schedule. For each new model, the objective functions are evaluated, leading to N misfit values, one for each bootstrap entity. The L1 norm is used to measure the mismatch between observation and modelled seismograms. The weighted misfit contributions from all station and phase observations are combined into a global misfit value and are normalized for convenience. For each bootstrap entity, a fixed size set of K best performing models is maintained ("high score list" and "high score populations"). The algorithm is capable of tracking multiple or irregularly shaped minima. Synthetic waveforms are modelled based on pre-calculated Green's functions (e.g. fomosto toolbox, https://github.com/pyrocko/fomosto-qseis/) and kept in a Pyrocko-GF store (http://doi.org/10.5880/GFZ.2.1.2017.001) for efficient use during the inversion. The algorithm is flexible in terms of input data; an arbitrary set of data fitting targets can be used, employing time traces, amplitude spectra, cross-correlation traces, envelopes, absolute amplitudes and P/S

ratios. Full waveforms or windowed body wave phases are automatically or manually selected and compared with modelled seismograms. Different filter and weights are associated to different targets. A host of quality checks is implemented to analyse data and metadata quality (e.g. station orientation, transfer functions) before performing the inversion and channels can be blacklisted for the inversion. Pre-processing of the data (azimuthal correction, restitution, timing correction, filtering, windowing) is automated; data and instrument responses can be downloaded from FDSN web services. We demonstrate the usage of the algorithm and the interpretation of trade-offs by means of different case studies, including shallow induced micro-earthquakes in soft sediments (Groningen, The Netherlands), deep micro-earthquakes close to the crust-mantle boundary (Leipzig, Germany) and superficial nuclear explosions in North Korea.

ESC2018-S19-473

TECTONIC STRESS REGIME IN THE 2003-2004 AND 2012-2015 EARTHQUAKE SWARMS IN THE UBAYE VALLEY, FRENCH ALPS

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We studied two earthquake swarms that occurred in the Ubaye Valley, French Alps within the last decade: the 2003-2004 earthquake swarm with the strongest shock of magnitude ML=2.7, and the 2012-2015 earthquake swarm with the strongest shock of magnitude ML=4.3. The 2003-2004 seismic activity clustered along a 9 km long rupture zone at depth between 3 and 8 km. The 2012-2015 activity occurred a few kilometers to the northwest from the previous one. We applied the iterative joint inversion for stress and fault orientations to 74 events of the swarm 2003-2004 and to 13 strongest events of the swarm 2012-2015. The stress regime is consistent for both seismic activities. The σ3 axis is nearly horizontal with azimuth of 103°. The σ1 and σ2 principal axes are inclined and their stress magnitudes are similar. The major active fault is well oriented for shearing with respect to tectonic stress and significantly differs from faults geologically mapped in the region. The estimated low value of coefficient of static friction 0.2-0.3 supports an idea of seismic activity triggered or strongly affected by presence of fluids.

ESC2018-S19-487

RUPTURE PROPAGATION OF THE MW 6.5 2016 CENTRAL ITALY EARTHQUAKE INFERRED FROM STRONG MOTION DATA AND REGIONAL SEISMIC ARRAYS

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We analyze the rupture process of the October 30th 2016 Norcia earthquake (Mw=6.5), the largest event of the 2016 Central Apennines seismic sequence. First we perform an inversion of strong motion data (in the frequency range 0.2 – 1 Hz) to retrieve the space-time evolution of the slip over the fault plane. The dataset consists of several hundreds of earthquakes recorded at 15 3-component near-field strong motion stations. The originality of the proposed approach is that the Green's functions are not estimated numerically.

ESC2018-S19-491

FITTING WAVEFORM ENVELOPES TO DERIVE FOCAL MECHANISMS OF MODERATE EARTHQUAKES

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Moment tensor determination of small-magnitude events is becoming increasingly important as a source of information on the stress field, the seismogenic potential of faults, the hydrocarbon exploitation etc. Nevertheless, at least for sparse seismic networks this is still a challenging task, since relatively distant stations must be used. Waveform modeling in this case is difficult due to imprecision of seismic-velocity models, restricting their use to lower frequencies only, which however are contaminated by noise. The problem can be solved by inverting focal mechanisms simultaneously with time shifts or by including the timing and amplitude corrections from calibration events (CAP method, Tan and Helmberger, 2007). Alternatively, data are inverted first into ad-hoc velocity models and then

waveforms are inverted with the path-specific models (Dias et al., 2016). Recently, using Bayesian approach, assumed uncertainties of velocity models have been projected into uncertainties of the focal mechanisms (Halló and Gallovic, 2016 To overcome such drawbacks, waveforms should be substituted by a robust characteristic of the seismic record, which still carries information about focal mechanism and moment magnitude. We propose to use the inversion of waveform envelope shapes, and have implemented the method in the widely used source inversion software ISOLA. The method is designed to calculate a point-source pure double-couple (DC) representation of the source. Waveforms are instrument corrected to velocity, filtered using a band-pass causal Butterworth filter and integrated to displacement. Real-data envelopes are calculated using the Hilbert transform. Green's functions are calculated in a 1D velocity model, using the discrete wavenumber method and are convolved with five elementary DC moment tensors, thus producing elementary seismograms. Real envelopes are inverted into the strike/dip/rake (s/d/r) angles by a grid search. Synthetic seismogram for any assumed s/d/r combination is calculated as a linear combination of the elementary seismograms. The envelopes of synthetic seismograms are calculated in the same way as the envelopes of real waveforms, using the same frequency band. The s/d/r search can be done in two ways, i.e. either in a non-constrained mode, where the whole s/d/r parameter space is searched, or in a pre-constrained mode. In the (considerably faster) pre-constrained method, the code visits only the s/d/r combinations previously checked for agreement with polarities (CSPS method, Fojtíková and Zahradník, 2014). In the non-constrained mode, the resulting focal mechanism must go through a posterior polarity check with at least one polarity, because envelopes do not resolve the 180° ambiguity of rake. The grid search minimizes global misfit between real and synthetic envelope shapes, using the L2 norm and user-specified weights. The misfit is calculated for the real and synthetic data optimally cross-correlated at every s/d/r. Seismic moment and moment magnitude are calculated for the best-fitting solution, and synthetic envelopes are then plotted together with the real ones. Uncertainty of the solution is presented as an ensemble of nodal lines and P-T axes fitting data within a certain threshold. We present three real-data examples that demonstrate the performance of the method, using earthquakes in various ranges of epicentral distance and frequency. In the examples, the focal mechanisms of the sample earthquakes are known from the near-source stations, and we try to obtain the focal mechanism from the distant stations. The waveform inversion fails, but a correct estimate of the solution is found using envelopes. Moreover, the envelope method does not suffer from instrumental problems, such as, e.g., flipped channel sign, errors in gain, or timing. This method may be of interest to seismologists who need to compute focal mechanisms for stress-field studies in sparse networks, where traditional waveform inversion and amplitude inversion methods often fail.

ESC2018-S19-500

STRESS PARAMETERS OF REPEATING EARTHQUAKES IN THE NUCLEATION VOLUME OF THE APRIL 6, 2009, MW 6.1 L'AQUILA EARTHQUAKE

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We analyze the state of stress for 28 repeaters, foreshocks, mainshock and aftershocks, in the rupture nucleation volume of the destructive L'Aquila earthquake including the strongest Mw 4.1 foreshock occurred one week before the main shock. In a previous paper, earthquakes clustered in this crustal volume were used to detect a transient anomaly of shear wave velocity in the fault zone a ten of hours after the Mw 4.1 foreshock. The purpose of this study is to investigate whether stress parameters had concomitantly temporal or spatial variations. Brune stress drop was computed in a EGF-approach and apparent stress was derived from energy of seismograms. Estimates of individual stations and individual events showed large fluctuations, mostly due to rupture directivity and site effects. A procedure was adopted to decrease the estimate uncertainty obtaining a 39% of the total variance reduction. Brune stress drop and apparent stress showed similar trends implying stable values of radiation efficiency around 0.23, which is the value expected for self-similar ruptures. No evident temporal change emerges

from the analyzed stress parameters of repeaters. In contrast, the spatial pattern of Brune stress drop shows a correlation with the b-value obtained by Sugan et al., 2014 that evidenced an asperity characterized by a low b-value on and around the nucleation zone of the mainshock.

ESC2018-S19-573

SLIP DISTRIBUTION AND RESULTING SURFACE DEFORMATION ASSESSMENT OF STRONG EARTHQUAKES IN GREECE

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The temporal and spatial slip distribution assessment is a vital tool for seismologists and other geoscientists towards understanding the spatiotemporal evolution of the earthquake rupture. Such an evaluation requires data which are typically extracted after a large event, meaning the earthquake's source parameters, including focal mechanism, fault geometry and hypocentral relocation. The slip inversion method has application potential for shakemaps, emergency response and aftershock hazard assessment. The LinSlipInv software (Gallovic and Zahradnik, 2011; Gallovic et al., 2014) is implemented using local and regional data recorded by seismographs belonging to the Hellenic Unified Seismological Network (HUSN), as well as by the accelerometric network of the Geodynamic Institute of the National Observatory of Athens (GI-NOA). Selected strong earthquakes (with Mw greater than or equal to 6.0) that occurred during the last decade in various regions of the Hellenic territory are examined, such as the Lesvos 2017 (Kiratzi, 2018; Papadimitriou et al., 2018), Lefkada 2015 (Sokos et al., 2016; Papadimitriou et al., 2017) and Lemnos 2014 (Kiratzi et al., 2016) earthquakes. Towards the slip distribution determination, several values of rupture velocities, number of time windows and time lag values were examined. Via back-propagation (using seismic source time-reversal imaging), it is possible to refocus seismic waves (Ishii et al., 2005; Larmat et al., 2006). Starting from an initial source model, based on the moment tensor solution determined by the Seismological Laboratory of the National and Kapodistrian University of Athens, the back-propagation residual seismograms are measured to obtain subsequent models by iteration, using a conjugate gradients technique. The theoretical impulse responses are calculated in a layered crustal model using the discrete wavenumber method (Bouchon, 1981). Emphasis will be provided in the utilization of stations lying along the fault direction, aiming to better identify the source directivity. The slip distribution results are used as input to extrapolate ground deformation, even in cases where no surficial trace of the fault is observed. The obtained slip distribution and crustal deformation are compared with the ones determined by other studies, including INSAR and GPS.

Acknowledgements

We would like to thank the scientists and personnel who participated in the installation or maintenance of the stations belonging to the HUSN and the GI-NOA accelerometric network.

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ESC2018-S19-599

BAYESIAN SELF-ADAPTING FAULT SLIP INVERSION WITH GREEN FUNCTIONS UNCERTAINTY: DEMONSTRATION ON THE MW7 2016 KUMAMOTO, JAPAN, EARTHQUAKE

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Kinematic finite-extent source models of earthquakes are inferred by inverse modeling of observed seismic waveforms and/or geodetic data. The solutions are subject of significant uncertainty as a result of inaccurate observations and imperfect physical description of the complex properties of the Earth's crust (Mai et al., 2016). In the case of waveform-based earthquake source inversions the major source of uncertainty is related to the uncertainty of Green's functions (GFs) due to the inaccuracy of the crustal model considered. Recently, Bayesian inversions of fault slip inversions taking into account the GF uncertainty have been introduced by several studies (Kubo et al., 2016a; Minson et al., 2013; Duputel et al., 2014, 2015). In the Bayesian framework the prior probability distributions (i.e. assumed uncertainties of Earth's crust and the modeling method) can be conveniently expressed by statistical models, typically by Gaussian probability density function parameterized by mean values and covariance matrices. Resulting posterior probability distributions permit the inference of a maximum likelihood model and assessment of model parameters' uncertainties. We have developed a novel Bayesian slip inversion approach, where the full covariance matrices of GFs are implemented following the paper by Hallo and Gallovic (2016). They introduced so called approximate covariance functions inferred from observed seismograms, and have shown that these functions can reliably represent the uncertainties of GFs. Such approach was successfully applied in the inversion of centroid moment tensors of the 2016 Kumamoto earthquakes (Hallo et al., 2017). Our Bayesian finite-fault inversion consists of four major components: 1) convenient parameterization of the model space to limit its number of dimensions, 2) fast direct solver, which provides synthetics for a given set of parameters along the fault, 3) trans-dimensional Markov chain Monte Carlo approach to sample the posterior Bayesian probability density in the model space, and 4) statistical processing of the ensemble of solutions to evaluate the resultant uncertainty. The parametrization relies on the regularized Yoffe function (Tinti et al., 2005) as the slip-rate function which was shown to be compatible with rupture dynamics (e.g. Bizzarri, 2012), and hence, it may interlink kinematic and dynamic rupture parameters. The total slip on the fault is modeled using biharmonic spline interpolation from N spline points (Sandwell, 1987; Causse et al., 2017). Such slip parametrization is especially advantageous as it substitutes smoothing constraint and reduces the number of inferred source parameters. Simple spatial slip distributions require only few control spline points, while larger number of the spline points allows modeling more complex slip distributions. This parametrization permits the use of the trans-dimensional Markov chain Monte Carlo method (Sambridge et al., 2006; Dettmer et al., 2014), where the number of parameters (i.e. number of spline points in our case) is also the subject of inversion, leading to a self-adapting model space parameterization driven by the observed data. Moreover, it also reduces the influence of the subjective selection of the slip parametrization on the inversion results. The performance of our parametric slip inversion method with analytical representation of the GF uncertainty is demonstrated on the inversion of the destructive Mw7 mainshock of the 2016 Kumamoto, Japan, earthquake sequence. We use strong motion records of the K-NET and KiK-net networks as the

data and infer an ensemble of more than 500k possible finite-source models, representing samples of the posterior probability density function. Such massive ensemble of solutions is then statistically processed to reveal which features of the finite source model of the 2016 Kumamoto mainshock are reliable and which are rather artifacts. Such result allows us to discuss the differences among fault slip models for this earthquake as inferred by other authors (e.g. Asano and Iwata, 2016; Kubo et al., 2016b; Yoshida et al., 2017).

ESC2018-S19-624

EFFECTS OF DIFFERENT EARTH'S STRUCTURES ON W-PHASE CMT PARAMETERS

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The source inversion of the W-phase has demonstrated a great potential to provide fast and reliable estimates of the centroid moment tensor (CMT) for moderate to large earthquakes. It has since been implemented in different operational environments (NEIC-USGS, PTWC, etc.) with the aim of providing rapid CMT solutions in real time. These solutions are in particular useful for tsunami warning purposes. Computationally, W-phase waveforms are usually synthesized by summation of normal modes at long period (100 – 1000 s) for a spherical Earth model (e.g., PREM). Although the energy of these modes mainly stays in the upper mantle where lateral structural variations are relatively small, the impact of 3D heterogeneities on W-phase solutions have not yet been studied. In this work, we quantify the impact of lateral heterogeneities and investigate possible bias in W-phase source parameters due to un-modeled complexities in the Earth structure. With this purpose, using the spectral element method, we simulate a global dataset consisting of synthetic seismograms of past large earthquakes that accounts for the Earth 3D structure (3D velocity anomalies, topography and ellipticity). We then use the W-phase algorithm to invert earthquake CMT parameters from the synthetic dataset. Results allow us to quantify the effect of 3D structure on inverted source parameters, and investigate the sources of the observed differences. We also analyze the influence of magnitude, seismic noise, filter and data coverage on W-phase solutions. Results show that large centroid mislocations are observed in South America and in the South mid-Pacific Rise due a combined effect of lateral velocity variations and the unbalanced distribution of seismological stations. The difficulty to constrain some of the moment tensor components close to the free surface result in a larger focal mechanism uncertainty at shallow depth. We also show that centroid depth estimates are affected both by topography and 3D velocity heterogeneities. This research is essential both to assess the accuracy of W-phase CMT solutions and to investigate how 3D heterogeneities could be accounted for in the future.

ESC2018-S19-684

UTILIZING LINEAR SUPERPOSITION AND INTERFERENCE EFFECT IN SEISMIC AND ACOUSTIC WAVES FROM NATURAL AND MAN-MADE SOURCES FOR EVENT IDENTIFICATION, SOURCE PARAMETERS ESTIMATION AND HAZARD EVALUATION

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In some cases of man-made explosions and natural earthquakes one can observe the phenomena of linear superposition and interference of induced seismic and acoustic waves from multiple sources. Using the statistical analysis of the wave radiation process and the spectral analysis of the records may contribute to the event identification, source parameters estimation and hazard evaluation. A stochastic superposition model of directivity in seismic energy radiation from earthquakes was proposed based on: 1) unilateral rupture propagation; 2) random character of stress energy release at inter-barrier zones; 3) random variations in rupture velocity and slip amplitude. The model provides a directivity ratio equation to assess asymmetry in the radiation pattern of seismic waves at local distances. The ratio depends on two parameters only: directivity angle q between the station azimuth and the strike direction, and the Mach number which is the Vr/Vs ratio of rupture and S-wave velocities. Using the developed equation can provide a seismic hazard correction: reduction or

enhancement in specific directions. Coherent spectral minima and maxima in seismic signals from ripple-fired quarry blasts, observed at local network stations at different azimuths and distances, were explained and analyzed, using the principle of linear superposition and the interference theory. The statistical analysis of superposition of seismic waves from multiple sources with random parameters is also applied for explanation of some spectral features of seismic records. A similar spectral modulation for seismic records from underwater explosions in the Dead Sea was revealed and interpreted as an interference effect caused by the gas bubble pulsations. This spectral analysis has an evident application in discrimination between earthquakes and explosions, and also in estimating the the yield or the depth of the explosion. The Low-Frequency Spectral Modulation (LFSM) method for discrimination of quarry blasts and underwater explosions from local earthquakes was developed, based on the spectral semblance statistic for smoothed amplitude spectra of seismic waves at different stations. Due to the interference modulation effect the spectra are coherent, providing high semblance values, as opposed to earthquake spectra. An interesting and poorly known phenomenon in air-blast waves was observed at seismic and acoustic sensors during Sayarim large-scale calibration surface explosions: superposition of Main Shock and Secondary Shock (SS), where the arrival time difference was depending on charge weight, distance and type of explosives. The new shock wave parameter – the SS delay – was introduced, and a novel empirical relationship was developed, providing a simple and cost-effective method of the TNT yield estimation. One of the main advantages of this method is that it does not require an expensive high-pressure gauge system placed at near-source distances, that should be protected from the blast impact; the SS delay is easily measured by any simple low-cost acoustic or seismic sensor, deployed at remote location. The method can be used for forensic studies of explosion accidents.

ESC2018-S19-731

ALONG-STRIKE RUPTURE DIRECTIVITY OF THE STRONGEST CENTRAL ITALY EARTHQUAKES OCCURRED IN THE TWENTY LAST YEARS

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Along strike rupture directivity is a persistent feature in normal-faulting earthquakes in the Apennines. It has been already documented for many of the small to moderate magnitude events occurred in the last twenty years. In this study we extend the analysis increasing the number of the investigated earthquakes (Mw>4.0) of the 2009 L'Aquila-Campotosto and 2016-2017 Amatrice-Norcia seismic sequences. Furthermore, we selected the strongest earthquakes (Mw>3.5) occurred in the Val Tiberina area (Gubbio). The study is based on azimuthal variations of the high-frequency S wave amplitude using an empirical Green's function deconvolution method. Our approach allows us to statistically quantify the rupture directivity of each event through a directivity index (0 < IDIR < 1) that is a measure of the spectral separation above the corner frequency of the target event at opposite along-strike directions. Depending on IDIR, source ruptures are classified as unilateral, bilateral or circular. As already observed, it is confirmed that the direction of rupture propagation is not random. Same portions of the fault system activated during the 2009 and 2016-2017 sequences show a similar behaviour, with different sectors of the Apennines depicting an alternating trend of preferential along-strike rupture propagation directions. This feature, if confirmed by further data, could lead to more refined hazard assessments of the investigated region.

ESC2018-S19-734

REAL TIME EARTHQUAKE ANALYSIS USING STRONG MOTION DATA

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The seismicity of Romania is significantly affected by earthquakes produced by the Vrancea seismic source with intermediate depth events (3

shocks/century with magnitude Mw greater than 7.0). The seismic activity on the Romanian territory consists on both shallow and intermediate depth earthquakes. The crustal seismicity is moderate and more scattered in comparison with the intermediate depth one. The recent upgrade of the seismic network in Romania with high dynamic range accelerometers (114 real time seismic stations equipped with episensors) allows recording of moderate to large magnitude earthquakes at very close epicentral distances (less than 10-20 Km). A network for monitoring the strong motion that can occur in a given area records data that provide an excellent opportunity to study how source, path and site influence the ground motion, specifically that in the near-source area. Such data are essential for updating seismic hazard maps and consequently building codes and earthquake-resistant design. A fast seismic data analysis is essential to provide rapid and useful information to Authorities that have to take decisions immediately after a strong earthquake occurrence. Modern accelerometers are the only instruments that can provide near-source high-quality data during a strong earthquake. The purpose of this work consists mainly in the estimation of moment magnitude Mw, seismic moment M0 and other engineering parameters (PGA, PGV, PSA, etc) using the strong motion network of NIEP. A stable and automatic method developed by Gallo et al., 2014, has been implemented in real time data acquisition and processing system (ANTELOPE) to estimate in real time the seismic moment, the moment magnitude and the corner frequency of events recorded by accelerometers, using Andrews et al., 1986, method applied to S waves. The main goal is the independent estimation of seismic moment and corner frequency for all events recorded by the strong motion network.

ESC2018-S19-740

SPATIOTEMPORAL IMAGING OF EARTHQUAKE RUPTURE PROCESS IN HIGH FREQUENCIES USING BACKPROJECTION METHODS

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Backprojection is an alternative novel approach to mage the spatio-temporal earthquake rupture. The method was firstly applied for large earthquakes at teleseismic distances but is nowadays used at local distances and higher frequencies. The greatest advantage of the method is that processing is done without any a-priori constraints on the geometry, dimension and size of the source. Thus, the spatio-temporal imaging of the rupture is feasible in higher frequencies (> 1Hz) than conventional source inversion studies even when the examined fault geometry is complex. This high frequency energy emitted during an earthquake is of great importance in seismic hazard assessment for certain critical infrastructures. The actual challenge in using high frequency local records is to distinguish the local site effects from the true earthquake source content. Otherwise, mapping them incorrectly to the source area limits the resolvability of the method. The real challenge is to remove the site effect part from all available records, or at least, to distinguish quantitatively good reference stations from hard-soil and rock sites. In this study, the advantages and limitation of the method are explored using waveform data from a well recorded events in Japan (Kumamoto 7.1 Mw, 2016), New Zealand (Kaikoura 7.8 Mw, 2016) and Taiwan (Hualien 6.4 Mw, 2018).

ESC2018-S19-772

RELATIONSHIP BETWEEN DEPTH OF SEISMICITY AND HEAT FLOW: THE CASE OF THE GARGANO AREA (ITALY)

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We consider a thermo-rheological model made of a viscoelastic half-space with Maxwell rheology and temperature dependent viscosity. The half-space is made of layers with different values of density, thermal conductivity, activation energy and heat productivity. The model relates the surface heat flow to the depth of the brittle-ductile transition and the thickness of the seismogenic layer. The model is applied to the Gargano area (Italy) which is subject to a frequent low-magnitude seismic activity, although it lies out of the Apennine axis, which is the main Italian seismogenic area. The seismic activity in the Gargano area and surroundings occurs at depths that are systematically different in the north-

eastern zone with respect to the south-western zone. In correspondence with the change in depth of earthquake foci, we observe a change in the value of surface heat flow. Starting from these observations and from the knowledge of the lithospheric structure, we propose two different geotherms for the two zones. Assuming a constant strain rate, the shear stress is computed as a function of depth and the thickness of the seismogenic layer in the two zones is inferred. The comparison of the results of the thermo-rheological model with the seismological observation is good.

ESC2018-S19-841

MODELING GREEK AFTERSHOCK SEQUENCES WITH THE STRETCHED EXPONENTIAL FUNCTION

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The stretched exponential function describes most relaxation data observed in Nature and is considered a universal property of relaxing systems. Earthquake aftershock sequences however have been mostly described since 1894 with a power law following the first empirical law of seismology, the Omori law and subsequently modifications in the Utsu and later in the ETAS modeling. After a careful review of these and other aftershock decay formulas, Mignan (2015, 2016) rigorously tested and compared the stretched exponential function in aftershock sequences from three different earthquake catalogs and his results showed that all sequences follow an exponential and not a power law. The Greek earthquake catalog of the Institute of Geodynamics of the National Observatory of Athens (NOA), Greece is the most detailed earthquake catalog for the Southeastern Mediterranean area and has recently improved reporting and detection of the local seismicity with the unification of the National seismic network. This study will model the aftershock sequences from several large earthquakes using the NOA catalog and the stretched exponential function, in order to investigate the aftershock decay process in different tectonic settings in Greece.

ESC2018-S19-871

SOURCE PARAMETERS OF MAIN SEISMIC EVENTS IN NORTHEAST ALGERIA

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Seismicity in the Northeast region of Algeria (Eastern Tellian Atlas) is intense of moderate to low magnitude. Recently several important events were occurs in this region such as, the 2010 Beni-Ilmane earthquake sequence, the 2012-2013 Bejaia earthquake sequence and the 2017 earthquake sequence along North Constantine Fault (NCF). The 2010 Beni-Ilmane earthquake sequence was marked by the occurrence of three successive main shocks of equal magnitude ($5 \leq M \leq 5.2$). The source parameters of the eighteen major events ($M > 4$) of this seismic sequence were estimated. The digital data used in this study was recorded by twelve Broadband stations of the Algerian permanent seismic network. The displacement spectra for P- and S-waves were analyzed with Brune's source model. Scaling relations between the seismic moment, the source radius and the stress drop indicates that the events with moments greater than about 2x1016 Nm have stress drops that are generally constant, while earthquakes with moments less than about 2x1016 Nm have stress drops that decrease with moment. On November 28, 2012 an earthquake of magnitude 5.1 was occurred 07 km east of Bejaia city (offshore part). Six months later, an earthquake sequence of two main shocks (M=5.2 and 5.0) was also occurred in the region on May 2013. The aftershocks distribution of this earthquake sequence shows a cluster oriented NW-SE and of about 20 km length. The focal mechanisms of the three mains shocks show near vertical right-lateral strike-slip fault plane. In 4th and 5th March 2017, NCF experienced a seismic sequence of magnitude ($0.8 \leq M \leq 4.7$). A set of 106 well located events distinguish three separate regions. One event in Roknia region, 90% of events clustered in Oum Toub region and eight diffuse earthquakes in Ain Bouziane town.

ESC2018-S19-883

ESTIMATION OF FULL MOMENT TENSORS WITH UNCERTAINTIES FOR EXOTIC SEISMIC SOURCES INCLUDING LANDSLIDES AND NUCLEAR TESTS

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A seismic moment tensor is a 3 × 3 symmetric matrix that provides a compact representation of seismic events within Earth's crust. We present a methodology developed in a separate study to estimate seismic moment tensors with uncertainties, and show its application to a variety of seismic sources. The algorithm for moment tensor inversion performs a grid search over the six-dimensional space of moment tensors, generating synthetic waveforms at each moment tensor grid point and then evaluating a misfit function between the observed and synthetic waveforms. The optimal moment tensor M for the event is the moment tensor with minimum misfit. The synthetic waveforms are computed using a 1-D structure model for the region; this approximation requires careful assessment of parameters such as time shifts between observed and synthetics. To describe the uncertainty associated with M, we first convert the misfit function to a probability function. The uncertainty, or confidence, is then given by a confidence curve P(V), where P(V) is the probability that the true moment tensor for the event lies within the neighborhood of M that has fractional volume V . The area under the confidence curve provides a single, abbreviated 'confidence parameter' for M. Here we apply the algorithm to waveform data from various seismic sources in different regions including landslides in the Swiss Alps and vicinity, and nuclear tests in North Korea. The moment tensor uncertainties presented here allow to quantitatively discriminate among different sources and to assign physical processes to the events.

ESC2018-S19-901

THE 2012-2013 BEJAIA, ALGERIA, EARTHQUAKE SEQUENCE: SOURCE PARAMETERS, SCALING RELATIONSHIPS AND STRESS TENSOR

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Source parameters of the major events of the 2012-2013 Bejaia (north-central Algeria) earthquake sequence were estimated using data recorded by Broadband permanent stations of Algeria Digital Seismic Network (ADSN). The displacement spectra for P- and S-waves were analyzed by applying Brune's seismic source model to obtain the spectra parameters. Spectra were corrected from path attenuation using coda-Q. The average seismic moment for P-and S-waves ranged from 5.5 × 1014 to 9.1 × 1016 Nm, with the logarithmic mean M0(S)/M0(P) ratio of 0.96. The source radius spanned from 735 to 1891 m, with average r(S) to r(P) ratio of 0.99. The stress drop varied from 2.5 to 118 bars with an average ratio of 0.58. The corner frequency (fc) varies from 0.9 to 2.4 Hz and the moment magnitude (Mw) ranges from 3.8 to 5.3. The scaling relation between the seismic moment, the source radius and the stress drop indicates a decrease in stress drop and source radius with decreasing seismic moment. We have also estimated the moment tensor solutions for the main shocks of this sequence. The seismic moment and the moment magnitude obtained show similar results compared to the results obtained by spectrum analysis. The focal solutions present a strike-slip faulting in agreement with those obtained by the first arrivals. Finally, we used these focal mechanisms to calculate stress tensor. The best solution for stress axis calculation indicates that the compression axis σ1 is oriented NW-SE (N318°) well correlated with regional stress field regime and in good agreement with stress tensor calculated from 2006 Lalaam earthquake.

ESC2018-S19-968

CENTROID MOMENT TENSOR DETERMINATION FOR MODERATE EARTHQUAKES IN PORTUGAL

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In this work, we present the implementation of seismic moment tensor's inversion for operational purposes at the Instituto Português do Mar e da Atmosfera (IPMA). To do this, we use the ISOLA code. A least-squares inversion is used to calculate the moment tensor, while the space-time centroid location, including the source depth, is retrieved

with a grid search scheme. The seismic network in Portugal mainland and adjacent area is composed of 52 broadband stations that provide a good azimuthal coverage and high-quality data that are transmitted in near-real time to IPMA. These data are used to calculate the seismic moment tensor for earthquake events occurring in Portugal and offshore areas. This is becoming routine analysis at IPMA for events with local magnitude (ML) larger than 3.8. The seismic moment tensor solutions are published at the IPMA web page. As an example, we present the web page solution of the ML4.9 earthquake that occurred in 2018 in the Arraiolos region. Taking advantage of the significant improvement of the seismic network in the Azores Archipelago in the past decade, which provides waveform data from 11 broadband stations, we perform here moment tensor inversions for five Mw 4.6-5.9 earthquakes that occurred in the Azores archipelago near the Mid-Atlantic Ridge in 2013-2016. We assess moment tensor uncertainties associated with both the data and the Earth model used. Currently, ISOLA is being handled semi-automatically to compute the moment tensor through its user-friendly interface (GUI). In the near future, we intend to automate this procedure, integrating it in the Seiscomp3 platform. This will present a step forward for real-time seismological applications already in place, such as Shakemaps and the North-East Atlantic Tsunami Early Warning system.

ESC2018-S19-1040

SOURCE COMPLEXITY OF THE MW 6.5, 2016, OCTOBER 30TH CENTRAL ITALY EARTHQUAKE

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In this work, we study the October 30th 2016 Norcia earthquake (MW 6.5) to retrieve the rupture history by jointly inverting seismograms and coseismic GPS displacements obtained by dense local networks. We noted that some preliminary attempts to model the slip distribution of the October 30th main shock using a single fault plane oriented along the Apennines did not provide convincing fits to the observed waveforms when both strong motion and GPS data are inverted. In addition, the deformation pattern inferred from satellite observations suggested the activation of a multi-fault structure, that is coherent to the extension of the geological surface deformation. We investigated the role of multi-fault ruptures and we found that this event revealed a remarkable complexity of the rupture geometry and its evolution. We found that the coseismic rupture propagated almost simultaneously on a normal fault of the Mt. Vettore-Mt. Bove fault system and on a blind fault inherited from compressional tectonics belonging to the Olevano-Antrodoco-Sibillini system. The kinematic parameters of the presented rupture models comprising two fault planes have been selected iteratively by performing more than 20k inversions and by measuring the fit through the variance reduction. In order to investigate the stability of the proposed solution and its uncertainties, we adopted some machine learning algorithm. This earthquake raises serious concerns on our understanding of fault segmentation and seismicity evolution during sequences of normal faulting earthquakes and has important implications on seismic hazard assessment and on the maximum expected magnitude in this tectonic area.

ESC2018-S19-1050

EXAMINING EARTHQUAKE STRESS SCALING VIA SEISMIC CODA-BASED SPECTRAL EVENT RATIO LEVELS

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The study of earthquake source parameters is complicated by changes introduced through wave propagation from the hypocenter to the recording stations. A typical way to remove such path and site effects is to compare the recordings of nearby events at the same seismic station, where these effects can be assumed to be in common. If a spectral ratio between the two nearby events is formed, it ideally cancels out the path and site effects, resulting in a sigmoid shape where the inflection points come from the corner frequencies of the two events. However, radiation pattern differences and directivity differences can

still distort and obscure the true spectral ratio. An additional technique is make use of the scattered energy in seismic coda, to get a better estimate of an azimuthally averaged source spectra that are less sensitive to radiation pattern and directivity effects. We use regional coda envelopes to form stable spectral ratios between nearby events to study event scaling behavior. There are several challenges in using corner frequency to interpret stress parameter scaling, including the need to assume a particular source spectral model. In addition, stress measures (e.g. stress drop and apparent stress) are related to the cube of the corner frequency. In practice this leads to high levels of uncertainty in measured earthquake stress since it is related to the uncertainty in the corner frequency cubed. We have developed a new approach using the low and high frequency asymptotic levels of spectral ratios between two closely located events recorded at the same stations (Walter et al., 2017). This approach has a number of advantages over more traditional corner frequency fitting. First, if the bandwidth of the spectral ratio is sufficient, the levels can be measured at many individual frequency points and averaged, reducing the measurement error. Second the apparent stress (and stress drop) are related to the high frequency level to the 3/2 power so the measurement uncertainty is not as amplified as when using the corner frequency. Finally, the measurement of the spectral ratio asymptotic levels is fairly independent of any particular source model assumption and its perhaps unknown corner frequency-stress relationship. In practice we find it is more stable to use regional waveform modeled moments to determine the low frequency level between the events. We also do need to make two key assumptions for measuring the high frequency asymptotic level. First, as with all ratio techniques, we must assume the source physics model is similar for the two events, so any model details will cancel out. Second, we must make the asymptotic measurement at sufficiently high frequency that we are well above any characteristic source dimension or time effects, so that the ratio between the two events is approximately constant. Here we measure regional coda envelopes, form spectral ratios and measure low and high frequency asymptotic ratios to form stress ratios for a number examples taken from a wide variety of crustal earthquake sequences. We are working on a software tool to make deriving source parameter measures from regional coda envelopes much more straightforward. We apply the coda-based spectral ratio level technique to a variety of events. We use these results to examine these stress source parameter results for implication on earthquake scaling with size, depth and other parameters. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

ESC2018-S19-1082

SOURCE PARAMETERS BASED ON SPECTRAL ANALYSIS OF CLUSTER ACTIVITY IN BULGARIA AND SURROUNDINGS

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Spectral analysis of seismic waves is one of the most important origin of information for the earthquake sources. For spectral characteristics, the most common seismic source model used is the Brune model. The model has been used extensively and it has been shown that it gives a good agreement with observations from different regions and for a large range of magnitudes. The source parameters like seismic moment, source radius, stress drop and moment magnitude of the events are computed following Brune's theory by using the corner frequency and the low frequency asymptote estimated from the spectra. The seismic moment M0 is a direct measure of the tectonic size (product of shear module, rupture area and average static displacement) and therefore does not saturate. The seismic moment can be determined by moment tensor inversion or spectral analysis. The moment magnitude, MW - scale is reasonably reliable since it is controlled by the fault size and the dislocation. Seismic moment magnitude scale is considered as the most reliable magnitude accurately describing the size of earthquakes. Stress drop σ is the average difference between initial and final stress along a fault after an earthquake. This is an important physical parameter associated with movement on a fault. Seismological data is well described with the Poisson process if the earthquake sequences or clusters are excluded. Such groups (or clusters) of earthquakes are foreshocks, aftershock

sequences and swarms. Foreshocks are one of the few well-documented precursors to large earthquakes. Foreshocks (rarely observed) are those earthquakes that occur prior to the main event in the same area. Aftershocks occur after the main shock and their frequency decays through time with approximately reciprocal of time elapsed since the main earthquake. Swarms are sequences of earthquakes that are clustered in space and time and are not associated with an identifiable main shock. Swarm activity may take days, weeks or months. The present study was aimed at estimating some source parameters using P and S wave spectra for seismic sequences - foreshocks, aftershocks and swarms that were realized in and near Bulgaria. Displacement spectra are derived using digital data from the Bulgarian Seismological Network - NOTSSI (National Operative Telemetric System for Seismological Information).

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ESC2018-S20-129

PREDICTING SIZE AND OCCURRENCE TIME OF CO-SEISMIC RUPTURE USING A SINGLE FAULT STICK SLIP MODEL: EXAMPLES FROM THE FIMBUL ICE SHELF, ANTARCTICA

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It is commonly believed that the deterministic forecast of the magnitude, time and location of earthquakes is impossible. We show the exceptional case of a natural, single-fault observation where a mechanical stick-slip rupture model explains almost all the seismicity. Our analysis covers 4 years of continuous seismic recordings from broadband stations and arrays, at the Fimbul Ice Shelf, Antarctica. The observed ice-quakes have periodic patterns of seismicity rates and magnitudes correlating with the neap spring and semi-diurnal cycles. Dozens of highly repetitive events occur in semi-diurnal cycles, with magnitudes and rates fluctuating steadily with the tide. The seismicity does not follow a common frequency magnitude distribution, and shows magnitude trends within single clusters, with spring tides and with tidal wave height. The inter-event time is unusually peaked and the highly constrained event sources migrate landwards during each 12-hour cycle. We suggest a mechanical stick-slip model on a small patch of grounding ice shelf, coupled to the ocean-tide height. This explains all of the uncommon observations, and the well fitted observations give new insights in the general process of frictional triggering of earthquakes.

ESC2018-S20-159

A NEW UNIFORM MOMENT TENSOR CATALOG FOR YUNNAN, CHINA FROM JANUARY 2000 THROUGH DECEMBER 2014

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There is a long history of large and damaging earthquakes in the southwestern Chinese province of Yunnan. Since 1908 there have been 99 earthquakes with magnitude larger than M6, and 14 with magnitude larger than M7 in the surrounding region. The largest events (> M7) have predominantly occurred on the major strike-slip faults in the area such as the Sagaing fault, the Xiaojiang fault, the Qujiang fault, and the Lancan-Gengma fault. The largest event in the region was the M8.6 Assam-Tibet earthquake that occurred on 15 August 1950 near the East Himalayan Syntaxis (EHS). This earthquake is currently the ninth largest in recorded history. The most damaging event in the region was the M7.1 Tonghai earthquake, which occurred on 5 January 1970 and caused 15,621 casualties (www.csi.ac.cn). Yunnan is adjacent to the EHS and its seismicity is mostly driven by the complex tectonics resulting from the collision of India and Eurasia. Both of the two most well-known geodynamical models for the Tibetan Plateau can find supporting evidence there. The large strike-slip Red River Fault converting between right-lateral and left-lateral motionsupports the extrusion model of Tapponnier et al., and the low velocity zone revealed by tomography and receiver functions supports the lower crustal flow model of Royden et al. Tectonic stress in the Yunnan region is also influenced by the oblique eastward subduction of the India plate beneath the Burma microplate. Together these factors cause Yunnan to have some of the highest seismic hazard in the world. For a seismically active region, a stable and uniform moment tensor catalog is essential for calculating the earthquake recurrence rates that are needed to quantify seismic hazard. Moment tensor catalogs also can shed light on the regional seismotectonics and state of stress. We present 1,833 moment tensor solutions for small-to-moderate earthquakes that occurred between January 2000 and December 2014. Moment magnitudes in the new catalog vary from 2.2–6.1 Mw and the catalog is complete to a magnitude of ~3.5 Mw. The moment tensors are constrained to be purely double-couple and they show a variety of faulting mechanisms. Normal faulting events are mainly concentrated in northwest Yunnan, while farther south along the Sagaing fault the earthquakes are mostly thrust and strike-slip. The remaining area includes all three styles of faulting but with a preference for strike-slip. We also invert our new moment tensor catalog for a model of the regional stress field using the MSATSI package. The stress field reveals

clockwise rotation around the East Himalayan Syntaxis, with northwest-southeast compression on the east side of the Red River Fault (RRF), and northeast-southwest compression on the west side of the RRF.

ESC2018-S20-163

MOMENT TENSOR SOLUTIONS DETERMINED FOR BROADBAND SLOW EARTHQUAKES

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Since around 2000, various slow earthquakes have been found in many seismic regions worldwide, mainly in subduction zones and along major faults. While most previous studies separately investigated tectonic tremors above 1 Hz and very low-frequency (VLF) earthquakes in 0.01-0.1 Hz, recent observation and theoretical models suggest that these are band-limited realizations of a united broadband physical process, which we may call broadband slow earthquake. For such a broadband process, we expect some VLF component behind high-frequency seismic signals of tectonic tremors. VLF signals are generally weak, but can be magnified by stacking relative to the timing of tectonic tremors. Stacked signals are simple, and easily inverted for moment tensor solutions, which have been published for slow earthquakes in Japan, Cascadia, Taiwan, and Mexico. The focal mechanisms of slow earthquakes are generally consistent with the orientation of local deformation. In subduction zones, the dip direction is consistent with the geometry of plate interface and slip direction is determined by relative plate motion. We can also recognize some spatial heterogeneity in focal mechanisms, with resolution as small as 5 degrees for the best case. Therefore, these solutions provide unique information to constrain the geometry of plate interface and faults. The seismic moment determined for stacked signal is proportional to the seismic energy of stacked tremors, with proportionality constant of about 10-9, which is smaller than that of ordinary earthquakes by about 4 orders. The similarity of observations in different regions suggests that the mechanism driving broadband slow earthquakes is fairly simple and universal in whole seismic regions.

ESC2018-S20-194

THE STRAINED STATE OF THE EARTH'S CRUST OF AZERBAIJAN ACCORDING TO EARTHQUAKES DATA

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Azerbaijan is characterized by strong level seismicity where earthquakes are distributed within several active areas. In the current study, we researched the source mechanism of earthquakes occurred in the northeastern part of Azerbaijan, using the digital waveform data recorded by the Republican Center of Seismic Survey (RCSS) at Azerbaijan National Academy of Sciences (ANAS) during the period from 2003 to 2017. The focal mechanisms are solved with high reliability on the basis of the polarity of the first motion of P-wave. These solutions are used to investigate the state of tectonic deformation and the contemporary stress field pattern affecting on different tectonic areas in the northeastern part of Azerbaijan. The results demonstrate mainly thrust faulting mechanism with a number ofnormal faulting and strike slip component. The Lode-Nadai coefficient technique schemesare used in the current study for determining the regional stress field parameters for earthquake focal mechanism solutions. Mainly western and central parts of Greater Caucasus ridge are characterized by north-eastern-south-western (NE-SW) tension. In the eastern part, the tension reverses into intensive compression.Additionally, it can be obviously traced the transformation of left-lateral strike slip motion into predominant right-lateral strike slip motion southward from mountain ridges of Greater Caucasus. The differences between these characteristics are considered for the large tectonic zones (Zagatala-Balaken, Sheki, Oguz-Gabala, Shamakhi-Ismailli). The analysis of the orientation of the compression axes has shown the NW-SE orientation in the Zagatala region, N-S in Sheki and further smoothly changing clockwise to the NE-SW direction in the Caspian Sea. The axis of stretching is mainly oriented NE-SW and N-S directions, which is connected with the heat of the Kur depression under the zone of the Greater Caucasus.Significant spatial variations in orientations of the axes of major normal stresses in the shear zone and their local weak

gentle variations are evidence of a consistent general stress NE-SW direction.

ESC2018-S20-261

RETROSPECTIVE INVESTIGATION ON THE PHASE PRECEDENT THE 2004 BOVEC-KRN EARTHQUAKE MD=5.1 (NORTHERN ADRIA).

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The present work is a retrospective investigation of phenomena that possibly accompanied and preceded the Mw=5.2 event that occurred near Bovec (Slovenia) in 2004, at the Northern edge of Adria microplate. Rossi et al. (2016), analyzing the cGNSS recordings reported the occurrence of a transient signal propagating through NE Italy and W Slovenia between 2006 and 2009. It was characterized by an approximately circular/elliptical pattern, spurring a movement initially oriented upward (with the exclusion of a site to the east of the area) and subsequently downward. The horizontal component showed similar behaviour, with a smaller oscillation about parallel to the principal tectonic fault systems. They interpreted the signal as bound to the propagation of fluids through a porosity wave. Porosity waves are packets of fluid-filled interconnected cracks that self-propagate upward and in the direction of minimum horizontal stress following the pressure gradient and permeability variations to achieve more efficient transport (Wiggins and Spiegelman 1995; Connolly and Podladchikov 1998; 2013; Revil and Cathles 2002). The transient originated approximately 3.5 months before the main shock, 6.5 km NW of the main shock epicentre at a depth of 9.2 km, on the continuation of the Ravne fault, recognized responsible for the Bovec-Krn seismicity. A valve behaviour (Sibson, 1992) of the Ravne Fault, was hypothesized as having originated the fluid diffusion. According to Sibson's model, faults that act as impermeable seals except in the post-failure phase, when they allow fluid discharge, may behave as fluid-pressure activated valves when cutting a supra-hydrostatic fluid pressure gradient. The interpretation of Rossi et al. (2016; 2017) is supported by the values of the hydraulic diffusivity inferred from the arrival times of the transient signal in the different cGNSS stations, consistent with the lithologies present in the area. Here, we start from Rossi et al. (2016; 2017) results to further validate their hypothesis. The patterns of motion in the various sites is compatible with a mass change that occurred in the transient signal's origin volume and was, then, distributed over an elliptical area along an NW-SE-oriented major axis coinciding with the orientation of the Ravne fault. Then, we calculate the permeability values and pore-pressure state at the source of the transient signal. The permeability values for the four most representative rock formations in the region (two flysch formations of Palaeozoic and Cainozoic age, Dolomitic limestone, and micritic limestone) are consistent with the permeability measurements for similar lithotypes. The ratio between the effective stress at the origin of the signal (Rossi et al., 2017) and the lithostatic load calculated in the Bovec area indicated a state of overpressure, with pore-pressure about 0.9 the lithostatic load in the phase preceding the Bovec-Krn 2004 main shock (Rossi et al., 2018). Furthermore, the seismic activity in the months preceding and following the 2004 main shock is analyzed, to verify its compatibility with a diffusion model (e.g., Shapiro et al., 2002). The investigation on the preparation phase of the 2004 seismic sequence, although done a posteriori, can be of help in a better understanding of the relationship between faults, fluids, and deformation and in forecasting similar behaviours also in other areas.

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ESC2018-S20-269

RUPTURE COMPLEXITY AND DIRECTIVITY EFFECTS FOR AN INJECTION INDUCED EVENT: THE 2016 MW 5.1 FAIRVIEW, OKLAHOMA EARTHQUAKE

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Complex rupture processes are occasionally resolved for weak earthquakes and can reveal a dominant direction of the rupture propagation and the presence and geometry of one or more main slip patches. Finding and characterizing such properties is crucial to understand the nucleation and growth of induced earthquakes. One of the largest earthquakes linked to wastewater injection, the 2016 Mw 5.1 Fairview, Oklahoma earthquake is analyzed using empirical Green's function techniques, revealing its source complexity. Two subevents are clearly identified and located using a new approach based on relative hypocenter-centroid location. The first subevent has a magnitude of Mw 5.0 showing the main rupture propagation toward NE, in direction of the higher pore pressure perturbation due to wastewater injection. The second subevent appears as an early aftershock with lower magnitude Mw 4.7. It is located SW of the mainshock in a region of increased Coulomb stress, where most aftershocks were relocated.

ESC2018-S20-297

MOMENT TENSOR AND STRESS INVERSION DERIVED FROM ANTHROPOGENIC SEISMICITY IN THE SONG TRAHN 2 RESERVOIR, VIETNAM

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The seismicity in the vicinity of the Song Tranh 2 reservoir that commenced in late 2010 is an example of reservoir-induced seismicity. Two main orientations of discontinuities reactivated by reservoir exploitation are identified, with clustering of events located in two main areas: northern and southern. Maximum seismic activities in clusters appear in different periods, with high seismicity in the southern preceding that in the northern. The results indicate significant differences between the northern and southern clusters. Seismic activity in the north is much greater than in the south, and also differs in magnitude distribution. It is shown that SC is an example of rapid triggering, while the NC is adelayed triggering type. The main stress regime is normal faulting in STR2 area as well as in both MT derived clusters, with the difference in the intermediate horizontal stress orientation. Tectonics of the area is dominated by system of W-E trending thrusts, with tectonic transport to the south. The reservoir related seismicity doesn't follow such main tectonic regime. The STR2 is characterized with normal faults with NW-SE strikes. Moment tensor (MT) solutions are mostly normal faulting mechanisms with shearing as the main component of full MT, which suggests reservoir exploitation stress field changes as a triggering origin of this seismicity. However, the local tectonic stress field plays a role in the seismogenic process, which is accelerated by the reservoir exploitation. In the northern cluster, although events are grouped within a relatively compact area, their locations are not indicative of any connection with known geological structures, while the distribution of shocks is not aligned with any faults. In the southern area the events are distributed within much broader space and also do not align with any supposed discontinuity. However in both clusters the nodal planes are parallel to known mapped faults. The local stress field and focal mechanism orientation can beclearly linkedto the mapped discontinuities,that represent weak zones for rupture. Results of spatio-temporal seismicity evolution and MT solutions analyses are supporting the thesis of seismic activitytriggeredon existing discontinuities by reservoirexploitation.

ESC2018-S20-335

INTRAPLATE SEISMICITY IN NORWAY RELATED TO ANOMALOUS UPPER MANTLE AND ELEVATED ATMOSPHERIC PRECIPITATION RATES

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Norway is one of the most seismically active intraplate regions in the world in the world, characterized by elevated seismic activity in two clearly defined zones in SW Norway and the Nordland county. The origin of intraplate seismicity in Norway has been studied for more than 100 years, when the earthquakes started to be instrumentally recorded. According to our results, the two zones of high intraplate seismicity are spatially correlated with upper-mantle, low-velocity anomalies and spatially and temporally with high atmospheric precipitation/snowmelt rates, implying a new mechanism to explain these features of regional, intraplate seismicity. We conclude that the presence of low-velocity zones in the upper mantle exerts a first-order control on seismicity. In addition, the gravitational forces due to highly contrasting relief and existing structural heterogeneities within the crust may, at least partially, contribute to these restricted zones of seismicity. Moreover, the effects of postglacial isostatic adjustment, Quaternary glacial erosion/deposition and Mid-Atlantic ridge push are probably minor but can be partially superimposed on the seismicity in SW Norway and the Nordland area, where intracrustal conditions are particularly favorable for strain and stress localization above the low-velocity, upper-mantle zones. A direct temporal correlation between the number of earthquakes within the upper crystalline crust and intensity of rain and snowmelt at the Earth's surface indicates that increased groundwater flow through fractured crystalline bedrock following periods of increased rainfall/snowmelt can act as a trigger of seismicity. The initiating mechanism is most likely associated with periodic increases in pore-fluid pressure within the fractures and cracks of the upper crystalline crust as a result of groundwater recharge, with gradual pore-fluid pressure diffusion to depth. Therefore, precipitation-related, seasonal pore-fluid pressure increases within the fractured crystalline rocks can be superimposed on the mantle- and gravity-controlled seismicity, causing relatively frequent, but mainly low-intensity earthquakes.

ESC2018-S20-359

SLOW SLIP EVENTS AND TRIGGERED EARTHQUAKES NEARBY THE M7 IBARAKI-OKI, JAPAN, EARTHQUAKES

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Slow slip events (SSE) occur in the vicinity of locked regions in subduction zones and are speculated to be related with occurrence of large earthquake as some SSE were reported to have preceded some large earthquakes. Two kinds of ordinary earthquakes are known to closely related to SSE activity in subduction zones. The one is earthquake swarm, which is a seismic sequence without a distinguished mainshock, and swarms triggered by SSEs have been observed in some subduction zones. The other is repeating earthquake sequence, which are repetitive rupture of almost the same area on the plate interface and can be used as a creep meter on the plate interface. In this study, we focus on the Ibaraki-Oki, Japan, region, where two earthquakes of M7 occurred in 1982 and 2008, due to the subduction of the Pacific plate. These M7 earthquakes were accompanied with many foreshocks. We applied the method of Nishikawa and Ide (2017) to detect swarm activity using epidemic-type aftershock sequence (ETAS) model, and the matched event detection to make a complete catalog of repeating earthquakes. We found 19 swarm sequences during 1982–2009 at almost the same location as foreshock sequences preceding the 1982 and 2008 M7 earthquakes. Both the foreshock and swarm sequences contain repeating earthquakes and have anomalously high seismicity rates inexplicable by the ETAS model, suggesting recurrence of SSEs in the source region of the 1982 and 2008 M7 earthquakes. The foreshock sequences in 1982 and 2008 have a larger number of events inexplicable by the ETAS model than the swarm sequences. The amount of slip of repeating earthquakes in the foreshock sequence in 2008 is also larger than those of the swarm sequences, and the slip rate increased 12 hours before the 2008 M7 event. These results imply that the SSEs that preceded the 1982 and

2008 M7 earthquakes have larger seismic moments than the other SSEs.

ESC2018-S20-382

STRESS AND DEFORMATION OF EARTH CRUST IN BULGARIAN TERRITORY AND SURROUNDINGS

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For understanding the complex tectonic pattern of Bulgaria, the tectonic evolution of the are between the Carpathian mountain to the north, Black Sea to the east, Adriatic Sea to the west, and Ionian basins to the south (central Balkan region) has to be considered. This region is very interesting for studding the kinematics and dynamics of plates interaction because of the variety of different tectonic processes. The present scientific communication contains generalized information on the focal mechanisms results of collection, processing and analysis of more than 400 seismic events for Bulgarian territory and adjacent lands. Around half of available focal mechanisms are determined by the author, using method of P-wave first motion polarities. Most of the events are with small to moderate magnitudes – 2.5 to 4.5 for Bulgaria (only one with Mw=5.7 and two historical earthquakes with M=6.8 and 7.0), and stronger events for surrounding countries – up to 7.4. All available beach balls are separated on nine different seismic zones, with special attention on the seismicity, different faults and fault systems. The frequency distribution of P- and T-axes utilizing available events was constructed in every zone, to correlate the geometry of the principle stress axes and fault orientations. The local stress tensor derived from the inversion of P- and T-axes of the fault plane solutions in every zone was determined by the Gephart and Forsyth method and the minimum sum of misfit rotation was calculated. The released strain is computed from the moment tensors of the focal mechanisms according to the relation of the Kostrov. In general, obtained mean strain tensors of deformation shows some agreements with the calculated mean stresses. Several local misfits and the whole geodynamic situation are analyzed according to some present tectonic hypothesis. Based on analysis of the current seismicity, stress and strain in the territory of Bulgaria, some ongoing geodynamic processes in the central Balkans are presented. Current study is part of the project for young scientists – “Assessment and analysis of stress and deformation of Earth crust in seismic zones of Bulgarian territory and adjacent lands” (2017-2019), financed by the Bulgarian Academy of Sciences.

ESC2018-S20-413

EARTHQUAKE STATISTICS, SPATIOTEMPORAL DISTRIBUTION OF FOCI AND SOURCE MECHANISMS AS A KEY TO UNDERSTANDING OF EARTHQUAKE SWARMS IN WEST BOHEMIA-VOGTLAND AND SOUTH-WEST ICELAND

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Earthquake swarms occurred worldwide in diverse geological units. They are mostly related to volcanic and post-volcanic areas, geothermal fields and ocean ridges. However, their origin is still unclear. West Bohemia-Vogtland represents one of the most active intraplate earthquake-swarm areas in Europe, South-West Iceland, which lies directly on the boundary between the North America and Eurasia Plates, is characterized by recurrence of intense interplate earthquake swarms. Both these areas exhibit very high activity of crustal fluids. Regarding West Bohemia-Vogtland, there were swarms in 1997, 2000, 2008, and 2011 and 2017 with magnitudes ML ? 3.8, three unusual mainshock-aftershock activities (ML 3.5, 4.43.6), happened in 2014. The swarm events together with the mainshock- aftershock sequences form a belt of about 15 x 6 km in depths between 6 and 15 km. We analysed earthquake statistics, spatiotemporal distribution of the foci and source mechanisms of all the activities in the period 1997 – 2017. A notable finding is a significant acceleration of the seismic moment release in each subsequent activity starting from the 2000 swarm up to the 2014 sequence, which signifies an alteration from the swarm-like to the mainshocks-aftershock character of the seismicity. Despite the different character of the 2014 sequence and the earthquake swarms the magnitude-frequency distributions show the b-values ? 1 and PDFs of the inter-event times indicate similar event rate of the individual swarms and the 2014 activity. Only a-value (event-productivity) in the MFD of the 2014 sequence is

significantly lower than those of the swarms.The swarms are located close to each other except swarm of 2017 which is located several hundred meters apart, thus indicating an intact asperity. We found that the main focal zone NK consists of several differently oriented fault segments (five segments disclosed up to now), some of them had been reactivated. Furthermore, we found that all the ML > 2.8 swarm events, which occurred in the given time span, are located in a few dense clusters. It implies that the most of seismic energy in the individual swarms has been released in step by step rupturing of one or a few asperities. The spatial distribution and focal mechanism patters of the individual swarms indicate their complexity. MTs of the most analysed events signify pure shears except for events the second phase of the 1997 swarm the MTs of which indicate significant amount of non-DC components. As regards South-West Iceland we analysed the earthquake swarms on the Reykjanes Peninsula in 2003 (ML 5.2) and 2017 (ML 4.1), and in the Hengill volcanic complex in 2007 (ML 4.5) and 2008 (ML 4.5). We found striking similarity between earthquake statistics and spatiotemporal distributions of the SW Icelandic and West Bohemian swarms except that SW Icelandic swarms are located at significantly lower depths (2 to 7 km) and show significantly higher rate of seismic moment release. We infer that the individual earthquake swarms in both West Bohemia-Vogtland and South-West Iceland are mixture of the mainshock-aftershock sequences which correspond to step by step rupturing of one or a few asperities. The swarms occur on short fault segments with heterogeneous stress and strength which may be affected by crustal fluids reducing normal component of the tectonic stress. Thus, critically loaded and favourably oriented faults are brought to failure and the swarm activity is driven by the differential local stress. We believe that these results could contribute sufficiently to understanding of some aspects of triggered seismic activities.

ESC2018-S20-435

STRESS DERIVATION FROM EARTHQUAKE FOCAL MECHANISMS IN THE WHOLE REGION OF MADAGASCAR

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Data gathered by the 2011-2013 MACOMO temporary seismograph deployment and from the local permanent stations by the Madagascar National Data Center (NDC) have been used to study earthquake activity and stress characteristics in Madagascar. Generally, seismic activity in Madagascar is moderate, except for the central region of this island, where it is high. Of the 30 well covered earthquakes by the stations from MACOMO between 2011 and 2013 including 295 earthquakes from NDC stations between 2000 and 2016, with magnitude ML >= 2.8, stress inversion were determined to characterize the principal stress direction beneath the whole part of the island after dividing the area into six regions. The inversion follows Michael's method based on a linear procedure. Focal depths of the selected earthquake are ranging between 1 km and 45 km. Direction of the principal stresses were defined as well as the characteristics of the stress field that is responsible of the extension. The results show domination of compressive stress trending NW-SE in the central region and a tendency for strike-slip and thrust faulting in the northern and southern regions of Madagascar. The observations may infer a potential effect caused by the separation of Madagascar from Africa, India, and Somalia.

ESC2018-S20-442

INTRODUCING A VERSATILE GEODETIC DATA INVERSION ALGORITHM WITH VARIABLE RAKE AND ADAPTIVE UNEVEN PATCH SIZES. AN APPLICATION TO THE 2016 CENTRAL ITALY SEISMIC SEQUENCE.

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In a previous work we have developed a variable patch adaptive algorithm, which subdivides the fault plane following rules related with the data distribution. Slip resolution depends on the data coverage and on the fault plane parameters and the retrieved subfault subdivision shows the real resolution power of InSAR and GPS measurements. One limitation of the code was the adoption of a homogeneous rake throughout every single fault plane. The adopted rake was an average of the real spatial rake variations on the fault plane. It was derived from a preliminary non linear inversion stage which considered a constant

slip distribution. Here we increase the versatility of our inversion code allowing the rake to vary within certain limits around the average value. We obtain heterogeneous slip field directions on the seismic structures. We apply the new algorithm feature to the Amatrice seismic sequence that struck the central Italian Apennines in 2016-1017.

ESC2018-S20-464

SEISMOTECTONIC ANALYSIS OF THE 2014 SEISMIC SWARM AT THE WESTERN CORINTH GULF (GREECE)

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The Corinth Rift (Greece) is one of the most seismically active regions in Europe and has been studied extensively during the past decades. It is characterized by normal faulting and extension rates between 6 and 15 mm/yr in an approximately N10E° direction. The seismicity of the area is continuously monitored by the stations of the Hellenic Unified Seismic Network (HUSN) and the Corinth Rift Laboratory Network (CRL Net). The availability of a dense permanent seismological network allows the extensive analysis of the seismic swarms which occur frequently. In this study, the September 2014 swarm located at the western part of the Corinth Gulf is analyzed. Initially 707 events, of a two month period, were manually located using data from 18 stations. Double difference relocation was applied using the HYPODD algorithm, incorporating both catalogue and cross-correlation differential traveltimes. Consequently, the initial seismic cloud was separated into several smaller, densely concentrated clusters. Moment Tensor calculation of the 35 largest events was performed using the ISOLA software. The swarm's parameters such as seismicity distribution and moment tensors were combined with the seismotectonic data of the area. The results indicate an initial activation of the Psathopyrgos normal fault; afterwards the seismicity extended both towards East and West, while most events occurred at the western part of the Gulf. The seismicity distribution revealed a main activation of the South – dipping faults. The seismicity migration with respect to pore pressure changes due to fluid movements was investigated through diffusivity calculations. The diffusivity value was found to be 4.5m2s-1, which is consistent with results of previous studies in the area. The results of the investigation of the fault- zone hydraulic behavior provide evidence for the fluid – triggered earthquake swarms and the related rock physical properties.

ESC2018-S20-633

SINGLE-STATION ESTIMATE OF THE MECHANISM OF WEAK SEISMIC EVENTS

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The mechanism is a parameter of an earthquake which typically demands for observations available well around the focus. If this is not at hand, a limited information only can be retrieved on the process of rupturing, e.g., its geometry (the orientation of the fault plane and the slip) but not its shear vs. non-shear nature. The extreme case is the monitoring by a single station, where the mechanism can be estimated only if more eismic phases are available in addition to the direct P and S waves. This is however not the case of weak seismic events, for which the station often records direct P and S waves only. The information is limited severely, and by standard synthetics-to-data-matching allows determine neither the most constrained seismological model of the mechanism, namely the double-couple. We applied a correlation approach and demonstrate its suitability. We tested the obvious requirements of its robustness with respect to a mislocation of the hypocenter and contamination of the P and S amplitudes by a noise, and demonstrate that it works provided the input errors are reasonably small. The bias may be harmful especially concerning the mislocation, as with a single station data only the localisation is limited to an estimate from the P-polarization vector and S-P delay time. The method was applied to selected events from a weak seismicity recorded by a 3-component borehole seismic station MDBI, Israel.

ESC2018-S20-637

MODERN TECTONIC STRESS FIELD IN THE OKHOTSK SEA REGION

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The Okhotsk sea region is characterized by high rate seismic and volcanic activity. The major structural feature of the region is a seismic focal zone. It is the main source of seismic energy which determines the level of seismic hazard in the region. The majority of earthquakes occur in the upper part of the seismic focal zone at a depth of 0-80 km. The quantity of earthquakes sharply decreases with increasing depth. The aim of this study is to investigate the modern tectonic stress field for different depths in the Okhotsk Sea Region. The reconstruction of the stress tensor parameters is based on the method of cataclastic analysis (MCA) of discontinuous displacements (Rebetsky, 1996; Rebetsky et al., 2012). The principal difference between the MCA and other methods is that the MCA allows one to select from all possible states of stress the one that has the maximum rate of dissipation of the energy stored in the elastic deformations (Drucker and Prager, 1952). The stress tensor components are calculated in quasi-homogeneous crustal domains. Each of these domains includes a group of earthquake focal mechanisms. The stress data on the earthquake focal mechanisms are taken from the Global Centroid Moment Tensor database (http://www.globalcmt.org). The orientation of the principal stress axes and the Lode-Nadai coefficient or stress ratio, which characterizes the shape of the stress ellipsoid, are evaluated during the first stage of the MCA algorithm. The obtained results show that the axes of the maximum deviatoric tension σ1, and compression σ3, for the depths 0–30, 30–60, and 60–90 km are usually suborthogonal to the Kuril Trench. The principal stress axis, σ1, dips at a steep angles (55-65°) beneath the continental plate. The principal stress axis, σ3, dips gently (15°–30°) eneath the oceanic plate. The intermediate principal stress axis, σ2, is subhorizontal and parallel to the Kuril Trench almost everywhere. At depths of 90–120, 120–220, and 480–660 km, the axes of the maximum deviatoric compression change their orientation into the opposite one. At these depths, the axes, σ3, are oriented toward the continent instead of the typical oceanward orientation. A similar pattern is observed for the axes of maximum deviatoric tension, σ1. The described tendency in the distribution of the principle stress axes is reflected in the type of stress state (geodynamic regime): most of the studied region is characterized by horizontal compression, depths of 0–30, 30–60, and 60–90 km. However, beginning from the depth range of 60– 90 km the stress state changes and new zones of different geodynamic regimes are formed. The Lode-Nadai coefficient (varies from –1 to +1) is characterized by values from 0.2 to -0.2 almost everywhere. These values correspond to a stress tensor of pure shear. The reduced values of the effective pressure and the maximum shear stress are determined during the second stage of the MCA. The effective pressure is mosaically distributed according to the stress inversion. At the same time, the areas of the highest effective pressure correspond to a high level of shear stress. The reported study was partially supported by the Grant of the President of the Russian Federation, research project MK-2421.2017.5 and by RFBR, research project No. 17-05-01251 a.

ESC2018-S20-638

STRESS INVERSION BEFORE THE DEEPEST EARTHQUAKES OF THE KURIL-OKHOTSK AND JAPAN REGIONS

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In the Kuril-Okhotsk region there were only 6 deep earthquakes with Mw > 7.0 in the 300–650 km depth range from 1976 to 2017: 12 May 1990 (Mw 7.2, h=612.5 km), 17 November 2002 (Mw 7.3, h=479.8), 5 July 2008 (Mw 7.7, h=635.6 km), 24 November 2008 (Mw 7.3, h = 491.6 km), 14 August 2012 (Mw 7.7, h=598.2), 24 May 2013 (Mw 8.3, h=609 km). The 2013 event was preceded by nearby large 2008 earthquakes. Nowadays, the 24 May 2013 Mw 8.3 Sea of Okhotsk earthquake is the largest ever recorded deep earthquake not only in the Kuril-Okhotsk region, but also in the world. In the Japanese region there were 8 deep earthquakes with Mw > 7.0. All events occurred at depths less than 600 km. Today the 30 May 2015 Mw 7.9 Bonin earthquake is the deepest large event in Japan. The goal of the present study is to reconstruct the state of stress before the 2013 Okhotsk and 2015 Bonin earthquakes. Reconstruction of the tectonic stress was performed using the method of cataclastic analysis (MCA) of discontinuous displacements (Rebetsky, 1996; Rebetsky et al., 2012). This

method integrates some of the main principles of the theory of plastic deformation and a generalization of the results of rock failure experiments. The reconstruction of the state of stress is based on earthquake foci data. Stress reconstruction is performed on a 0.5 degree × 0.5 degree grid, at different depths. The 2013 Okhotsk deep earthquake (normal faulting) and 2015 Bonin deep earthquake (normal faulting) are located within the area of horizontal tension, according to the results of the reconstruction. The presence of a large area of stress state with low and moderate levels of the effective pressure may cause strong earthquakes according to (Rebetsky and Marinin, 2006; Rebetsky, 2007). Overcoming the friction forces for such areas requires less energy, correspondingly, more energy is preserved for the development of the earthquake source. Seismological data available for the studied earthquakes were insufficient to obtain detailed stress field at a depth of 400– 700 km. However, the fragments of the stress state, which were calculated in our studies, indicate the possible presence of vast area of low effective pressure. The reported study was partially supported by the Grant of the President of the Russian Federation, research project MK-2421.2017.5 and by RFBR, research project No. 17-05-01251 a.

ESC2018-S20-807

SEISMOTECTONIC AND SEISMIC HAZARD STUDIES IN THE CENTRAL SEISMIC GAP OF THE NORTHWEST HIMALAYA, INDIA

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In the Himalaya region, four great earthquakes have occurred in the last one hundred and twenty five years, viz. Shillong earthquake (1897), Kangra earthquake (1905), Bihar–Nepal earthquake (1934) and Assam earthquake (1950). The region between the great earthquakes of Kangra (Mw~8) and the Bihar-Nepal 1934 (Mw8.2) is a potential zone for future great earthquake and is termed as Central Seismic Gap (CSG) (Khattri & Tyagi, 1983; Khattri, 1987). Recently, a large earthquake of Mw7.8, April 2015 occurred in the eastern side of the CSG in Nepal. This earthquake is smaller than the expected overdue large magnitude event by seismologists, but this earthquake and its aftershocks sequence certainly released a major amount of accumulated strain in this part of the CSG. Therefore, the region lying between west of Nepal Earthquake (Mw7.8) and the 1905 Kangra earthquake is most vulnerable zone for a great earthquake in future. Moreover the seismic activity has been increased in this part of the CSG after the Mw7.8 Nepal earthquake and the present study is carried out for this region. In order to measure vulnerability of the region, in this study the spatio-temporal relationships, source characterisation, moment tensor solution (MT) and stress inversions of the earthquakes has been studied. Two case studies: Rampur Swarm activity in Himachal Pradesh and MW5.8 earthquake in Rudraprayag region, Uttarakhand has been discussed in this study. For source characterization, the source parameters are determined for small to moderate size earthquakes occurred in the Garhwal-Kumaun region. The estimated shear wave quality factor values for each station at different frequencies have been applied to eliminate any bias in the determination of source parameters. Spectral analysis shows the low stress drop values, suggesting that the upper crust has low strength to withstand accumulated strain energy in this region. We performed the stress inversion of the MT for small-to-moderate earthquakes. All these events are of dominantly thrust fault mechanism located near the mid-crustal ramp structure of the Main Himalayan Thrust (MHT) at the seismogenic depth of 7-18km beneath the lesser to higher Himalaya region. The P-axes and the maximum horizontal compressive stresses are NE-SW oriented; the relative motion of the Indian Plate. The present study reveals that the swarm activity in the Himachal region of NW Himalaya is related to the Lesser Himalayan Duplex system. The seismicity nearby Chamoli region indicates the presence of fluids which influence the prevailing stress in the region.

ESC2018-S20-818

STRESS RECONSTRUCTION AFTER THE 2011 GREAT TOHOKU EARTHQUAKE

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Six years have already passed since the 2011 Great Tohoku earthquake. Usually, the aftershock process is completed during this period of time and the system enters the new phase of the preparation of next strong earthquake. However, the magnitude 9.0 Tohoku earthquake was a catastrophic mega earthquake and in this case the presence of an anomalous state of stress can take a long time. Therefore, in present study, the task was to investigate the regularities of spatial distribution of the tectonic stress field, that appeared immediately after the 2011 Tohoku earthquake and continue to the present, by the methods of tectonophysical analysis. It was also established how the relaxation process at the aftershock stage are reflected in the stress field. The work provides new information that helps to clarify the structure of the external loading conditions of the lithosphere of the study region. The reported study was partially supported by the Grant of the President of the Russian Federation, research project MK-2421.2017.5 and by RFBR, research project No. 17-05-01251 a.

ESC2018-S20-867

ANALYSIS OF SEISMIC ACTIVITY DURING THE 2013 GALATI SEISMIC SWARM AND ITS PREPARATORY PERIOD

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The 2013 Galati seismic swarm of southeastern Romania occurred in the area known for its dispersed seismicity characterised by small to moderate crustal events occurring along the major crustal faults. The seismic swarm started on September 23, 2013 and continued with alternating intervals of enhanced and reduced seismicity till November 2013. Between September 23rd and November 5th over 1000 events with the magnitudes (Ml) of 0.2 – 4.0, located between the depth of 5 – 10 km, have been detected. Despite their relatively small magnitude, events generated ground motions that were strong enough to be felt by the local people, leading to panic in the area. The proximity of active oil fields caused additional annoyance and caught the attention of mass-media. Currently, there still does not exist a clear understanding of the mechanism that may be responsible for the generation of this seismic swarm. To provide a better understanding of what might have been a possible cause of the 2013 Galati seismic swarm, we performed a detailed analysis of the seismic activity recorded by the seismic stations in the region. The analysis focuses on providing a more careful investigation of space-time clustering and migration patterns of seismicity during the swarm period. We used the available earthquake catalogues for performing the clustering and template waveform analysis of the recordings from the near-field temporary seismic stations of National Institute for Earth Physics (NIEP). The preliminary results indicate that seismic activity during the swarm can be divided into several clusters well separated in time and corresponding to the different stages of swarm evolution. Investigation of the ROMPLUS earthquake catalog of NIEP indicates that there might have existed an increase of the seismic activity in the area with the spatial features resembling those of activity during the 2013 swarm. To better understand the preparation phase of the swarm we performed a match-filtered analysis of the three-component continuous recordings at CFR station, located about 30 km away from the source region, using the template events identified in the swarm catalog. CFR is the only closest station that recorded both the seismic activity during the swarm and has a history of high-quality continuous recordings going back to 2008. We will present and discuss the results of this analysis and its relation to the preparatory phase of 2013 seismic swarm. The presentation will also discuss the ongoing effort for seismic activity monitoring in the region and its potential contribution to the reduction the seismic hazard in the area.

ESC2018-S20-989

EXPLORATION OF CHANGES IN RADON CONCENTRATION AND FAULT DISPLACEMENT IN THE BACHO KIRO CAVE (BULGARIA) AS SEISMIC ACTIVITY PRECURSORS

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Since 2009 the Experimental Laboratory of Karstology of the NIGGG-BAS developed a model for Integrated Monitoring of Karst System (MIKS). The research started along the International Research Project „Development of an experimental model of complex monitoring for sustainable development and management of Protected Karst Territories" (ProKARSTerra), supported by the Bulgarian Science Fund. Experimental studies are conducted in representative karst geosystems in Bulgaria. Radiological monitoring (222Rn, 14c and gamma-background) and Fault displacement monitoring (with precise three-dimensional extensometer TM-71) are parts of this model and are conduct together with the Department of Radiation Dosimetry, Nuclear Physics Institute and the Department of Engineering Geology Institute of Rock Structure and Mechanics (incl. and with the financial support provided by a bilateral international research agreement between the Bulgarian and the Czech Academy of Sciences). The most important result is establishment of correlation between abrupt fluctuations of radon concentrations in cave air and fault displacements in the Bacho Kiro cave, due to registered seismic activity (1). The Bacho Kiro cave is one of the largest caves in the region (total length investigated about 3600 m) and also one of the most popular touristic caves. It is situated in the eastern part of the inverse karst plateau Strazhata in Central Bulgaria. The plateau is made up of Lower Cretaceous limestones. The Bacho Kiro cave entrance (5.8/1.4 m) is at 355 m of altitude, in the base of a rock cliff Buruna. The cave system is a sub-horizontal (slightly ascending, with total displacement of +65 m), four storey labyrinth, oriented along the Strazha syncline axis. In the cave is supported by a relatively good ventilation, which is reflected in the low concentrations of CO2, even in the internal cave parts (seasonal variations between 550-600 and 1200-2200 ppm). These cave parts show stable microclimatic conditions: the cave air temperature stays constant, between 10.8 and 12.6°C, relative humidity of 95-99% (for the entire period of experimental integrated monitoring). The stable temperature and humidity in to the cave are giving perfect laboratory conditions. During 2012 in the Bacho Kiro the permanent extensometer TM-71 and passive solid state detectors for radon-222 concentration measurement were installed as a part of monitoring networks EU-TecNet and BGSpeleo-RadNet. The extensometer TM-71 is able to measure relative fault displacements in three co-ordinates (x, y, z), with a precision better than ±0.007 mm and horizontal and vertical rotations (gxy and gxz), with a precision better than ±0.00016 rad. The results between the sharp fluctuations in the radon concentration and the tectonic regime are compared with several local and regional earthquakes with M≥3.5. A correlation between these physical parameters was established. Especially distinct are 3 episodes of significant abnormalities after Aegean Sea earthquake (May 24, 2014, Mw = 6.9 and the long aftershock sequences), Nova Zagora earthquake (April 18, 2016, Mw = 4.3, ML=4.0), and Vranchea, Romania earthquake (23.09.2016, Mw = 5.7, shows a sharp rise of the radon-222 concentration, followed by a drop). These episodes are clearly marked in the TM-71 extensometer records. The focal mechanisms of all earthquakes were determined and compared with the extensometer measurements. Relation between fast fault sliding and slow tectonic movements were established. The obtained results correspond to the regional stress field of the northern part of Balkan peninsula (2). The slow movements due to tectonic pulses in the plates and fluctuations in radon concentration can be very valuable precursors for seismic activity and are giving additional information in tectonic regime of Bulgaria. Therefore, their precise monitoring is extremely important for seismic risk assessment. The Bacho Kiro cave has a proven potential of an underground station for this type of research. A strategic goal is to implement a state-of-the-art scientific infrastructure in the cave. Since March 2018 the instrumental monitoring of radon concentration in cave air have begun, parallel with passive detectors measurements. The maintenance and development of Integrated monitoring in the Bacho Kiro cave continues with two new international projects of the Bulgarian Science Fund:"Exploration of changes in some geophysical fields preceding the occurrence of earthquakes in the Balkans", and "Current impacts of global changes on evolution of karst (based on the integrated monitoring of model karst geosystem in Bulgaria", which results will complement each other. Additional contribution brings the project "Plate-wide tectonic pressure pulses (Correlation of the extensometric monitoring in Mediterranean and Central Europe)", which

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ESC2018-S20-1008

SUBCRUSTAL AFTERSHOCK ACTIVITY IN THE NE-PART OF THE SOURCE RUPTURE AREA OF THE OCTOBER 23, 2011 VAN EARTHQUAKE (MW=7.1), EASTERN ANATOLIA (TURKEY)

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Focal mechanisms of 50 aftershocks (equal/larger than Mw 3.5 since 2011, the Van earthquake) taking place in the NE part of the source rupture area of the devastating Van earthquake (Mw 7.1), E-Anatolia (Turkey) are under investigation in this study. Broadband waveforms recorded at the seismic stations operated by Kandilli Observatory and Earthquake Research Institute (KOERI, Turkey) are inverted to their sources using the waveform modeling methodology developed by Kuge (2003), which models displacement seismograms at one or more stations within local distances (0–200 km). A centroid location is determined by a 3D-grid search scheme that achieves the best fit between observed and synthetic displacement seismograms. The data were band-pass filtered between 0.04 and 0.1 Hz during the inversion process and a uniform weight was assigned to all the seismograms. The best fit between observed and predicted seismograms is evaluated using variance reduction (VR). The variance reduction is calculated for various depths, and the faulting mechanism in which VR is maximum was selected. The variance reductions determined for different depths suggest that the aftershock activity in the NE part of the source area is confined in the lower crust where most of the aftershocks show predominantly strike-slip mechanism. Two distinct lineaments are obvious from the spatial distribution of the centroids confined in depth ranges between 20-30 km; one extending in NW-SE direction and the other oriented almost N-S. The two lineaments intersect at the N tip of Lake Erçek (E of Lake Van region), suggesting potential seismic risk of possible subcrustal earthquake activity across NNE-part of Lake Erçek region where vertical faults with reverse components and faulted uplifting blocks were observed from seismic reflection data collected in Lake Erçek Basin.

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SESSION 21

ESC2018-S21-70

EXPERIMENTS ON FORCED STICK-SLIP: IMPLICATIONS TO INDUCED SEISMICITY.

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According to the general theory of synchronization of integrate-and-fire processes (Pikovsky et al., 2003) the phase space plots (the Arnold's tongue plot) for synchronized stick-slip sequences independent of the processing method should have an inverse triangle (bell-curve) form, namely, is has both low- and high frequency branches. Note that according to this general model: i. the observed frequency at synchronization can be lower or higher than the natural frequency of integrate-and-fire processes due to coupling of the forcing with autonomous oscillator (actually, this leads to Arnold's tongue formation); ii. in addition to phase locking at , the phenomenon of high order synchronization (HOS) can be observed at multiples of natural frequency , i.e. at frequencies higher or lower than (Pikovsky et al., 2003; Chelidze et al., 2009, 2010). The parameter is called a winding number. Last years the another - "nucleation" model - was suggested, where it is supposed, that if the forcing's period is less than some nucleation (stick) phase duration, it cannot lead to synchronization: as a result synchronization area plot should reveal only low-frequency branch (Scholz, 2003; Beeler and Lockner, 2003; Bartlow et al., 2012). The nucleation model do not agree with the general theory of synchronization of integrate-and-fire nonlinear systems, where the slow nucleation (integrate, stick, stress accumulation) phase terminates necessarily by a slip (fire, stress drop) phase and which, under forcing, as a rule, demonstrates conventional synchronization plot with multiple Arnold's tongues. Our experiments show that the Arnold's tongue model works well, though stick-slip is definitely a process with a nucleation phase: nucleation phase corresponds to a stick phase, when the stress accumulates to overcome friction resistance. Her we again can address the general model of integrate-and-fire oscillators (Pikovsky et al., 2003), where in the each cycle of the recurrent process the driving force slowly accumulates (integrate) and at some threshold value instantly relaxes (fire). This picture fully describes stick-slip process: stick phase is a slow phase, when the stress accumulates and fire phase is an instant slip, which in our experiments we identify as acoustic bursts. Our experiments confirm predictions of the general theory of synchronization of integrate-and-fire processes in the particular case of stick-slip. We show that varying the forcing frequency and drag velocity it is possible to reveal all predicted by theory regimes of phase locking from 1:1 synchronization to high order synchronization (HOS) at multiples of natural stick-slip frequency. We found that not only the onsets/maxima of AE signals are synchronized with forcing, but also AE wave train terminations. The data allow delineating the synchronization regions (Arnold's tongues) in the phase space plot of forcing intensity versus forcing frequency. Our experiments with mechanical periodic forcing, as well as our earlier experiments with electromagnetic forcing on the same slider-spring system, support the view, that forced stick-slip phenomenon belongs to the general class of integrate-and-fire systems and consequently, phase space plot of synchronization area has configuration, close to the inverse bell-curve form, known as the Arnold's tongue. In the phase space plot of synchronization area of forced stick-slip (as generally in integrate-and-fire systems), both low- and high-frequency branches of Arnold's plot are frequency dependent. Lastly, we applied the tools of nonlinear dynamics to reveal complexity/synchronization patterns in earthquake time series under weak external periodic forcing, such as water level variation in large reservoir. Our analysis reveals appearance of the annual component as well as the 4-months harmonic in the local seismicity during periodic load-unload of reservoir, which are absent in the preceding reference period. The 4-months harmonic can be an example of high-order synchronization related to the annual cycle. The finding that forcing can change synchronization regime of stick-slip point to possibility of existence of seismic tidal effects at frequencies, different from tides' periods classic values due to phenomena of high order synchronization and slips' waiting times shortening by decreasing firing threshold.

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ESC2018-S21-81

WESTERN DRIFT OF SEISMIC OSCILLATIONS AFTER STRONG EARTHQUAKES

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The structure of the pulsations with a period of 129–130 min is studied in greater detail from the records at dozens of IRIS broadband seismic stations located in the different regions of the world. The microseisms in the interval of the periods of about the seconds and the semidiurnal and diurnal oscillations (the Earth tides) were suppressed by Gaussian filters. The analysis of the records revealed wave trains with a period of ~ 129.5 min caused by the earthquakes in Sumatra (December 26, 20014, M = 9.1), Chile (February 27, 2010, M = 8.8), and Tohoku, Japan (March 11, 2011, M= 9.0). At the stations located at an angular distance of 180 grad (in the opposite hemispheres), the oscillations appear simultaneously but have the opposite polarities. At the same time, they emerge with a time shift in the records at the stations that are shifted in longitude. The time shifts of the arrivals of the wave trains at the stations in the eastern and western hemispheres demonstrate a linear western drift by 2.5 grad per hour with the high coefficients of determination R**2 > 0.95. The wave trains are earlier recorded at the stations that are close to the earthquake epicenter and to its antipode. As a result, when the oscillations have the maximal amplitude at a certain time instant at a certain station, the oscillations at the station that is shifted by 90 grad in longitude are absent at this time and are most manifest 36 h (1.5 days) later. The oscillation trains are earlier recorded at the stations that are close to the epicenter and antipode of the epicenter of the earthquake. They become less manifest with the increase in the distance from the station to the line connecting the epicenter with its antipode. The amplitude of the oscillations in the wave trains is estimated at a few mm. The wave trains presumably reflect the emergence of an area of free post seismic flexural oscillations of lithosphere.

ESC2018-S21-124

STATISTICAL ANALYSIS OF MANIFESTATIONS OF THE ROUND-THE-WORLD SEISMIC ECHO IN AFTERSHOCK SEQUENCES

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The existence of the effect of the round-the-world surface seismic waves (“seismic echo”) in evolution of aftershock process was shown in the work on a broad evidence base, including hundreds of the main shocks and thousands of aftershocks. At the same time, we by no means believe this effect has been fully proven. We only present a version of our own understanding of the physical causes of the observed phenomenon and analyze the regularities in its manifestation. The effect is that the surface seismic waves excited in the earthquake source by the main shock makes a complete revolution around the Earth and excites strong aftershock in the epicentral area of the main shock at the time T = 3 +/- 0.5 hours after the moment of main shock. The physical nature of the effect is that a critical concentration of wave energy in epicenter is created by converging surface waves under achieving of epicentral area (cumulative effect). Effect of the first seismic echo is manifested most clearly. For the statistical analysis of the dynamics of the seismic events flow after strong earthquakes (main shocks), we selected several datasets from a long time series of the earthquakes contained in the global catalog USGS/NEIC for the period 1973-2014 and in the regional catalog of Northern California for the

period 1968-2007. For data processing and efficiently detecting the effect of a seismic echo, we used an algorithm based on the well-known superposed epoch analysis, or synchronous detection method. Thus, the present work supports our hypothesis of the activation of rock failure under the cumulative impact of an round-the-world seismic echo on the source area which is releasing ("cooling") after the main shock. The spatial regularities in the manifestations of this effect are established, and the independence of the probability of its occurrence on the main shock magnitude is revealed. The detected phenomenon of the seismic echo can be used to increase the probability of a forecast of a strong aftershock in determining the scenario of seismic process in the epicentral zone of occurred strong earthquake. This work was partially supported by the Russian Foundation for Basic Research (project # 18-05-00096) and Russian Governmental assignment programs of the Schmidt Institute of Physics of the Earth RAS.

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ESC2018-S21-146

THE 150TH ANNIVERSARY OF FUSAKICHI OMORI

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Our report is devoted to the memory of the outstanding Japanese scientist. In 1896, Fusakichi Omori discovered the law of the aftershocks evolution that bears his name. We represent the Omori law in the form of a differential equation. This allows us to take into account the non-stationarity of rocks in the earthquake source, which cools down after the main shock. By using aftershock equation we put the inverse problem of physics of the earthquake source. On this path we hope to find approaches to the diagnostics of the state of rocks in the source and to forecast of the likely evolution of processes leading to a subsequent strong earthquake. This work was partially supported by the Program 28 of the Presidium of RAS, RFBR projects # 16-05-00056 and # 18-05-00096, Russian Governmental assignment programs # 0144-2014-0097 and # 0144-2014-00103.

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ESC2018-S21-176

A NEW APPROACH TO MINING SEISMIC MONITORING

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Summarizing information about large-scale man-caused and tectonic earthquakes (structures of focal zones, triggering factors, mechanics of generation of different slip modes in faults, seismic efficiency, etc.) and methods of fault shear stiffness assessment allowed to elaborate a technique of remote monitoring of areas potentially dangerous for mining operations. The persistent efforts undertaken by the international seismology society to evolve short-term earthquake prediction methods have very modest results and demonstrate restrictedness of predictability of an oncoming seismic event using indirect signs recording across a wide area of initiation of an earthquake: increase and decrease of the level of seismic activity, variation of geophysical fields and many others. For instance, it is extremely difficult to relate a rise or lowering of water level in an observation well with the initiation of a catastrophic earthquake hundreds or thousands of kilometers away. The situation with the large-scale induced events is more encouraging. Geomechanical modeling allows sufficiently reliable identification of probable

deformation concentration sites in many cases and enables narrowing the monitoring range. The generalized observations over hypocenters of the strongest mining-induced events have shown that this type of deformation occurs as movement along the existing faults. The universal macroscopic parameter controlling the seismic efficiency of a slip on a fault is the shear stiffness or the rate of decreasing the frictional resistance during relative fault side displacement. Irrespective of P–T conditions, tectonic mode, material constitution of a fault, water content, pore pressure, etc., a sliding mode will be determined by the ratio of stiffnesses of a fault and an enclosing rock mass. From the experimental evidence, transition of a section of a fault to meta-stable state goes with the decrease of its dynamic shearing rigidity. An abrupt decrease of the fault shear stiffness, judging by the results of laboratory experiments, is caused by the presence of some minerals or watered clays in the fault principal slip zone. The decrease of stiffness inside a rock mass can be registered as increasing amplitudes of waves reflected from the fault zone, and thereafter as decreasing amplitudes of refracted waves. As judged by the experimental results, the transition of the interface in the metastable state is accompanied by the decrease in the dynamic shear stiffness of the interface. The process of change in the mechanical properties of the interface starts long before a macroscopic displacement is recorded. In the tests, the time of a precursor was 10 s, i.e. more than 1/3 of the length of the “seismic cycle.” So the alteration of the mechanical properties starts long before macroscopic movement of the fault surfaces is recorded. This effect is detectable using instruments and can be used as a foundation for a new approach to monitoring of induced earthquakes. In order to test the measuring techniques and the principles of the observation system arrangement, measurements were set up in the pit of the Kursk Magnet Anomaly in Russia. Deformation and seismic measurements in the pit were held on two faults of different scales. Relative displacements, accelerations and velocities of fault sides under the action of seismic waves produced by explosions in the close quarry and in the pit itself were recorded. Durations of both disturbances were actually the same but a noticeable difference in reactions of the rock massif was detected to the action of seismic waves produced by these two different sources. Changes of waveforms caused by passage through the tectonic discontinuities were registered. Records of the deformograph showed creep and slow events - abrupt changes of the deformation character (failures) during which the deformation rate increased noticeably, but didn't reach values intrinsic for normal earthquakes. This work was supported by the Russian Science Foundation (Grant No. 16-17-00095).

ESC2018-S21-179

MECHANISM OF MICROEARTHQUAKES FROM ACOUSTIC EMISSION IN A LABORATORY: HOW TO EFFICIENTLY EVALUATE A LARGE AMOUNT OF DATA

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The importance of laboratory experiments is based in the fact that conditions in a laboratory represent a significant simplification compared to the actual conditions in situ and, at the same time, they represent the only chance to control the physical conditions under which the investigated physical phenomena occur. Acoustic emission (AE) is the process accompanying the brittle fracturing of solid body and simultaneously an indispensable tool for its study. Laboratory experiments under controlled loading conditions make it possible to differentiate the effect of important factors like material structure, stress field, crack presence, etc. on fracture initiation and development, and allow simulate the nature in situ. Microearthquakes detected during AE are similar to natural ones therefore it is natural to exploit an experience from seismology and applied the methods originally that came from seismology for quantitative AE analysis. The shear-tensile crack (STC) description of source mechanism was used to process AE data with the aim to detect the mode of rock fracturing, in particular to distinguish between a shear slip and tensile crack, both in the phase of its opening and closing. The benefit of discerning between shear and tensile fracturing will be an insight into changes of the permeability of the rock massif both in space and time. By contrast to natural seismology, tens of thousands AE events occur in laboratory during the experiment. Expecting to process large volumes of data, an urgent demand was to make

the STC inversion as fast as possible. It is a non-linear procedure, thus alternative minimization schemes apart two step grid search (combining a coarse global search and a fine grid in low-misfit zones of the model space) were tested. It should be stressed that it is important not only to calculate a large number of mechanisms, but also to realistically estimate their stability and reliability. This aspect is often neglected in practice. To assess the reliability of the STC solution obtained, the confidence zones of source model parameters need to be evaluated. Confidence zones are objects within the model space that specify the volume in which the solution of the inverse task is contained in an a priori specified probability, taking into account errors in the data. The size and shape of the confidence zones indicates the uncertainty of the estimated parameters: large confidence zones indicate a poor solution while small confidence zones suggest a good solution. For the procedure, we scanned the model space within a regular grid and evaluated a match to the data and the probability density function (PDF) for the grid points. We then integrated the PDF across a trial volume within the model space and searched for a patch in which the cumulative probability acquired certain values, generally 0.9, 0.95, and 0.99. Investigating individual events, we displayed complete plots of the confidence zones, both for the mechanism orientation and its decomposition. Aiming to process a large bulk of AE data, a method of assessing of these zones needs to be proposed, which describes them by estimates of their extreme size. This allows us select effectively for subsequent interpretation from all solutions only those that are stable and reliable. We have applied this approach to the experimental data obtained from a uniaxial compression test performed on a Westerly Granite specimen using a 14 channel AE monitoring system.

ESC2018-S21-184

CAN WE FIND THE TRACES OF EARTHQUAKE NUCLEATION IN THE SPECTRUM OF AMBIENT NOISE ?

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One of the grand challenges in seismology is the search for macroscopic characteristics that could be used in monitoring seismically active areas in order to predict earthquakes. Most of phenomena which are used as precursors do not characterize the rupture zone itself, they rather deal with a larger area of elastic energy accumulation. For this reason, considerable efforts have not resulted so far in any reliable short-term earthquake precursor, although some positive progress has being made. As an alternative to observing characteristics of a huge area where earthquake precursors may be revealed, various methods of local monitoring seismically active faults can be used. The spectrum of ambient noise should inevitably contain components corresponding to natural frequencies of a blocky structure. And the evolution of mechanical characteristics of a local fault segment may be encoded in the ambient noise, thus, converting the ambient noise to an efficient source of information about the fault stress-strain conditions. We present laboratory experiments designed to study a possibility to recover some information about fault stress-strain conditions from the ambient seismic noise. Micro-vibrations of a block-fault system induced by weak external disturbances were studied to get reliable evidences of laboratory earthquake nucleation. We show that precursory changes of spectral characteristics of micro-vibrations are observed during the final stage of failure preparation. All the experiments were performed in the statement of spring slider model. A granite block was laid on the surface of a long granite rod, in the middle of it. The contact between rough surfaces of the block and the rod was filled with a layer of granular material 3 mm thick. A constant normal static load was applied to the block through a special device. The shear force was applied to the block through a spring, which was pulled by the edge at the constant velocity of V0 = 8μm/s. The shear force was measured by a force sensor with the accuracy of 1 N. The block displacement relatively to the base was measured by a laser sensor in the frequency range of 0–5 kHz with the accuracy of 0.1 μm. Vibrations in the granite rod were excited by impacts over its edge. The impacts were produced by a plane rough striker attached to the diaphragm of the coil driven loudspeaker, which was fed by the signal from the white noise generator. Elastic vibrations were measured with accelerometers mounted on the rod and on the block. These vibrations had no visible effect on the macroscopic parameters of slip regime - peak velocity, recurrent time, fault strength.

Experiments have shown that the value of natural frequency of the block fault system fc drastically decreases during preparation of dynamic slip episodes. After the rupture stops, fc grows rapidly reaching its maximal value, which corresponds to the characteristic value of fault shear stiffness at the loading stage. At the "interseismic" stage variations of fc are relatively small. During the process of elastic energy accumulation, long before the ultimate strength is reached, both fc, and fault shear stiffness start to decrease, and the rate of that decrease gradually grows as the moment of dynamic rupture approaches. Our experiments have demonstrated that the shift of the characteristic frequency of natural oscillations toward low frequencies may serve as an indicator of dramatic decrease of the fault shear stiffness and the transition of the block-fault system to a metastable state. It is evident that detecting natural frequencies of blocks in the ambient noise is undoubtedly a separate problem, requiring special methods of observations and data processing. Apparently, most advantageous for detecting the characteristic values for a certain region, can be the intervals of seismic records after the passage of surface waves from distant earthquakes. These vibrations with periods of several tens of seconds have noticeable amplitudes and rather long durations, which promotes excitation of resonant harmonic oscillations of block-fault systems. Determination of such frequencies, specific for each area, and tracing their variations can, in our opinion, make the base for a new approach to local monitoring of seismogenic faults and to solution of the problem of short-term earthquake forecast. This research was supported by Russian Foundation for Basic Research grant no. 16-05- 00694

ESC2018-S21-213

UNDERSTANDING SEISMIC AND VOLCANIC PRECURSORS THROUGH SHEAR-WAVE SPLITTING: CURRENT KNOWLEDGE AND PROSPECTS

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Shear-wave splitting (SWS) occurs when a S-wave enters an anisotropic medium and splits into two components, travelling with different velocities, the Sfast and Sslow. The time difference between the arrivals of the two is commonly referred to as time-delay or time lag td and has been utilized as a diagnostic tool of the stress regime in tectonic and volcanic areas. While stress builds up, fluid-filled microcracks in the upper crust are undergoing changes that affect td. Shortly before the event, the increase of stress stops and a significant drop occurs, due to microcracks coalescing to form the fault plane. These variations represent the stress accumulation and release in the medium. A “stress-forecast” of an impending M=5.0 earthquake in Iceland was achieved by Crampin et al. (1999), approximately two weeks prior to its occurrence, by analyzing shear-wave splitting and observing the temporal variations of normalized (per the hypocentral distance) time-delays tn. Similar observations have been reported by various research teams since then, but always in hindsight. Concerning volcanic eruptions, an additional phenomenon of shear-wave splitting can be considered as a precursor, i.e. the 90° flip of the polarization direction before an event. Shear-wave splitting as a robust tool for earthquake prediction is facing certain obstacles. The method is highly dependent on the occurrence of intense seismicity in the vicinity of the station, given that a significant number of recordings will be rejected due to selecting suitable data and, while feasible, manual shear-wave splitting analysis is time-consuming. Automatic methods have been widely applied but require even stricter selection criteria, which leads to even less usable results. In addition, SWS studies have observed significant scattering of time-delays, attributed to high pore-fluid pressure, which could contaminate data showing fluctuations of time-delays due to a stress cycle linked to an event. In Greece, such phenomena have been observed in both tectonic and volcanic environments. In the Western Gulf of Corinth, tn have been linked with the occurrence of significant (Mw > 3.5) earthquakes during the seismic swarm of 2013. In the island of Santorini, a period of increased volcanic activity during 2011 – 2012 was not accompanied by a significant volcanic event. No 90° flips of the polarization direction were derived from shear-wave splitting.

Nevertheless, tn exhibited gradual increase and sudden drop, related to the major Mw = 5.1 and 5.2 events which took place about 40 km SW of Santorini. Shear-wave splitting can be combined with other techniques that study precursor phenomena. Variations of VP/VS ratios and shear-wave velocity obtained from seismic interferometry can complement each other. In addition, development of robust and fast algorithms that can automatically perform shear-wave splitting analysis in big data is important for entrenching seismic anisotropy in the consciousness of researchers studying precursory phenomena. Shear-wave splitting cannot be currently implemented in operational forecasting, but increased interest on the topic can lead to clarifying the source of anisotropy and fully understanding the mechanisms behind stress cycles, rendering the method reliable.

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ESC2018-S21-226

ANALYSIS OF THE RADON TIME SERIES ACQUIRED IN FRIULI (NORTH EAST ITALY), OF THE CRUSTAL DEFORMATION AND OF THE SEISMOMETRIC DATA.

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Radon is a radioactive noble gas formed by the decay of the radio, generated in turn by uranium and present in the earth's crust. Its decay time is 3.8 days. It rapidly spreads in the ground by diffusion or by convection by means of carrier gases such as methane, carbon dioxide, and nitrogen through cracks and by permeability of the soils. It was at the beginning of the past century that radon began to be analysed as a seismic precursor. Changes in the chemistry of fluids that manifest as transient phenomena can provide indications on the state of the deformation and, consequently, on the various phases of the earthquake cycle. Almost all the proposed models are based on the principle that during the earthquake preparation process, the increase of stress, due to deformation, leads to changes in pressure in the pores, formation of new fractures and consequent variation of the geochemistry of fluids (e.g., Scholtz, 1973). However, the major difficult is in distinguishing the various factors that determine the time variations of the radon emissions, so to evidence possible anomalies bound to the rock deformation. The object of the present work is to compare the radon measurements with data about the crustal deformation. The study area is located at the northern boundary of the Adria microplate, where its collision with the Eurasia manifests in a complex tectonics. The eastern sector of the Southern Alps is characterized by E-W trending overthrusts, crossed by subvertical faults with N-S direction, gradually substituted, to the east, by NW-SE trending Dinaric transpressive lineaments. Several strong earthquakes both in the past and more recently hit this region (Gemona, May 6, 1976, Mw 6.4; Bovec, April 12, 1998, Mw=5.6, and July 12, 2004, Mw=5.2). The radon monitoring site is equipped with a continuous radon recording, Lucas scintillation cell type. The operating modalities are continuous and grab sampling; the sensibility is of 4 Bq/m3. The air is inhaled by pumping, from a 40.5 m deep well with a 9 cm diameter, at a 7 m depth. The groundwater level is about 17 m deep from the top of the well. The sampling interval is of 3 hours. The survey site is operating, continuously, from November 2002 up to now, constituting the longest time series of radon in soil on the national territory. During the whole period, the meteorological influence on the radon behaviour has been verified in order to discriminate transient signals potentially influenced by the crustal deformation. A radon anomaly is defined as a radon concentration which deviates for more than twice the standard deviation (2 sigma) from the average radon concentration (Igarashi and Wakita, 1990), and it is considered correlated with the meteorological events, if the time gradient of barometric pressure and of the time gradient of radon concentration in soil gas have the same sign (Vaupotic et al., 2010). The radon concentration time series has been compared with seismicity, GPS and InSAR data with a particular for the period 2006-2010, where both radon and GPS data showed anomalies (Petrini et al., 2012; Rossi et al., 2018). The analysed seismicity was recorded by the North-East Italy Seismic network managed by Istituto Nazionale di Oceanografia e di Geofisica Sperimentale -OGS and by the Italian National

Seismic Network managed by Istituto Nazionale di Geofisica e Vulcanologia (INGV). The seismicity was analyzed according to the Hauksson and Goddard (1981) relation, by means of which the minimum magnitude required to obtain transient phenomena at a definite distance is calculated and compared with the radon short period variations, and through its variations on the whole area, expressed by b-value (Gutenberg and Richter, 1944). The analysis of the deformation of the studied area makes use of the geodetic measurements detected with GPS and InSAR technology that monitor, in continuous the deformations of the area. The GPS data are from the FReDNet permanent GNSS network (Friuli Regional Deformation Network) managed by OGS, consisting of 17 sites operating starting since 2002. The InSAR have been provided by the Italian Ministry of the Environment, which since 2008 develops SAR images through interferometric techniques acquired from satellites since 1992.

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ESC2018-S21-245

SHEAR-TENSILE CRACK: SOURCE MODEL FOR LABORATORY ACOUSTIC EMISSION

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Acoustic emission (AE) is a phenomenon that spans the generation and propagation of acoustic (elastic) waves caused by sudden irreversible changes in the internal structure of a type of material. In the case of rock, it is closely connected to the generation, growth, and interaction of microcracks and leads to a brittle failure. As such, an AE event may be considered, on a very small scale, as an earthquake with a size on the order of millimeters in the case of laboratory experiments. Considering phenomena similarity and approximately 70 years of seismology, it is not surprising that most of the methods for quantitative AE analysis originally came from seismology. Here, a shear-tensile crack (STC) model is presented as suitable for acoustic emission events. Experimental data was obtained from a uniaxial compression test performed on a Westerly Granite specimen (cylinder with diameter 50 mm and length 100 mm) using a 14 channel AE monitoring system. The advantage of the STC versus a traditional MT (Moment Tensor) approach is, as follows: (i) it is a physical source, contrary to the MT, since the STC describes the straight and simple fracture modes anticipated inside a loaded sample, namely the shear-slip and both of the opening and closing tensile cracks; and (ii) it is simpler because it is described by fewer parameters (5 instead of the 6 required for an unconstrained MT), which is essential for solving the inverse problem. The presented STC procedure was tested on 38 AE events selected over a range of 50 – 98% for the uniaxial compressive strength. As compared to the MT model, the STC model displayed a similar fit for input data while providing far smaller confidence regions. The results indicate a more certain determination for the mechanism orientation and improved reliability for the decomposition components. In addition, use of STC model allowed better distinction between tension and shear type for AE events, which may be a crucial for recognizing an approaching failure. The main goal of this work is not to present a detailed analysis of the fracturing process, but to test and present an STC approach for AE mechanism determination for a set of 38 selected AE events (from approximately 20,000 registered events). Despite limitations for the AE data set, discussing how STC obtained mechanisms fit the general idea of the fracturing process in compression tests is illustrative.AE crack length was determined to be slightly above the range of the largest grains. The principal stresses orientation, inverted from the STC mechanisms, corresponded to stress conditions for a uniaxial compression test. Transition from tension to shear microcracking was recognized while crossing the crack damage

threshold. Preferential orientation of the shear cracks was determined to coincide with orientation of the failure plane.

ESC2018-S21-324

IDENTIFYING ASPERITY PATTERNS IN CENTRAL IONIAN ISLANDS VIA MACHINE LEARNING ALGORITHMS

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The aim of this work is to identify asperity locations in the area of central Ionian Islands using machine learning techniques. This area is well known for its high seismicity rate and frequent occurrence of M5 earthquakes, the anticipated occurrence of which constitutes the target of the current study.With a feature vector of selected earthquake statistic attributes, the machine learning algorithms Logistic and FT were trained with data from Hokkaido region used as ground truth. Consequently with the same feature vector calculated herein for the area of Ionian Islands, the algorithms were utilized to predict possible asperity locations. To create the feature vector the calculations were performed at the nodes of a normal grid superimposed onto the study area composed of cells with dimension 0.1°X0.1°. The catalog compiled by the Geophysics Department of the Aristotle University of Thessaloniki (http://geophysics.geo.auth.gr/ss/), based on the recordings of the Hellenic Unified Seismological Network (HUSN), was used for constructing the data sets. The earthquake statistic features proposed as asperity identifiers were calculated for every cell, which are the b-value, the recurrence interval (Wiemer et al. 1997), and earthquake density (Takahashi et al. 2007). The training part of the algorithms was made with data from the area of Hokkaido in Japan (Arvanitakis et al., 2018). In order to validate the classification results of the two algorithms, the earthquake catalog of central Ionian Islands had to be separated in 7 distinct data sets. For every set a smoothed seismicity map was created to identify areas with higher probability of generating ≥M5 earthquakes. Coincidence of areas that were classified by the algorithms as asperities, to areas with high probability of generating ≥M5 earthquakes, were assumed as an evidence of a correctly classified pattern. We acknowledge support of this work by the project "Telemachus - Innovative OperationalSeismic Risk Management System in theRegion of Ionian Islands", funded by the Regional Operational Programme Ionian Islands 2014-2020, co-funded by the European Union and Greece. Geophysics Department Contribution 000.

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ESC2018-S21-381

TIME-DEPENDENT EARTHQUAKE RECURRENCE MODELS IN NORTH AEGEAN TROUGH (GREECE) BASED ON A NEW SEGMENTATION MODEL

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The determination of the recurrence time of strong earthquakes with magnitudes above a predefined value, that area associated with specific fault segments, consists an indispensable component of seismic hazard assessment. The occurrence of these earthquakes is neither periodic nor completely random but often exhibits either short and long term clustering behavior or quasi – periodic occurrence. When this is taken into account along with the shortage of the available catalogs, it evidences that a deterministic approach for recurrence time

calculation is not either feasible or effective and for this reason stochastic processes engagement is required. This approach is followed for the exploitation of historical catalogs comprising strong (M>6.5) earthquakes that occurred along the North Aegean Trough (NAT), Greece. The study area is among the most active ones in the Greek territory exhibiting frequent occurrence of strong earthquakes given that NAT consists the active boundary between the Eurasian plate and Aegean microplate across which the latter is moving southwestwards with rates between 22.5 to 12.5 mm/yr from to westward. A new segmentation model consisting of 5 distinctive although adjacent fault segments is attempted, based on seismicity properties, fault plane solutions and local morphology. For each segment the recurrence time modeling was implemented by the Brownian Passage Time (BPT) distribution. The BPT model assumes that the evolution of the stress loading between two strong earthquakes on a given fault or fault segment is the summation of a constant loading rate, $\lambda(t)$, and a random component, $\varepsilon(t)$, which can be described in terms of Inverse Gaussian distribution with parameters: μ, the mean time between successive earthquakes and α, the aperiodicity that controls the randomness of the model and is equivalent to the coefficient of variation. Application of BPT distribution was made by the calculation of each segment recurrence time means among with a suite of predefined values of aperiodicity (α = 0.3, 0.5, 0.7) whereas the Time-Independent model was also applied. All the four models were then evaluated by the Anderson–Darling goodness of fit statistical test in an attempt to identify the best performing one. The conditional occurrence probabilities are thus calculated with the distribution that better fits each segment's data for the next 10, 20 and 30 years. These calculations reveal the remarkable differences of the occurrence probabilities among the segments in which Mw≥6.5 were recent occurred instead of those with longer elapsed time. This research has been supported by the project "HELPOS – Hellenic System for Lithosphere Monitoring" (MIS 5002697) which is implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

ESC2018-S21-410

TRACING ASPERITIES IN KAMCHATKA AREA USING BREAK OF SLOPE IN MAGNITUDE-FREQUENCY DISTRIBUTION

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Magnitude-frequency distribution is usually regarded as a straight line (in logarithmic scale of the frequency) up to largest magnitudes in accordance to the well-known Gutenberg-Richter law. However, it was shown recently that this straight line may experience a break of slope at moderate magnitudes in zones of significant aseismic deformation (creep). Here, based on the statistics of earthquakes in Kamchatka slab, we exploit this phenomenon to trace possible boundaries of zones of higher seismic coupling (asperities) using band-limited analysis of the slope of the magnitude-frequency distribution. We compare our results with known observations and independent models of asperities in the considered area. The research was supported by Russian Foundation for Basic Research (Project 16-05-00263).

ESC2018-S21-418

INVESTIGATION OF DEFORMATION PRECURSORS OF MAGNITUDE MW 7.2 VAN 2011 EARTHQUAKE, TURKEY DERIVED FROM LONG TERM GNNS OBSERVATION

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Turkey is one of the most seismically active countries in the world due to its tectonic position. Seismicity of the area is related to the continent–continent collision of the Anatolian and the Arabian plates. A destructive and strong earthquake of magnitude Mw 7.2 occurred in the eastern part of Turkey that known as Van region on October 23, 2011. The region of the Van

earthquake is located at the northern front of the Bitlis-Zagros Fold and Thrust Belt. It was reported that the earthquake originated at a depth of 19 km with a thrust faulting mechanism. This earthquake was affected a broad area, and caused the death of 644 people, and more than 2000 people were injured. 2300 aftershocks with Mw>3 were recorded in the three months after the main shock according to AFAD (the Republic of Turkey Prime Ministry Disaster and Emergency Management Authority) reports. The seismicity of the region is described as shallow that the depths of occurred earthquakes are less than 50 km. The estimation of the surface deformation in relation to the earthquakes higher then magnitude 6.0 is one of the important issues. GPS/ GNNS studies give significant results for this purpose. The Turkish real time kinematic GPS network (TUSAGA-Aktif) was established by Istanbul Kültür University between May 2006-2009 in corporation with the General Directorate of Land Registry and Cadastre (GDLRC) and General Command of Mapping (GCM) in Turkey and Northern Cyprus. The network consists of 147 GNSS reference stations to obtain crustal movements and provide RTK implementations There were 15 reference stations near the epicenter of the Van earthquake. In this study the earth's surface deformation characteristics before, during and after the Van earthquake were analyzed. The data from permanent GPS network with an area 300x300 km2 were used to evaluate deformations of the earth's surface around the epicentral region of the earthquake in the time interval January 16, 2009 - October 29, 2012 with a daily temporal resolution. Dilatation deformations, maximum shear, horizontal and vertical displacements were determined approximately 3 years before and one year after the 2011 Van earthquake. Deformations of the earth's surface were determined for every day. Kinematic visualizations (movies) of motions and deformations are created with the purpose of investigating the evolution of the deformation process. Unusual deformations were discovered several months before the earthquake at a distance of about a hundred kilometers from the future epicenter. The aim of this study to identify deformation earthquake precursors from GPS data with a daily resolution and wide coverage of the study area. Kinematic features of deformation of the earth's surface in connection with the Van earthquake, seismic regime and tectonic structure of the region were obtained. Key Words: Earth's surface deformation; GNNS (GPS) observation; Van earthquake

ESC2018-S21-424

ON ONE METHOD OF DETERMINATION AND MONITORING OF STRESS-STRAIN STATES OF THE EARTH CRUST LITHOSPHERIC PLATES AND BLOCKS, THE POSSIBILITY OF EARTHQUAKES PREDICTION

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In the 60-s of the 20th century the change of the acial surface geometry of the Earth crust before the earthquakes was discovered. Then a natural question arose: is it possible to find the stress-strain state of the locality and to follow its change in time, having the terrain structure (lamination, thickness, elastic characteristics and layers density), applying the values of the displacements points of the facial surface, as the data of measurements of seismic stations, GPS systems, inclination measurements and other measuring devices. This question is considered for the class of the spatial problems of elasticity theory for a layered package from orthotropic plates (the case of the isotropic plates is a private case), modeling behavior of the Lithospheric plates and the Earth crust in the process of preparation of earthquakes. Connected with the earthquakes preparation two basic processes are studied: slow (age-old) and jump-like (fleeting). The first one of these processes which may last for decades, is quasi-static during which critical deformations, bringing to global destruction – earthquake, are accumulated. The second process is dynamic (foreshocks, earthquakes, aftershocks). By an asymptotic method of solution of singularly perturbed differential equations the solutions of the above mentioned spatial quasi-static and dynamic problems of elasticity theory are found. Cases, when found solutions are mathematically exact, are noted. Applying the data of the periodically conducted measurements, it is possible to trace the whole process of the earthquake preparation and the processes after the earthquake. By the found solutions the potential energy of deformation is calculated and depending on its magnitude the possible magnitude of the expected earthquake is predicted.

ESC2018-S21-456

FLUID INITIATION OF ROCK SAMPLE FRACTURE: LABORATORY MODELING OF TRIGGERED SEISMICITY

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It is widely accepted at present that the infiltration pore pressure plays a controlling role in reservoir triggered seismicity. When water from a reservoir infiltrates into the rock mass at the depth of several kilometers, the increasing pore pressure reduces the effective stress, thereby lowering the shear strength of a potential seismogenic fault in the vicinity. This may initiate a crack, which would propagate and trigger an earthquake. The complex mechanisms of RTS are not yet well understood due to the very limited knowledge of the rheology of crustal material and groundwater movement under high pressures and high temperature conditions in the hypocenter region. Therefore, in the absence of instrumental data directly from the hypocentral zone, laboratory experiments on interactions of fluid infiltration, pore pressure and acoustic emissions of selected samples can provide vital insights on processes which take place in the crust. We have used dry cylindrical samples (length 60 mm, diameter 30 mm) of granite from boreholes in the Koyna-Warna area, western India for our laboratory experiments, which were carried out under two different confining pressures, 10 and 25 MPa, with pore pressures varying between 1 and 5 MPa. Uniaxial load applied to the dry sample under confining pressure of 10 MPa created a complex fracture zone in the sample. Then the loading rate was reduced by an order of magnitude and water was injected into the sample to pressure of 1 MPa, by which time the dry sample was water saturated. The pore pressure was now increased by consistent jumps from 1 MPa to 3 MPa. The same process was repeated under confining pressure of 25 MPa. The reaction of the samples to strain and pore pressure is recorded as acoustic emission (AE) patterns. The following observations were apparent after post processing the data: (i) background AE occurs almost simultaneously with flow of fluid into the dry sample. (ii) at smaller values of pore pressure (1 MPa) maximum AE is observed with a time delay relative to the pore pressure front, leading to a 'swarm activity' of acoustic response. (iii) At 2-3 MPa pore pressure and beyond, the AE is 'aftershock like', particularly noticeable during the first injection of the fluid in a relatively dry fractured zone. Stepwise increase of pore pressure causes a corresponding response in acoustic activity, linearly dependant on the magnitude of the pressure. Re-injection into an already saturated sample showed AE diminished by an order of magnitude. We find that the delay in the initiation of fracture during the propagation of fluid in a dry rock was several times greater than under the propagated diffusion of pore pressure in a water saturated rock. The effect of the difference in diffusion rates due to the difference in the coefficients of effective permeability is known in the theory of fluid filtration. It was indicated earlier that this difference can be as high as one order. Through several experiments, the effect of a noticeable delay in the maximum of the acoustic response relative to the onset of pore pressure (tens of seconds or more) was revealed. It should be noted that in real conditions, the induced seismicity in the Koyna-Varna region is also characterized by both a rapid and delayed response to the filling of reservoirs, and the delay mechanism remains not completely clear. The results of the conducted experiments qualitatively confirm the assumption about the nature of reactivation of seasonal seismicity in the south of Koyna-Warna area due to the different rate of initial watering and subsequent pore pressure fronts caused by the filling and operation of the Koyna and Warna reservoirs. Financial support under the Russian-Indian project RSF - DST India: RSF grant No. 16-47-02003, grant of the Department of Science and Technology, Government of India, INT/RUS/RSF/P-13 is gratefully acknowledged.

ESC2018-S21-524

A REDUCED-MEMORY STRESS RELEASE MODEL FOR THE EARTHQUAKE OCCURRENCE IN THE CORINTH GULF (GREECE)

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The formulation of stochastic models for seismic hazard assessment has blossomed during the last several decades in an attempt to bridge the gap between physical and statistical models. The complexity of the earthquake generation process requires the development of stochastic models, the application of which aims to improve our understanding of the evolution of the seismic activity and the associated underlying mechanisms. Self-correcting point processes, used in ecology, forestry, finance and other fields, consist a large class of procedures that model occurrences well-dispersed. The equivalent model in seismology is the Stress Release Model (SRM), introduced by Vere-Jones (1978), which transfers Reid's elastic theory in a stochastic framework. In the SRM, the probability for an earthquake occurrence depends on an unobserved quantity that represents the stress level in an area changing over time. It is increased linearly between two consecutive earthquakes based upon the assumption that the strain energy is accumulated due to continuous tectonic loading and drops suddenly as it is released when an event occurs. The energy released during an earthquake results then in a period of quiescence until the re–accumulation of the energy and the genesis of the next earthquake. The point process is uniquely defined by the conditional intensity function, which is the instantaneous occurrence probability. It is a convenient and intuitive way of specifying how the present depends on the past in an evolutionary point process. In the original form, the conditional intensity function depends on the whole history of the process. In an attempt to identify the most appropriate model that fits the data and better describes the earthquake generation process, we introduce an "m-memory" point process where only the m most recent arrival times are present in the conditional intensity function. That means the curves of the conditional intensity functions may exhibit different behavior and features since the drop when an event occurs depends not only on the magnitude of the earthquake but also on the time intervals taken into account before the occurrence of the earthquake. The memory of the point process is investigated in the case of moderate earthquakes (M>5.2) occurring in the Corinth Gulf, one of the most active structures in Greece, by considering. The models are then compared with the simple stress release model in its original form and they are evaluated in terms of information criteria and residual analysis. The financial support by the European Union and Greece (Partnership Agreement for the Development Framework 2014 -2020) under the Regional Operational Programme Ionian Islands 2014-2020, for the project "Telemachus – Innovative Operational Seismic Risk Management System in the Region of Ionian Islands" is gratefully acknowledged.

ESC2018-S21-580

CHANGES IN SURFACE LAYER COMPOSITION OF KOYNA-WARNA HOLES ROCKS UNDER FRICTION

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The texture and clay mineralogy of a slickenside surface and a freshly created fracture in core samples from Phansavale (in ferruginous and silicified metamorphosed gneiss) and Paneri (in basalt showing porphyritic structure with phenocrysts of Plagioclase and Ortho-pyroxenes in fine grained mass with rare zeolites amygdales) deep boreholes at 503 m and 560 m depth from Koyna region is investigated by Infrared (IR), Raman spectroscopy and Photo Luminescence (PL). We report slickenfibres striations and thin films of clay minerals on slickenside surface and 1-4 mcm thick surface layers of Li-montmorillonite on freshly created fracture in laboratory. The results are compared with the parameters and composition of the surfaces outside the fracture zones. It is shown that shear surface consist of clay minerals with a low coefficient of friction, while the concentration of such minerals on the undisturbed surface is negligible. Presence of clay minerals along existing fracture surfaces indicates creep deformation due to low coefficient of friction. We suggest that new minerals are formed due to mechanical destruction of chemical bonds

in the crystal lattice of quartz, feldspars, calcite and dolomite, as a result of which new free radicals and ions are produced along fracture surfaces initiating chemical reactions causing changes in the chemical structure of rocks. We propose creep movements in basalt rocks associated with triggered earthquakes along basement faults in the seismically active Koyna-Warna region in western India. This observation is supported by absence of earthquakes in the top (about 1 km) Deccan Trap rocks during the last five decades. This work was supported by the RFBR grant 16-05-00137 (spectroscopy measurements) and by the Russian-Indian project RSF – DST India: grant of the RSF 16-47-02003, grant of the DST of the Government of India - INT/RUS/RSF/P-13 (preparation of rock samples and conducting experiments).

ESC2018-S21-631

THE RELATIONSHIP OF THE LOCAL MAGNETIC RESPONSE OF THE GEOLOGICAL ENVIRONMENT WITH THE PROCESSES ASSOCIATED WITH THE PREPARATION OF THE EARTHQUAKE (ON THE EXAMPLE OF THE EARTHQUAKE WITH THE MAGNITUDE 6.3 OCCURRED IN ITALY IN 2009)

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Activation of lithosphere geodynamic processes accompanying the preparation of earthquakes is associated with the movement of fluids in the geological environment. This leads to a change in electrical conductivity, dielectric and magnetic permeability and causes a change in the local magnetic response of the medium to global variations of the geomagnetic field. As a result, the magnetic field in the medium is the sum of external and local fields caused by bound charges and currents. Thus, the activation of various geodynamic processes is reflected in the intensity of the magnetic field. The dynamics of these local contributions to the magnetic field can be estimated by comparing the amplitudes of the same global magnetic variations recorded at different pairs of spaced stations. The first results of applying this technique were obtained by analyzing the data of a network of geomagnetic stations in Armenia. In the works of Skovorodkin Yu.P. and Grigoryan A.G., a connection between the variations of the local magnetic response of the medium and the preparation of the catastrophic Spitak earthquake (1988) was shown. Currently, due to the development of the instrument base and the existence of a vast archive of geomagnetic data, for example, Intermagnet, it becomes possible to comprehensively study the observed effect. Software implementation of the algorithms of the method of searching for variations of the local magnetic response made it possible to construct time series of these variations for different pairs of European geomagnetic stations. The work revealed anomalies of variations preceding the earthquake of magnitude 6.3, which occurred on April 6, 2009 near the station AQU located in Central Italy. This work was carried out with the financial support of the grant of the President of the Russian Federation for the support of scientific schools No. SS 5545.2018.5.

ESC2018-S21-786

PREPARATION PROCESSES IN ANALOGUE EARTHQUAKE EXPERIMENTS

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It is believed that asperity contact at the frictional interface plays an important role in friction and rupture dynamics. However, there remain very few studies controlling the surface asperities and observing their effects on macroscopic stick-slip behavior. In this study, we performed in-situ visualization experiments between compliant (rigidity is about 100 KPa) and optically transparent gels having well-controlled asperities. We found that, as curvature radius of the asperity becomes larger and the normal stress becomes smaller, velocity dependence turns from rate-strengthening to weakening and accordingly, frictional behavior transitions from steady sliding, coexistence of slow and intermittent fast slip, to periodically generating giant slip. By applying the gel exhibiting the coexistence of fast and slow slips, we observed the preparation process toward a giant event with the particle tracking and the stress inversion technique. As a result,we found two different types of stress accumulation stages: a successive slow slip stage generating stress heterogeneity at an intermediate stress level and a stress-uniforming stage just before the giant event. Finally, we discuss the relationship

between the stress accumulation process and the rupture behavior.

ESC2018-S21-796

NUMERICAL STUDY OF THE RATE-STATE FRICTION LAW MODIFICATIONS. APPLICATION TO THE EXPERIMENTAL DATA.

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It's known that the rate-state friction law could be used to reproduce the seismic activity generated by tectonic fault sliding. The authors previously showed that the spring-block system with two-parametric friction law exhibits various types of chaotic motion. In the same time, the results of numerical experiments showed that used variant of the friction law did not allow to describe correctly some modes of the block movements. To solve this problem, several modifications of the friction law were considered, and numerical modeling of the spring-block system with modified friction law was conducted. By varying the model parameters, the various slip patterns were obtained, which were different from the patterns obtained using the "general" two-parametric friction law. The numerical results were compared with measurements of the slider-block movements in laboratory experiments; the comparisons were conducted for several variants of the friction law modifications. The modifications allowing to achieve the best matching with the experimental measurements for the different slip modes were found. The application of the modified friction law to real tectonic faults will allow to describe the seismic activity variations more adequately.

ESC2018-S21-985

IMPACT OF FRICTION COEFFICIENT AND FAULT PARAMETERS VARIATION ON COULOMB STRESS CHANGE ANALYSIS

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The broader Aegean area is characterized by a high seismicity rate with severe earthquakes (M≥6.5) having struck well defined seismogenic zones both in instrumental and historical era. Coulomb stress change analysis has been widely employed for identifying potentially risky areas in such environments, with a basis to the distribution of stresses on a known strong seismicity background. For doing so, the knowledge of the dislocation models responsible for the earthquakes as well as the brittle crust properties are required. The purpose of this work is the development of a regional earthquake likelihood model based on Coulomb stress analysis, emphasizing on the variation of the parameters introduced into our calculations. The coseismic stress changes in our case, are calculated for strong earthquakes (M≥6.5) having occurred in two seismogenic areas, the North Aegean Trough in northern Aegean sea and the Corinth Gulf, in southern Greece. According to the methodology, the earthquakes are introduced as test points in order to investigate stress change calculation variability. The Coulomb failure criterion ($\Delta CFF=\Delta\tau+\mu(1-B)$) which is used, requires an estimate of the friction coefficient (μ) and Skempton's coefficient (B) related with pore fluid behavior, which have to be assumed. Static stress changes are calculated at earthquake hypocenters with a range of values for the coefficient of friction (0.0 to 0.8), Skempton's coefficient (0.2 to 0.9) and varying rake angles depending upon the seismogenic pattern for each study area. Additional uncertainties are involved in the approximation of the target fault geometry, for resolving stresses on known faults according to their strike, dip and rake. A significant uncertainty source which influences the calculated stress pattern is associated with the target fault dip and is either assumed from the seismogenic crust properties or defined by focal mechanisms, when known. Taking into account the vast value ranges, conclusions on ΔCFF changes are finally drawn based on frictional variations, rake, dip, either separately or combined. Given that the aforementioned calculations are time consuming the Coulomb Stress Application software was developed. It regards a user-friendly tool for entering input data and provides an efficient way

to perform complex calculations. The tool is designed for two main purposes. The first purpose concerns the incorporation of scaling laws for calculating source parameters (fault dimensions and coseismic slip) for each earthquake, whereas the second regards the estimation of the accumulated stress changes. The main advantages of using the Coulomb Stress Application are: a) provision of a friendly way to collect and store information concerning faults and earthquakes in a certain area, b) development of a standardized fast and efficient way to perform a series of estimations (e.g. fault length (L), fault width (w), coseismic slip (u)), c) with a significant reduction of the risk for an erroneous calculation, avoided due to the automated and tested procedure, d) provision of an interactive environment such that the user at any stage is able to check the procedure step by step and to control the input files from the tables and the results and e) allowance with an easy way to enter or delete data such as earthquake groups, parameters of earthquakes and faults or scaling laws. An additional potential of the new version of the Coulomb Stress Application is that it can perform a series of calculations concerning μ, B, rake, dip and combined calculations for a wide range of values. The results can be provided and examined in forms of text files and maps of ΔCFF. The Coulomb Stress Application is a desktop application based on .NET and SQL Server. By performing a wide range of calculations the Coulomb stress analysis (likelihood of potential earthquakes, triggering, aftershock sequences) can be improved and provide more robust results.

ESC2018-S21-1075

THE RESULTS OF INTEGRATION THEORETICAL RESEARCHES AND SOFTWARE DEVELOPMENT IN AZERBAIJAN FOR THE OPERATIONAL PREDICTION EARTHQUAKES ON SEISMIC GEODINAMICAL FIELDS OF FLUID

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Azerbaijan concerns to seismically active regions of the world. On the basis of a 39 year (1979-2018) all the year-round monitoring of seismic geodynamical fields in the fluids (SGDF) of Azerbaijan, we have concluded that the solution to the main issues in the field of reliable seismic prediction can be carried out only on the basis of the daily interprettie data "SGDF Database monitoring" (26 objects of observations in the seismic active zones). The foundation for this conclusion were the analysis of own results and the work of other researchers in the world: only the fluids in the system "water-rock" are a sensitive indicator of seismic, tectonic, physical-geochemical processes and etc., which operate in the hypocenter of earthquake. During 1998-2014, after the realisation in our region of strong earthquakes (Lerik-1998; the Southern Caspian sea-Baku-2000), were developed mathematical and the software for calculate the "diapazons": coordinate of the hypocenter, the magnitude of the predicted earthquake and the time of its realization. In particular, we have developed, implemented and tested 2 different in content "Automated technologies, N.1 (January 2008) and N.2 (October 2014) for the rapid assessment of seismic situation in the region and operational seismic prediction only on the SGDF anomalies in Azerbaijan". On the basis of their daily, in automatic mode, we solve the following important problems: a) determining the presence of anomalies according to a year-round SGDF monitoring (1 day: 305 values for the 17 parameters on a 26 observation objects); b) calculation of the "diapazon" of coordinates, magnitude and time of the realization; c) differentiation of the different hypocenters. The regions of the our seismic prediction are: a) the Caspian sea and the Azerbaijan - ml>=3.0, h>=0 km; b) neighboring countries (mb>=4.0, h>=0 km: Russia-Dagestan; Georgia, Armenia; mb>=5.0, h>=0 km: Turkey, Iran); c) countries with the deep focus (h>=90 km) earthquakes of the Hindu Kush seismic zone – mb>=6.0; d) the foci of the planetary catastrophic earthquakes (mb>=6.0, h>=33 km) - Indonesia, Japan, Chile. All these works are performed in automatic mode, but duplicated and clarifies by the different technologies. However, the automatic conclusion in tabular and cartographic options we receive only on the basis of "Automated technology N.2 ... ". Based on the "express-method and an automated program identifying the coordinates and the time of realization of the forecasted earthquake", also daily automatically is created the identification schedule (IG) on the anomalies in SGDF fields. We named it "on-line" portrait of the prediction the dangerous seismic centres. It is

compared with "retro" portrait, which we developed in "Atlases of the standard SGDF portraits of the strong earthquakes". The main condition for the correct prediction of the earthquake is numerous realisation of it in the given place during 1986-2018. The working out of this express-method is based on important law, which we have found: the standard SGDF "portrait" of the concrete hypocentre is stable, individual, and reflects the final stage of earthquake preparation. It is equal to 1:16 days. As a result, the level of our the authentic forecast of the seismic situation reaches 80-85% and for the period 2008-2011 and 2013-2018 there is irrefutable evidence. However, work in this direction has not been completed. In our theoretical researches we explain mechanism of the occurrence short-term SGDF anomalies on the basis of the new facts, which have been published in the scientific literature in 2000-th years. They have established informational properties of water-molecules of the water at the quantum level taking information from the environment, memorize, accumulate, and transmit it back. This fact explains the stability of the SGDF "portrait" for the specific seismic hypocenters. In addition, we proposed new explanation to the mechanism of occurrence of a short-period of SGDF anomalies for the preparation earthquake in the crustal and deep hypocenters. In the end, note that our works in the theoretical researches, and software continue are modernized.

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SESSION 22

ESC2018-S22-148

A PHYSICS-BASED PSHA CONCEPTUAL WORKFLOW FOR LOW-STRAIN AREAS

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In probabilistic seismic hazard assessment (PSHA), the contemporary framework for quantifying the impact of seismicity, occurrence rates of future earthquakes are estimated from earthquake catalogues under the assumption of stationarity. While PSHA is well-established for regions of high seismicity, it has been questioned in recent years if this approach also provides a reliable framework for low-strain regions where the earthquake catalogues may contain insufficient information to constrain long-term activity rates. Stable continental regions (SCRs) are a prominent example of such regions, since low strain and, consequently, low energy loading rates lead to low seismicity rates. Additionally, a discussion has sparked recently whether SCRs are in fact stationary systems, or if their seismicity consists solely of unique relaxations of a pre-stressed lithosphere or temporal changes in crustal strength. In this work, we propose a physics-based modification of the established PSHA source workflow that relaxes the underlying assumptions only minimally. This novel approach to PSHA integrates conservation of energy using geomechanical models to estimate the energy density and its accumulation rate. In combination with existing records and material properties this density is used to determine the spatial variation in the parameters of a Gutenberg-Richter type magnitude-frequency relation. Through the introduction of the physical properties, the approach is feasible for all regions whose catalogues contain data above the magnitude of completeness and for which sufficient information for geomechanical models is available. As a result, it may enhance the achievable accuracy of the classical PSHA in SCRs, where seismicity at high magnitudes is scarce, and may benefit, through constraints in stress accumulation, from the increase in 3D surface deformation time series from geodetic observations. Furthermore, this new framework gives the opportunity to include specific physical or geological knowledge of the region to be implemented to further enhance the precision. We present the basic conceptual workflow of our physics-based PSHA and a feasibility test.

ESC2018-S22-171

CRUSTAL STRESS-FIELD FROM THE INVERSION OF FOCAL MECHANISMS IN THE GREEK REGION: NEW INSIGHTS FOR REGIONAL DEFORMATION

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Greece is one of the most rapidly deforming parts of the continents globally, with significantly large strain-rates along the Hellenic Arc, owing to the active subduction of the eastern Mediterranean lithosphere beneath the Aegean, but also in the North Aegean Trench, caused by the westwards propagation of the North Anatolian Fault. In the present study we employ a massive dataset of over 2000 focal mechanisms (Kassaras et al., 2016) of Mw>=3.5 earthquakes that occurred at crustal depths to resolve the stress field in a grid of nodes with 0.25° spacing and 30km search radius that covers the entire region of Greece, using a damped least-squares inversion (Hardebeck & Michael, 2006). We explore the properties of the stress field, including the orientations of the principal stress axes and the stress-shape, R, to determine key characteristics of its variation across the Greek territory. We compare our results with the expected focal mechanisms and maximum compression principal strain-rate axes of the Global Strain Rate Model (GSRM; Kreemer et al., 2003). The two models are generally in good agreement with the exception of regions where the strain-rate magnitude is low, such as NW Greece, near Corfu, where the stress-field suggests compression more transverse to the Apulian collision front than the strain-rate field does, and SW Aegean, where the strain-rate tensor is overwhelmed by the contraction along the Hellenic Arc, whereas the stress-field is related to strike-slip faulting near Crete and N-S normal faulting in southern Peloponnese and near Rhodes Island. Regions with dual stress-state were identified by employing the Multiple Inverse Method (Yamaji, 2000) on areas delineated by joining several neighboring Area Sources of the European Seismic Hazard Model 2013 (ESHM13;

Woessner et al., 2015). NW Greece and Corfu Island are mainly affected by NE-SW contraction causing NW-SE reverse faulting and, in addition, strike-slip faulting, mainly in Epirus. Northern/central Greece and the Corinth Rift are primarily characterized by E-W normal faulting, with secondary stress-states favoring oblique-normal to dextral SW-NE or sinistral NW-SE strike-slip faulting. Central Aegean, including Lesvos, Chios and Samos islands, is mainly governed by SW-NE dextral faulting but also N-S extension, with a very stable minimum principal stress axis (S3) in Northe Aegean, also causing E-W normal faulting which becomes dominant near Dodecanese. The southern part of the Hellenic Arc around Crete is dominated by SW-NE sinistral faulting with additional E-W reverse faulting, in the vicinity of the subduction zone. The stress-tensor was also applied on the Fault Sources (FS) of the ESHM13 to evaluate its relation with their geometry and kinematics. In most regions, our results were found to be compatible with the ESHM13 FS, in terms of orientation and expected faulting type, which was examined by imposing the direction of maximum shear on the fault plane as the direction of slip. Some differences were observed in regions of low strain-rate, such as the southern Aegean, where left-lateral strike-slip E-W faulting is expected, in contrast to the registered E-W normal FS. Discrepancies were also found in areas with complex tectonics, such as pull-apart basins in Western Greece, where the resolution of the regional stress-field is insufficient to explain local stress heterogeneities. However, such areas were also highlighted by anomalies in the stress-shape, R, which are strongly dependent on the variation of one principal stress axis while another remains relatively stable. A high R, E-W oriented anomaly marks a significant rotation of the stress field by 90° that occurs along the latitude of 37°N, turning E-W (in the north) to N-S (in the south) normal faulting in Southern Peloponnese and Dodecanese Islands, as well as dextral to sinistral SW-NE strike-slip faulting in Northern and Southern Aegean, respectively.

Acknowledgments

We acknowledge support of this study by the project “HELPOS - Hellenic Plate Observing System” (MIS 5002697) which is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

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ESC2018-S22-237

SPACE PATTERNS OF THE GROUND MOTION PARAMETERS, GENERATED BY MODERATE-TO-STRONG UNDERCRUSTAL EARTHQUAKES OF VRANCEA REGION, ROMANIA

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The Vrancea intermediate-depth seismogenic zone, located at the bend of the Southeastern Carpathians, is one of the most active intracontinental seismic areas in Europe; it generates 1-to-5 events with moment magnitude greater than 7 each century, according to the existing historical earthquake catalogues. During the past half-century, 4 events with moment magnitude greater than 6 occurred in the region: the seisms of March 4, 1977 (Mw 7.4); August 30, 1986 (Mw 7.1); May 30, 1990 (Mw 6.9); May 31, 1990 (Mw 6.4). The detailed macroseismic intensity maps of these events provide the most accurate descriptions of the variations of shaking and damage available for Vrancea earthquakes. All

four maps display a couple of unusual common features and a specific asymmetrical shape of the isoseismals. In contrast with the macroseismic data, the number of local strong motion records of these events is modest, due to the poor seismic instrumentation in the region, at the time of their occurrence; the strong motion data are analogue, and collected from sites located in the Extra-Carpathian area. The strongest digitally recorded undercrustal earthquake of Vrancea is the Mw 6.0 event of October 27, 2004 – the largest seism which occurred in the study area, after the events of 1990. Using the data from the five events listed above, we developed regression relationships between macroseismic intensity in MSK scale and horizontal peak ground acceleration (PGA) and peak ground velocity (PGV), for intensity in the range V ? I ? VIII. For this range – where the intensities are defined by the level of damage – a simple power-law representation appears to be adequate. The relationships allow a rapid evaluation (from instrumental real-time data) of the extent of potential damages following a significant Vrancea earthquake. Taking advantage of the substantial and continuous development of the Romanian seismic network during the past decade – which resulted in a significant amount of high-quality strong motion data – we analyzed the peak ground motion space distributions generated by about hundred moderate-size undercrustal events with Mw > 4 (four earthquakes with Mw > 5), that occurred within the entire seismogenic zone. These ground motion space patterns display a few pregnant common characteristics, revealed by the macroseismic maps of the strong earthquakes (Mw ? 6) as well, pointing that the distributions are strongly controlled by the local and regional geological conditions. On the other hand, the space patterns exhibit a noticeable variability, determined by the characteristics of the individual sources – location within the seismogenic volume, size, fault plane orientation, time evolution of rupture. We explore the available strong motion data, attempting to detect the sign of particular hypocenter locations / source parameters on the ground motion space distributions.

ESC2018-S22-238

FRACTURE PATTERN OF THE CRUST IN SWITZERLAND AT DEPTH AND ATSURFACE: A FIRST COMPARISON OF SEISMICITY AND FAULTS

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General knowledge of geoscientists holds that earthquakes occur on faults, and faults are created by brittle failure. While this can be clearly demonstrated for homogeneous media at relatively small scales, reality can be more complex due to various scales and material heterogeneities. This is especially true in an orogenic environment with a long deformation history such as the Alps. The region of Switzerland hosts a wealth of faults, which reflect the integrated time history of fractures at surface, and a long catalogue of earthquakes, which reflect the geologically most recent fracture pattern at depth. We here perform a comparison of these two datasets to analyse and quantify how much of the seismicity is fault-related, and how much of it is relatively distant from known faults. By calculating the distance from each earthquake to the nearest fault, we observe that about two-thirds of the earthquakes can be considered as being close to a fault, yet about 10% are far. This match is surprisingly good considering the very disparate construction of the databases, but still deviates from the general knowledge that earthquakes occur on faults. Although both databases are likely incomplete – earthquakes in time, faults if they are blind, or covered by sediments or snow, – sensitivity tests and considerations about earthquake location uncertainties do not affect these general results. The comparisons of earthquake magnitude with hypothetical magnitudes obtained from fault lengths show a discrepancy, both in general for the database, and also when earthquakes and respective nearest faults are paired. The applied scaling law may not be appropriate for the region, but if it is, this result means either that earthquakes rupture is partial with respect to the fault's extent, or the deep fracture pattern is clearly more segmented than the superficial one. The two-third overlap in deep and superficial fracture patterns, and the 10% remote seismicity are the first of such quantifications in an orogenic zone, which typically deforms in a diffuse manner. The analysis of results by close comparison to geological data,

especially at depth, as well as state-of-the art numerical modelling integrating field data and rheological characteristics can shed light on how stress and strain evolve in a broadly, and in this case slowly deforming system. Finally, statistics on faults' distance to the nearest earthquake reveal results that strongly depend on the selection criteria. All supposedly active faults in Switzerland have experienced a M2.5 or larger earthquake in our current knowledge, and only one sixth have not done so in the past 42 years, since the beginning of instrumental earthquake detection. Further work can be done to complete the databases, and to rightly choose which elements of the analysis presented here can be reasonably included in earthquake hazard assessment. The message for educators: the general knowledge taught in schools must be taken with a pinch of salt. Earthquakes can happen in areas without (known or mapped) faults, and not all faults produce earthquakes within a human lifetime, but they seem to do so over long times.

ESC2018-S22-314

THE DYNAMICS OF PAMIR-HINDUKUSH REGION AFGHANISTAN

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Afghanistan is one of the most seismically active regions of the world, yet due to regional political instability, has been scarcely studied using modern geophysical methods. Located on the western syntaxes of the India-Eurasia convergence, the region is subject to high strain rates, manifesting in frequent large magnitude earthquakes and related hazards. In the past few decades, large earthquakes in Afghanistan and their secondary hazards, including rock falls, landslides, and avalanches have affected the lives and livelihood of those living in both urban and remote areas, forcing evacuations and displacing local populations. A lack of both advanced tools and local expertise present a major barrier to studying regional crustal deformation as well as developing and implementing strategies to mitigate the damaging effects of seismic hazards. Since 2015, in partnership with the Norwegian Afghanistan Committee (NAC), the University of Montana (UM), and the German Research Center for Geosciences (GFZ), we have been working to train local scientists on advanced geophysical methods, including geodesy and GNSS processing, in addition to collecting high-quality data. Through this partnership, we have deployed a number of campaign and continuous GPS stations in the Panjshir and Badakhshan regions of north-eastern Afghanistan in order to measure slip rates and quantify regional deformation. The past three years of GPS data was processed by the University of Montana and German Research Center for Geosciences for 14 sites in Afghanistan and numerous sites in the surrounding Central Asian nations to produce the most up to date regional velocity solution. Relative to a stable Eurasia, we have measured approximately 25 mm/yr of N-S convergence between northern Pakistan and southern Kyrgyzstan. Across the eastern Pamir, the majority of convergence is centered on the Main Pamir Thrust in the north of the mountain range. In the western Pamir and Hindu Kush ranges, however, we observe more distributed deformation with strong westward components. This indicates a complex interplay between the Indian and Eurasian plates with significant left-lateral motion (approximately 7-10 mm/yr) accommodated on or near the Darvaz Fault Zone. Additionally, there is significant strain accumulating between sites in the Panjshir region north of Kabul and sites in the Tajik Depression, though sparse data prevents a clear understanding the partitioning of deformation.

ESC2018-S22-446

IS EARTHQUAKE ACTIVITY IN THE NORTHERN BRITISH ISLES DRIVEN BY GLACIO-ISOSTATIC RECOVERY?

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A number of authors have suggested that main cause for earthquake activity in northern Britain is deformation associated with glacio-isostatic recovery. This appears to be mainly based on the correlation between the spatial extent of the seismicity in northwest Scotland and the region of maximum ice thickness during the last glacial maximum, rather than the properties of the earthquakes or the measured strain field. Detailed analysis of spatial distribution of observed

seismicity suggests that most clusters of earthquake activity are associated with steeply dipping faults that strike approximately NE-SW or NW-SE. Similarly, focal mechanisms determined for instrumentally recorded earthquakes consistently show strike-slip faulting with N-S compression and E-W tension, which results in either left-lateral strike-slip faulting along near vertical NE-SW fault planes, or right-lateral strike-slip faulting along near vertical NW-SE fault planes. These trends match the recent geological history of the large-scale fault structures in British Isles where Alpine-related compression has driven faulting. In addition, the strain rate field calculated from continuous Global Positioning System measurements also exhibits predominantly left-lateral strike-slip loading along a NE-SW trend. These results suggest that earthquake activity across the region is driven by reactivation of favourably oriented, steeply dipping fault systems by deformation associated with first-order plate motions rather than deformation associated with glacio-isostatic recovery.

ESC2018-S22-492

THE AITOLO-AKARNANIA (WESTERN GREECE) GNSS NETWORK PPGNET - FIRST RESULTS

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Greece is an earthquake prone country located at the convergence boundary between Nubian and Eurasian plate. The fast convergence (~30mm/y) at southern Greece and Aegean Sea, is transformed to crustal collision in northwestern Greece and Adriatic Sea. This transition is accomplished through the Cephalonia dextral strike slip fault located in the Ionian Sea. To the east of the Ionian islands and in the central Greece area, crustal extension in an EW direction dominates. A major tectonic element in this area, is the Corinth Gulf rift, which is a fast-extending continental rift (~15mm/y). It is not clear yet how this extension is linked with the collision and strike slip motions in the Ionian Sea. In any case the answer to this question should be searched in the Aitolo-Akarnania area which is located between the Corinth Gulf and the Ionian Sea. Active faults have been mapped in Aitolo-Akarnania including the Katouna sinistral strike slip fault and the Trichonis Lake normal fault. Since 2013 crustal deformation in the area, is monitored by a network of five GNSS stations, complementary to permanent seismic network. The GNSS Network PPGNet consists of six stations one in Messenia and five in Aitolo-Akarnania, i.e. Katochi, (KTCH), Lepenou (LEPE), Paravola (PVOG), Rigani (RGNI) and Retsina (RETS). The instruments are owned by the Charles University of Prague and the Research Institute of Geodesy, Topography and Cartography, Czech Republic. Station operation is managed by the Seismological Laboratory of University of Patras, Greece. Stations are equipped by Leica and Septentrio instruments. Data are stored in RINEX format using two sampling frequencies, 1 Hz for stations RETS, RGNI and 10Hz for KTCH, LEPE and PVOG. Hourly and daily files are produced and the daily files with 30 seconds sampling interval are freely available. Data with 10Hz sampling are available upon request in the frame of CzechGeo/EPOS project.

Daily data are processed using the Bernese GNSS Processing Software using final orbits of the International GNSS Service. The double-difference solution is computed using data from the PPGNet network data complemented by four stations from the GNSS network of National Observatory of Athens and six stations from METRICA network. Processing of data from more than two years was referenced to 9 Class A stations of EUREF Permanent Network. Coordinate time series were checked for searching of jumps and yearly periodicities. The velocities (changes of coordinates in time) were fixed to Patras/Rio GNSS stations PATR/PAT0. The first results show a NNE movement of PVOG station at 12 mm per year and a similar movement of RETS station at about 9 mm per year. This means that the Trichonis Lake normal fault system, that is located between these two stations, depicts a slip rate of 3mm/y. The KTCH and RGNI stations move eastwards at a velocity of about 5 mm per year. We believe that data from PPGNet will provide valuable information on the Aitolo-Akarnania area internal deformation and eventually will help us understand how this deformation is linked to the major active structures in the broader area.

Acknowledgements: Financial support by the CzechGeo/EPOS (LM2015079) project is

acknowledged by V. Plicka, V. Filler and J. Kostelecky. E. Sokos and E. Lyros acknowledge financial support by the HELPOS Project, "Hellenic Plate Observing System" (MIS 5002697).

ESC2018-S22-601

CORRELATION BETWEEN SEISMIC ACTIVITY, SURFACE DEFORMATION AND LITHOSPHERIC PROPERTIES IN IBERIA, SW EUROPE

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Iberia, located on the SW edge of Europe, is a region of active but slow lithospheric deformation, where the paleoseismological and historial records document abundant moderate to high magnitude destructive earthquakes. The region is bounded to the south by the Eurasia-Nubia plate boundary and by the westernmost end of the Mediterranean arc system. A number of mechanisms have been proposed as drivers of active deformation in Iberia, including the Eurasia-Nubia oblique convergence, pull related to the subducted Gibraltar slab, block extrusion, gravitational potential energy on high-elevation regions, and mantle dynamics. Recent numerical modelling indeed points to the co-existence of several driving mechanisms at work. The seismicity of Iberia has been classically described as diffuse, however recent studies using high-quality data show that earthquakes in the recent high-quality instrumental record (1996-present) collapse along well defined lineations and clusters. These clusters of earthquakes do not show a clear correlation with mapped faults or geotectonic units, begging the question of what are their controls. We contribute to answering this critical open question by studying the correlation between seismic activity, surface deformation and the lithospheric properties of Iberia, SW Europe. We follow the approach proposed by Hauksson (GJI 2011) in order to assess the correlation between epicentre density (i.e., density of earthquake nucleation points) and cumulative seismic moment, on one hand, and static and kinematic lithospheric parameters, on the other hand. Static lithospheric parameters include heat flow, topography, crustal density (as inferred from gravity anomaly), Vp/Vs ratio, crustal thickness, lithospheric thickness, mantle velocity anomalies (as a proxy for mantle dynamics), and distance to active faults. Kinematic parameters include the shear and the dilatational strain rate fields, as inferred from recent dense GNSS observations. The analysis is performed both on finer grids, using only the most recent high-quality earthquake catalogs (1996-present), and on coarser grids, using a catalog than includes the historical period. This work is supported by FCT-Portugal (UID/GEO/50019/2013 – IDL; PTDC/GEO-FIQ/2590/2014 - SPIDER).

ESC2018-S22-643

ESTIMATING INTRAPLATE DEFORMATION AND STRESSES IN BRAZIL:
COMPARISON OF GNSS DATA AND FOCAL MECHANISMS

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Focal mechanisms in Brazil show that mid-plate stresses in South America are predominantly compressional: 85% are reverse or strike-slip, and only 15% are normal faulting. Despite the small number of focal mechanisms and sparse coverage, regional patterns can be recognized with SHmax oriented roughly E-W in the south and central part, similar to the sub-Andean region, and NW-SE in the northern, Amazonian region. This pattern is believed to result from plate boundary forces, spreading stresses along the continental margin and flexural stresses from lithospheric loading. We attempt to estimate mid-plate strain rates using the best GNSS stations (operation periods of 8 or more years, and velocity uncertainties less than about 0.1 mm/y). Velocities for the best stations of the Brazilian Continuous Monitoring System (RBMC, which is part of SIRGAS – Geocentric Reference System of the Americas) were calculated with GIPSY code including all atmospheric corrections, tide effects and seasonal variations, similar to the JPL/NASA method. Linear strain rates were obtained between several pairs of stations. In the central part of the country, most linear strains (measured between pairs of stations) indicate shortening, consistent with the predominance of reverse faulting. However, strain

rates do not clearly indicate a preferred principal direction and do not seem compatible with the stress patterns derived from the focal mechanisms. When a station pair includes one station near the coast, the linear strain rates indicate extension. This could be interpreted as due to spreading of the continental margin towards the ocean, away from the central part of the continent. Similarities and inconsistencies between the estimated strain rates and stress patterns will be discussed.

ESC2018-S22-686

PROBLEM OF A LEVEL OF RECENT LONG-TERM SEISMICITY OF FENNOSCANDIA

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A set of data on the present, historical and prehistorical seismic activity of Fennoscandia is considered. An evident disagreement takes place between the low level of instrumental seismicity (in particular, the estimation of the maximum possible magnitude of an earthquake using the methods of the theory of extreme values) and historical and, especially, paleoseismic data. Paleoseismicity appears to be unexpectedly high that is supported by data from both western Fennoscandia (Norway, Sweden, Finland) and its Russian part (Kola Peninsula and Karelia). Within the latter a dozen of active fault zones mainly of NW direction had been delineated. The assumption of a close relationship between strong paleoseismicity and the process of deglaciation seems to be quite natural according to most traces of strong seismic events found in the Early Holocene. But there are also some data about strong earthquakes which had occur much later. Evidences of strong seismogenic impacts were found from the numerous presumably seismogenic displacements of the rock blocks, the tectonic inclination of the Middle Holocene terrace and seismogenic ruptures found in soft deposits in the valley of the river Vuoksa at the Karelian Isthmus and from the soft-sediment deformations of the bottom deposits of similar age of the Lake Imatra at the Kola Peninsula. Similar features were found at some other places. The possible maximum level of a current seismicity is not clear however. It is not clear also, whether the strong regional paleoseismicity is associated with the deglaciation only, or plate-tectonic factors such as a push from the mid-Atlantic ridge also has a significant role. Methodologically, the first arising question concerns the reliability of data on paleoseismic dislocations; to what extent they can be caused by other impacts, such as glacial deformations, weathering, kriogenic processes, etc. In cource of verification of data on paleoseismicity, a comparison of results obtained at several key-sites of active development of rock deformations in the Russian sector of Fennoscandia with similar observations performed in focal regions of a few recent strong earthquakes was carried out; the comparison testifies for seismogenic nature of majority of the examined dislocations. Thus, the evidence on the high level of paleoseismicity of Fennoscandia looks convincing enough. Note however, that post-glacial seismogenic faults with lengths and amplitudes of discolations similar to those found at the West Fennoscandia were not found yet in the Russian sector of the Fennoscandia. We suggest that this failing may be connected with a location of a majority of linear active tectonic structures at the Eastern part of Fennoscandia in the lowlands with thick postglacial sedimentary cover or under water of large basins such as Barents and White seas, Onega and Ladoga lakes. The signs of Holocene tectonic activity of these structures can be seen, but their full analysis is not performed yet. Thus, a high level of paleoseismic activity appears to be confirmed both for the eastern and western parts of the shield. The second problem is whether this seismicity is almost exclusively associated with the process of deglaciation, or a significant contribution is provided by a push from the Mid-Atlantic Ridge also. We present arguments “pro” and “contra” both these suggestions but can not yet offer an answer to this question. Having in mind the problem of seismic assessment it seems suitable to note that according to recommendations of the International Atomic Energy Agency the paleoseismic data should be taken into account in a seismic risk assessment in the case of Nuclear Power Plants and other similar objects. We are not sure however that this would be correct for the case of Fennoscandia because the seismic level can decrease here very essentially due to strong decrease in a rate of postglacial deformations. Determination of veritable current level of seismicity could be done

only from the finding of mechanism of regional seismicity. The work was supported by the Russian Foundation for Basic Research (project no. 17-05-00351, and partly in frames of the IG RAS research topic 0148-2014-00016 and of the IPE RAS research topic 0144-2014-0097).

ESC2018-S22-715

SEISMICITY AND SEISMOTECTONIC CHARACTERIZATION OF THE WESTERN BRANCH OF THE SOUTH CARPATHIANS IN ROMANIA

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Seismic activity is widespread along the Carpathians Orogen as a testimony for the neotectonic process shaping this area. The bulk of seismicity concentrates at the point of sudden curvature of the mountain belt known as Vrancea Region (Romania). Unusually high density of seismic activity is observed here in the mantle range (depth down to about 180 km) generating continuously earthquakes of magnitude up to Mw 7.9. A significantly lower and sporadic seismic activity is noted all along the Southern Carpathians branch in the crustal domain with particular enhancement in the western side. As a result of several earthquake sequences occurred in the recent years in this region (two sequences in the Hateg Depression in 2011 and 2013, one sequence in the Caransebes-Mehadia Depression in 2014, and one sequence on the Northern rim of the Getic Depression, in 2011-2012), we have at hand a rich set of waveform data with particular informative potential for investigating regional geodynamic processes. The paper goal is to analyze these new seismic data and integrate them with geological/structural interpretations for a better understanding of the neotectonic processes affecting the South Western Carpathians Bend Zone. The tectonic regime of the region is controlled by the last stage of collisional process that affected this area from Lower Miocene times with the clockwise rotation and collision of the Carpathian Orogen along the Moesian Platform Corner, driven by the subduction and roll-back of the Vrancea slab. The representative seismic activity (Mw > 4.0) appears to be generally concentrated along the faults systems bordering the Tisa-Dacia Block, intersections of faults of different ages, internal shear zones and with the border of the former structural terrains, and neostructures. The analysis of seismicity patterns together with the focal mechanisms reveals a complex tectonic regime with significant short-scale lateral changes of the stress alignment and faulting type, from extension (in the intra-mountainous depressions) to compression (at the contact of the Getic Depression with the Carpathian Orogen). The implications of our analysis on a refined delineation of the earthquake-prone areas in correlation with the configuration of the active faults and finally on the seismic hazard assessment are discussed.

ESC2018-S22-744

CHALLENGES OF INTEGRATING GEODETIC AND MODEL-BASED STRAIN RATES INTO SEISMIC HAZARD CALCULATIONS IN REGIONS OF LOW DISTRIBUTED DEFORMATION

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In the last decade, significant efforts have been made to integrate strain rate data into seismic hazard models on regional and global scales (e.g., GEM Strain Rate Project). These strain rate estimations are primarily derived from geodetic data, complemented in a few cases with estimations from physics-based numerical models. In contrast with the classical usage of geodetic velocities to derive slip rates on individual faults, strain rate data are used to constrain budgets of seismic moment rates, and thus hazard calculations, over spatial scales of few 10s to 100s km2. This process requires several assumptions, especially when dealing with geodetic data. The two primary assumptions are that, when processed on a “large-enough” spatial scale, strain rates can be considered (1) stationary and (2) fully representative of seismic deformation on the temporal scale of the seismic hazard calculation (typically 100s-1000s yr). In other words, strain rate data are treated as a steady-state representation of “long-term”

seismic deformation, smoothing out processes such as fault interaction, aseismic transients, etc.
In this presentation, I address some of the challenges of integrating strain rate data in seismic hazard calculations by taking examples in three regions of low, distributed deformation where the strain rate and seismic moment budgets can be compared using earthquake catalogues, geodetic data, and physics-based numerical models: The Rocky Mountains (western Canada and USA), the Apennine Mountains (Italy), and the St. Lawrence Valley (eastern Canada). These three regions present varying tectonic settings (orogeny, extension, and stable intraplate) but are characterized by low (few mm/yr) and distributed deformation. The comparisons of strain and seismic moment budgets show a large panel of behaviors across these regions. In a few cases (e.g., Cascadia margin, central Apennines), geodetic, seismicity, and model-based budgets are compatible within their uncertainties, suggesting that the assumption of steady-state and fully seismic deformation may be appropriate. However, in several cases, geodetic strain rates differ significantly from the seismicity catalog budgets. In these cases, physics-based models of steady-state and transient deformation can provide strong constraints on the time scales over which strain and seismicity can be considered stationary. In contrast, the choice of a seismic / aseismic deformation ratio, and its potential spatial variability, remains a major limitation for the practical integration of strain rate data in seismic hazard calculations.

ESC2018-S22-745

FOCAL MECHANISM AND RESULTING HORIZONTAL STRESS IN THE EARTH CRUST OF ROMANIA

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A catalogue of fault plane solutions for earthquakes recorded in Romania between 1929 and 2000 is analyzed in order to outline statistical features of the fault plane solutions in correlation with the earthquake-prone areas in Romania. The catalogue contains both groups: crustal and deep earthquakes.

ESC2018-S22-784

A NEW TECHNIQUE TO ESTIMATE FAULT POTENTIAL AND AFTERSHOCK FORECASTS

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During the last few decades the implementation of Coulomb stress changes is the main method for explaining the stress transfer hypothesis. The initial enthusiasm of the early 90s for understanding the physics behind aftershock occurrence has faded in recent years as more high-quality datasets make possible a broader hypothesis testing that now challenges long-standing ideas about the efficiency of static stress changes. Recent literature supports that the spatial distribution of aftershocks can be explained by the co-seismic fault loading, described by static stress changes. However, the observed stress shadows and the estimated optimal oriented for failure fault planes are often inconsistent with the inferred stress changes. A critical view of Coulomb stress changes framework is required to evaluate how simple assumptions and current triggering concepts affect the success rates of forecast models. A new technique is presented based on the consideration of the total stress field, taken as the sum of the pre-seismic and the co-seismic stress tensor, and all possible fault planes. Under a positive failure condition we determine the probable planes. We then compare the results for probable and optimally oriented failure planes. In order to illustrate our extended solution space (app. 1M stress estimates per geographical grid point), we use 2D histograms (Euclidean Distance of Strike/Dip vs. Rake), frequently used in DNA sequencing. We use pre-mainshock focal mechanisms, geological fault structures and spatially varying maximum horizontal axis orientation to represent the regional stress field. We compare estimated and observed 2D histograms to determine if there is at least one common combination of parameters in which the model can reproduce the observed rupture style of aftershocks. We use the new model to answer the questions: (1) Do earthquakes occur on maximum-stressed planes?, (2) How does pre-mainshock stress heterogeneity controls aftershock populations?, (3) How often do aftershock ruptures happen on optimally

oriented planes?, (4) How do long-term nucleation probabilities change when we move from an ideal fault zone representation to complex diverse multi-branching fault systems? We present results from 3 earthquake sequences in California, Japan and Italy, which are known for complex faulting patterns and diversity of aftershocks and foreshocks; the M=7.2 2010 El Mayor-Cucapah, the 2016 M=7.0 Kumamoto and the 2009 M=6.4 L'Aquila sequences. We find a low success ratio (=number of consistent aftershock ruptures/total number of aftershocks) for optimal planes (0.22-0.35) whereas the new technique which includes heterogeneity in the form of pre-seismic ruptures, reaches a high success ratio (0.70-0.82). Furthermore, we find that aftershocks do not usually occur on the maximum stressed faults since this criterion leads to very low success ratios (0.02-0.18). The latter finding has implications for short and long-term earthquake hazard studies, since it shows that critically loaded faults in different times within their loading cycles may be triggered even with a small stress perturbation.

ESC2018-S22-866

PHYSICS-BASED LONG-TERM EARTHQUAKE FORECASTS FOR LOW SEISMICALLY ACTIVE REGIONS

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The frequency and size of large magnitude earthquakes are key input in seismic hazard assessment. Statistical analysis of instrumental seismicity (the recorded small-to-moderate magnitude earthquakes) is a common way to assess the recurrence of large-magnitude earthquakes. In general, instrumental and historical earthquake catalogues are incomplete in time and space, as complete cycles of large-magnitude earthquakes are not presented, especially in low seismicity regions. Estimating the recurrence times of large magnitude events is hence challenging. One way to tackle this problem is to use earthquake simulations based on theoretical basis of stress interaction between active faults and provide synthetic catalogues spanning any desired time period and capture the recurrences of large-magnitude earthquakes. In this contribution, a new procedure is proposed in an attempt to evaluate the recurrence of large-magnitude events, by building a model of synthetic faults from different homogeneous datasets: observed seismicity and tectonic deformation rates. As a first step, synthetic faults are generated based on location and magnitude of observed earthquakes, and augmented with specific focal mechanism solutions. Next, the slip rates are estimated from the regional tectonic strain regime, and further assigned to each synthetic fault. Green's functions are used to model the stress interaction and stress changes are calculated on the synthetic faults as a function of time. Once the stress level exceeds a given threshold, an earthquake happens and rupture propagation are modelled in an iterative way. A sensitivity analysis accounting for different assumptions is also conducted with focus on the suitable values of the input parameters. The resulting synthetic catalogue is covering a set of large-magnitude earthquakes over a long period of time and further used to estimate the earthquake probabilities for the given region. The proposed procedure is illustrated by two case studies: a region of moderate-to-high seismicity, Dasht-e-Bayaz, Iran, where active faults are fully mapped and characterized; and a region of a low-to-moderate seismicity, Valais, Switzerland, without mapped faults. Considering the first case, the estimated slip rates are in a good agreement with the previous estimates provided by geological/geomorphological investigations. Considering the second case, the obtained activity rates are also consistent with the regional earthquake rates, statistically estimated within the 2015 Swiss Seismic Hazard Model. Given the simulation period of 400 000 years, the time-dependent or time-independent earthquake probabilities are directly estimated from the obtained synthetic catalogue for different magnitudes without any assumption on the shape of earthquake recurrence time distributions.

ESC2018-S22-914

GRAVITATIONAL POTENTIAL ENERGY IN IBERIA: ROLE IN ACTIVE DEFORMATION AND RELATION WITH DYNAMIC TOPOGRAPHY

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In this study we assess the relative contribution of gravitational potential energy (GPE) to the present-day stress field and deformation. We present a new estimation of the GPE in Iberia, as well as new solutions for the geodetic velocity and strain rate fields. Taking advantage of recent neotectonic modelling developed for Iberia and northwest Africa (that included contributions from lithostatic pressure forces, tectonic boundary forces, basal shear tractions and forces on faults), we isolate the dynamic contribution of GPE-related stresses. We compare results of two models – one including only the stresses generated by GPE, and another reproducing the total stress field – with the most up-to-date compilations of stress indicators, hypocenter clusters and geodetic strain rates. Our results suggest that the main effect of GPE is to induce second-order spatial variations in the stress field. GPE appears to play an important role in high topography regions, where it is able to explain stress patterns mainly associated with extensional regimes. In north Iberia, especially in the Pyrenees and Cantabria, GPE causes an extensional regime over the highest peaks. In the Iberian Chain and eastern Betics, GPE justifies the observed extensional deformation. Normal focal mechanisms of shallow earthquake clusters appear to be related with GPE maxima and GPE-induced extensional regimes. Wavelength analysis suggests that both GPE and the long-wavelength topography of intraplate Iberia record the plate boundary forces that acted in Iberia during the Alpine orogeny at Eocene to Lower Miocene times. The relation of dynamic topography (vertical normal stresses originated by mantle flow, which were not included in the previous neotectonic model) with GPE gradients and crustal uplift will further be addressed. M.N. acknowledges support by the Portuguese National Science Foundation (FCT, fellowship SFRH/BPD/ 96829/2013). Also acknowledged is support by projects UID/GEO/50019/2013 - Instituto Dom Luiz, and SPIDER - Seismogenic Processes In slowly DEforming Regions (PTDC/GEO-FIQ/2590/2014).

ESC2018-S22-941

NEW INSIGHTS INTO THE SEISMIC POTENTIAL OF THE VENETIAN SOUTHERN ALPS (ITALY) FROM THE INTEGRATION OF HIGH-RESOLUTION GPS AND INSAR VELOCITIES

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Diffuse deformation, slow tectonic rates and long repeat times of large earthquakes make the estimates of seismic hazard at continental plate boundaries a challenging task. This is the case of the Alps, which are a classic example of a broadly deforming continental collisional belt. Present-day convergence between the Adriatic and Eurasian plates is largely accommodated in the Eastern Southern Alps (ESA), where the Adriatic lithosphere underthrusts the Alpine mountain belt. The pedemountain front of the Italian ESA has been the locus of several M>6 earthquakes, but for its Venetian sector (between the Schio-Vicenza line and the Cansiglio plateau), both historical and instrumental earthquake records indicate a lower seismic moment release rate with respect its eastern (Friuli) sector. Moreover, despite geological or geomorphological evidence of Quaternary deformation, the identification of the seismogenic faults here is still challenging, including the source of the 1695, Mw 6.4 Asolo earthquake. In this prospective, geodetic data provide fundamental constraints on the kinematics of continental deformation and the identification of active and seismogenic faults. In this work we integrate high spatial resolution InSAR data and GPS data in the Montello and Bassano-Valdobbiadene thrust system, with the goal of determining a new 3D interseismic velocity field. We use two InSAR velocity fields obtained from ENVISAT satellite acquisitions along both ascending and descending orbits, processed adopting the multi-temporal SBAS technique in the time window 2004-2010. GPS velocities have been estimated from the analysis of several networks of continuous GPS stations, including semi-continuous observations from a local network installed in the Montello area. The GPS velocity field highlights an horizontal shortening of ~1 mm/yr across the Montello and Bassano-Valdobbiadene faults along the direction of the Adria-Eurasia convergence and, importantly, a

transition from subsidence to uplift across the pedemountain front, reaching positive values of ~2 mm/yr in the Belluno valley. The integration of InSAR and GPS velocities provides both a validation of the geodetic observations and an improvement of the spatial resolution of vertical ground motion rates. The GPS velocities, projected in the Line Of Sight (LOS) of the two SAR acquisitions, have been used to adjust InSAR velocities in the same geodetic reference frame, while estimating the offset, orientation and tilt of a planar ramp in the InSAR velocities, assumed to be a residual orbital error of SAR processing. This correction has brought to a sub-mm agreement between GPS and InSAR velocities, allowing to improve the spatial resolution of the vertical velocity gradient across the pedemountain front. Using ascending and descending InSAR velocities, we obtain the E-W and vertical velocity components, assuming the North-South component as estimated from the GPS velocity field. The integrated GPS-InSAR vertical velocity field has been compared with an IGMI terrestrial first order leveling dataset, related to the 1952-1984 time interval, finding a good agreement among the three independent datasets. The three geodetic observations identify a vertical velocity gradient of 2 mm/yr occurring in less than 20 km of distance in correspondence of the Bassano-Valdobbiadene thrust fault, which is unlikely related to isostatic glacial adjustment or other long-wavelength dynamic processes. In order to provide insights into the origin of the geodetic uplift we developed a simple 2D dislocation model, jointly inverting GPS and (subsampled) InSAR velocities along a NNW-SSE oriented profile, crossing the Montello and Bassano-Valdobbiadene faults. We fixed the sub-surface model faults, resembling a flat-ramp geometry, using both instrumental seismicity and the interpretation of the TRANSALP profile, estimating the locking depth and slip-rate of the Montello and Bassano-Valdobbiadene thrust faults. The results indicate a shallow locking depth for the Montello fault (~3 km) and almost 8 km of locking depth for the Bassano-Valdobbiadene fault. The estimated geodetic slip-rates are ~1 mm/yr for the Montello fault and at least 2 mm/yr for the Bassano-Valdobbiadene fault. Our results suggest, in agreement with previous results that modeled inter-seismic elastic coupling along the ESA thrust front, that the Montello thrust is partially coupled and likely characterized by a moderate seismic potential, whereas the Bassano-Valdobbiadene thrust is accumulating interseismic stress and characterized by a non-negligible seismic potential.

ESC2018-S22-957

A LOCAL MAGNITUDE SCALE FOR IRELAND AND ITS OFFSHORE REGIONS

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The seismicity of Ireland is characterized by low magnitude, infrequent and sparsely distributed earthquakes, in remarkable contrast with the numerous, densely distributed seismic events observed in Great Britain, its nearest neighbour. The apparently quieter seismogenic behaviour of Ireland may reflect crustal to lithospheric scale differences in the respective physical properties of Ireland and Britain. Despite these probable differences, earthquake magnitudes have been routinely calculated by the Irish National Seismic Network (INSN) using the British local magnitude scale, under the assumption that seismic wave attenuation characteristics are the same across both regions. However, magnitudes calculated for local events using Irish seismic stations are consistently higher than those reported by the British Geological Survey (BGS), suggesting that the attenuation properties are different on the two sides of the Irish Sea. A recent study of Irish seismicity has yielded over 200 new event detections for the time period 2010-2016, and together with the unprecedented seismic network coverage across Ireland during this time period, sufficient data are available to determine a local magnitude scale specific to Ireland and its offshore regions. In addition, we obtain an estimate of the frequency dependent quality factor Q for Ireland.

ESC2018-S22-986

EVIDENCE FOR COSEISMIC SURFACE RUPTURES FOLLOWING THE 1997 COLFIORITO EARTHQUAKES

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There is an ongoing debate regarding whether surface fault scarps in the central Apennines should be considered as active and connected to the seismogenic fault at depth or not. This is an important debate to resolve because firstly, if surface faults are used as an input to seismic hazard assessment, then it needs to demonstrated whether they are active or not. Secondly, that if fault scarps are active, this demonstrates that they can be utilised for a range of other studies, for example 36-Cl exposure dating. To resolve this debate, we conducted a field survey and gathered structural data along a section of the fault scarp along the Mt. Le Scalette fault (near Colfiorito, Umbria, Italy) exposed during the 1997 earthquake sequence. These collected data are used to investigate the relationship between the throw associated with a debated surface rupture (observed as a pale unweathered stripe at the base of the bedrock fault scarp) and the strike, dip and slip-vector. We show that the strike, dip and height of the surface rupture show a systematic relationship with respect to the geometry and kinematics of faulting in the bedrock. The strike and dip co-vary and the throw is greatest where the strike is oblique to the slip-vector azimuth where the highest dip values are recorded. This implies that the throw values vary to accommodate spatial variation in the strike and dip of the fault across fault plane corrugations, a feature that is predicted by theory describing conservation of strain along faults, but not by compaction. In contrast, if compaction or other gravity driven measurements had produced this pale-unweathered stripe, then this co-variance would not be expected. In addition, some of the debate surrounding the activity of surface faults focuses on the discrepancy between the dips and hypocentral locations from seismology and from observations of the surface fault scarps. However, we demonstrate that published earthquake locations and reported fault dips are consistent with the analysed surface scarps when natural variation for surface dips and uncertainty for nodal plane dips at depth are taken into account. This supports that the fresh stripe is indeed a primary coseismic surface rupture whose slip is connected to the seismogenic fault at depth. Therefore where similar features are seen along surface fault scarps, it should be assumed that they are active, can be studied and are capable of generating damaging earthquakes.

ESC2018-S22-1003

SOME CHALLENGES IN MODELLING SEISMIC HAZARD IN DISTRIBUTED SEISMICITY REGIONS

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Computing seismic hazard in low distributed deformation regions (as known as Stable Continental Regions, SCRs) is one of the biggest challenges in Probabilistic Seismic Hazard Analysis (PSHA) because of the paucity of the information available for the characterisation of earthquake occurrence and the modelling of strong ground shaking. Besides, a proper characterisation of hazard and risk in these areas is of significant importance given the limited protection measures generally adopted for the design of building and infrastructures. The first step in the construction of a SSM for a low deformation region is to set its limits and basic properties, preferably on the basis of objective and clear criteria (e.g. Chen et al, 2018). The regionalisation studies completed during the last decades relied mostly upon geological information; more holistic approaches might help to identify areas with similar tectonic characteristics and the possible development of tectonic analogues, as done in previous studies (e.g. Johnston, 1994). Similarly, the location and geometry of earthquake sources in SCRs is determined by the geographic distribution of past seismicity and, to a minor extent, by geological and geophysical information. The use of data from tectonic modelling and geodesy is limited and should be possibly expanded, although recent scientific literature reports levels of measured strain (e.g. Craig and Calais, 2014) so low that their use for the characterization of seismicity seems extremely challenging. Constraining earthquake occurrence is a key step in the construction of a SSM; recent research recommends the use of different paradigms for the modelling of seismicity in SCR (e.g. Calais et al., 2016) given the crucial role of seismic clustering on long time scales (see also http://www.ceus-ssc.com/). On the computation side, using the OpenQuake engine

software as a term for comparison, several are the possible improvements in terms of quality of the hazard computed and computational efficiency. In this contribution, we review some of the methodologies currently adopted for the construction of seismic source models (SSMs) and the calculation of seismic hazard in SCRs and we outline some possible methodological improvements.

ESC2018-S22-1012

IS CANTERBURY SEQUENCE TRIGGERED BY DISTANT SUBDUCTION ZONE EARTHQUAKES?

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Despite the proximity of New Zealand to active plate boundaries, the 2010-2011 Canterbury earthquake sequence came as a surprise for the country, as a result of sparse seismicity prior to the sequence compared to other more seismically active parts of the country. However, it has been noticed that there has been a "significant" westward velocity increase in the GPS daily movement through the South Island following the occurrence of the M7.8 Dusky Sound earthquake on July 2009 in the Puysegur subduction zone on the southern tip of South Island. In fact, this disturbance is far wider and longer in time than what the post-seismic slip can account for. This naturally leads to the suspicion: is the Dusky Sound earthquake the smoking gun that leads to the triggering of Darfield Earthquake? We hypothesize that if the Dusky Sound earthquake and the subsequent velocity increase activated the high-angle basement fault where Darfield earthquake occurred, we could see the elevated micro-seismicity prior to it. Such microseismicity is not reported in the GeoNet seismic network, whose magnitude of completeness is 2.7. To compensate for non-reporting of the microseismicity, we resort to template matching using local events on continuous waveforms from 2004 to 2010 to search for earthquakes below the network's magnitude of completeness. Having enriched the routine catalog with the microseismicity (detected using template matching), we also investigate if the two earthquakes can be linked using statistical declustering methods. In particular, these methods allow us to test the hypothesis that the Darfield earthquake is a higher order generation aftershock of the Dusky Sound earthquake. Furthermore, these methods allow us to investigate if there was a significant increase in the background seismicity rate prior to the Darfield earthquake.

ESC2018-S22-1078

A NEW PARADIGM FOR LARGE EARTHQUAKES IN STABLE CONTINENTAL PLATE INTERIORS

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Large earthquakes within stable continental regions (SCR) show that significant amounts of elastic strain can be released on geological structures far from plate boundary faults, where the vast majority of the Earth's seismic activity takes place. SCR earthquakes show spatial and temporal patterns that differ from those at plate boundaries and occur in regions where tectonic loading rates are negligible. However, in the absence of a more appropriate model, they are traditionally viewed as analogous to their plate **boundary** counterparts, occuring when the accrual of tectonic stress localized at long-lived active faults reaches failure threshold. Here we argue that SCR earthquakes are better explained by transient perturbations of local stress or fault strength that release elastic energy from a pre-stressed lithosphere. As a result, SCR earthquakes can occur in regions with no previous seismicity and no surface evidence for strain accumulation. They need not repeat, since the tectonic loading rate is close to zero. Therefore, concepts of recurrence time or fault slip rate do not apply. As a consequence, seismic hazard in SCRs is likely more spatially distributed than indicated by paleoearthquakes, current seismicity, or geodetic strain rates. We will illustrate this concept using recent results from the New Madrid seismic zone in the Central-Eastern U.S., late-glacial earthquakes in Fennoscandia, and the M6.5, April 2017 Botswana earthquake.

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SESSION 23

ESC2018-S23-251

PRELIMINARY RESULTS OF CRUSTAL STRUCTURE VARIATIONS IN GREECE DEDUCED BY P-RECEIVER FUNCTIONS

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P-receiver functions is a popular method, applied worldwide, to determine crustal and upper mantle discontinuities beneath seismic stations. The main concept of this technique is that receiver functions provide valuable information regarding the earth structure in the vicinity of the station. P-receiver functions in the framework of the present study are calculated in the Greek region using teleseismic events recorded by stations belonging to the Hellenic Unified Seismological Network (HUSN) during the period 2010-2017. The selected events have moment magnitude Mw greater than or equal to 6 and epicentral distances in the range of 30°-90°. The isolation of the converted seismic phases in the P-wave coda, in order to generate the receiver functions, is achieved by bandpass filtering and, following, rotating the original waveforms to the ZRT coordinate system. In the next step, iterative and waterlevel deconvolution is applied to remove the source effects from the waveforms. In addition, the P-receiver functions are stacked at each station, after moveout correction, aiming to enhance the Moho converted phases. For each station, reliable Moho depths and Vp/Vs ratio are estimated using H-k analysis, i.e. an algorithm that sums, at theoretical arrival times, amplitudes of receiver functions for different crustal thicknesses H and Vp/Vs ratios. For that purpose, a grid search is performed and the optimum H, Vp/Vs pair is estimated. By combing the obtained results at all stations, a 2D Moho topography map in the Greek region is constructed. Acknowledgements: The present study is co-funded by the Special Account for Research Grants of the National and Kapodistrian University of Athens.

ESC2018-S23-427

A NOVEL EVALUATION OF THE SEISMIC/GEODETIC DEFORMATION-RATE RATIO FOR THE ZAGROS FOLD-AND-THRUST COLLISIONAL BELT

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The Zagros Fold-and-Thrust Belt (ZFTB), one of the youngest and most seismically active zones on Earth, represents the present-day boundary between the Arabian and Eurasian plates. ZFTB extends for about 2000 km from eastern Turkey where it connects with the Eastern Anatolian Fault, through SW Iran to the Oman Sea, where it connects to the Makran subduction zone. The belt varies in width, from ~150 km in the west to ~300 km in the east. The ZFTB involves parallel folds that have formed by buckling above an evaporitic formation, thrust-cored anticlines, and thrusts verging both to the SW and to the NE (the last category responsible for some recent large earthquakes) in the sedimentary cover and its underlying basement, implying both thin- and thick-skinned shortening across the belt. By using both instrumental and historical seismicity data coupled with deformation-rates deduced from plate movements, Jackson and McKenzie (1988) made a first quantitative comparison between seismic and deformation-rates of ZFTB. Based on a combined analysis of geodetic and seismic data that had accumulated over the years, Masson et al. (2005), provided a more recent estimation of the contemporaneous seismic versus deformation-rate ratio. They observed that a low seismic strain-rate, especially in the southern sector of ZFTB, accounted for a small percentage of the observed deformation-rate. This has indicated that the crust is deforming mostly aseismically, or that elastic strain is being accumulated. Here, based on a novel combination of GPS and seismological observations we provide an updated statistical evaluation of the seismic/geodetic deformation-rate ratio for the whole ZFTB. We inferred that on Northern Zagros and on the Turkish-Iranian plateau, a moderate to large fraction (~49% and >60%, respectively) of the crustal deformation occurs seismically. On the Sanandaj-Sirjan zone, the seismic/geodetic deformation-rate ratio suggests that a small to moderate fraction (<40%) of crustal deformation occurs seismically; locally, the occurrence of large earthquakes (M≥6) coupled with the high geodetic deformation, could indicate overdue M≥6 earthquakes. On Southern Zagros, aseismic strain dominates crustal deformation (the ratio ranges in the 15-33% interval). Such aseismic deformation is

probably related to the presence of the weak evaporitic Hormuz Formation which allows the occurrence of large aseismic motion on both sub-horizontal faults and surfaces of décollement. These results, framed intothe seismotectonic framework of the investigated region, confirm that the fold-and- thrust-dominated deformation is driven by buoyancy forces; by contrast, the shear-dominated deformation is primary driven by plate stresses.

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ESC2018-S23-535

NEW CONSTRAINTS TO PHYSICAL MODELING OF GEODYNAMIC PROCESSES IN THE IONIAN SEA AND THE SICILY CHANNEL FROM EARTHQUAKE AND SEISMOGENIC STRESS DISTRIBUTIONS

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We analyze seismic data and seismogenic stress distributions in the southern and eastearn offshores of Sicily, e.g. in areas of the Central Mediterranean where seismological and geodetic information useful for regional geodynamic modeling is still relatively poor because of low density and poor geometry of monitoring networks. Using Bayesian non-linear methods for hypocentral locations and hypocenter error estimates we check and improve the earthquake locations performed by more traditional linearized techniques, and this allows us to make significant progress in the interpretation of seismicity especially where seismometric network geometry is more critical. Epicenter maps and hypocenter vertical sections, together with (i) the best quality focal mechanisms coming from seismic waveform inversion and (ii) the orientations of stress principal axes estimated by inversion of focal mechanisms, give us new insight to better recognize the geodynamic engines and plate margin fragmentation in the study area. NW-trending convergence between Nubia and Europe is recognized as the main source of tectonic stress in the study area, producing clearly detectable signatures in terms of σ1 orientations over the whole area including the western Ionian and the Sicily Channel. However, while the focal mechanisms and the seismogenic stress tensor highlight uniform compressional dynamics related to plate convergence in the western part of the study area, seismicity and stress inversion results reveal some degree of heteogeneity in the eastern one. Our findings are evaluated in the light of the rich literature available on the geodynamic processes and microplate architecture and dynamics in the Central Mediterranean. We furnish new constraints to physical modeling of the regional geodynamics and also suggest that modeling should include more realistic assumptions on thermo-rheological features of lithosphere (than microplate or block rigidity generally adopted to date) if the current uncertainties and ambiguities concerning the plate margin fragmentation are to be solved.

ESC2018-S23-720

ESTIMATES OF COSEISMIC AND ASEISMIC SLIPS AND REGIONAL STRAIN RATES BY GEODETIC DATA INVERSION

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Usually, when inverting geodetic data to estimate the coseismic slip distributions on a fault, the area is made large enough to more than cover the rupture zone, with regularization producing regions of large slip with very small slip over the rest of the surface. We have developed a new inverse method which assumes that nonzero slip is confined to a rectangular region, and which jointly estimates, using Bayesian methods, the boundaries of this region as well as the slip distribution within it, using a smoothing parameter also determined as part of the inversion. We apply our method to coseismic

displacements measured by GPS for the 2009 L'Aquila (Mw=6.3) earthquake, central Italy. We first determine the orientation of the fault assuming a simplified model with uniform slip, and then determine the probability density functions for the slip distribution, as well as for the location, length, and width of the rupture area. The slip has a standard of about 10 cm and describes a normal-faulting earthquake with a maximum slip of 88±11 cm and seismic moment of 3.32_(-0.29)^(+0.30) 10^18 N m. The estimated length and width of the rupture area are 18.93_(-2.74)^(+3.59) km and 20.72_(-4.02)^(+14.22) km, while the along strike position is resolved with a precision of a few kilometres. This new method solves the issue of how large to set the rupture area in order to invert geodetic data that, at present, is a subjective choice based on the common sense. At the same time, this theoretical advancement in inverse theory also improves the resolving power on the slip distribution. Synthetic tests show indeed that our method can successfully image deeper slip regions not resolved by previous methods and does not produce spurious regions of nonzero slip. Another advantage of our Bayesian method is that it does not need prior positivity constraints on the slip distribution. We also apply Bayesian methods to interseismic velocities measured by a GPS campaign from 2003 to 2010 in the Pollino area, south Italy. This case is even more complicated than the inversion of coseismic displacements, because interseismic velocities are the result of rigid plate motion, regional tectonic deformation and aseismic slip, which occurs both on the Castrovillari and Pollino faults. We show that all these processes have to be jointly estimated from the geodetic data inversion and that it is important to consider independent regularizations of the aseismic slip distribution over the two faults (i.e., one smoothing parameter for each fault). Furthermore, in order to not underestimate the aseismic slip, we need to apply an additional regularization to regional tectonic deformation. In order to keep low the computational costs of the inverse problem, even in this case we avoid the use of positivity constraints. This also allow to keep the block structure of the inverse problem implied by the increasing number of smoothing parameters entering the Bayesian method, and, taking advantage of this, we develop an algorithm that solve simpler subproblems in order to obtain the whole solution. The estimated aseismic slip indicates that the Castrovillari and Pollino faults are normal and left-lateral transcurrent, with maxima of about 4 mm/yr and 6 mm/yr, respectively. The standard deviation is about 2 mm/yr. The maximum and minimum principal strain rates are 30.9±32.2 and -25.7±36.0 10^(-9)/ yr and the azimuth of the extensional principal axis is 117.9°. These regional strain rates are about one third and rotated clockwise by about 40° with respect to those obtained assuming no aseismic fault. In terms of the rigid plate motion and regional tectonic deformation alone, we indeed estimate maximum and minimum principal strain rates of 96.9±49.6 and -56.6±41.3 10^(-9)/ yr, with an azimuth of 77.2°. These findings show the importance of including aseismic faults when we interpret geodetic strain rates. Otherwise we overestimate regional tectonic deformation and provide misleading information for seismic hazard assessment. In order to improve the estimate of the regional tectonic deformation and make it compatible with the tectonic regime expected on the basis of geological arguments, we extend the inversion scheme in order to include prior information about the tectonic regime. This means that we can discriminate between extensive, compressible and transcurrent regimes and control the direction of the principal strain rates, but not their amplitudes. Requiring an extensional regime for the Pollino area and fixing the azimuth of the extensional principal axis at 80.0°, the aseismic slip distribution does not change significantly, while the maximum and minimum principal strain rates become 69.2±35.4 and -12.1±36.0 10^(-9)/ yr . In terms of rigid plate motion and regional tectonic deformation, alone instead, we estimate maximum and minimum principal strain rates of 125.0±39.7 and -39.6±26.3 10^(-9)/ yr.

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SESSION 24

ESC2018-S24-36

REMARKABLE DIRECTIVITY OF VECTORS CONNECTING PAIRS OF NEIGHBOR EPICENTERS OF KAMCHATKA SUBDUCTION ZONE

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Earthquake epicenters, when considered in space-time, possess certain organisation. A common study subject is clustering which features as aftershock series. This feature represents a specific deviation from the pure-random point field model, of the particular kind when short inter-event distances are unusually frequent. Instead of the common accent on statistics of distances, in the present study we analyze statistics of directions defined by epicenter pairs; the pairs analyzed are those, which are close in space-time (pairs of “neighbors”). Let r be vector connecting neighbor epicenters. We analyze statistics of such vectors with bounds on the distance |r| and on the inter-event time delay, extracted from the Kamchatka regional earthquake catalog. The pair selection ranges were 30-70 km for |r| and 0-12 hours for delay. We constructed histograms of azimuths (rose diagrams of directions) from epicenters in three circles of 150-km diameter for five 10-yr time intervals. To obtain stable results, the effects of two distorting factors on rose diagrams were suppressed in advance: (1) common aftershocks; and (2) the trivial preferred orientation of vectors along the island arc (the latter feature is present for all delays, short or long.) Let us fix Az0=37° as the average strike/elongation of Kamchatka island arc. The rose diagrams show the following. (1) Petals, often rather expressed, are regularly oriented across the arc, along the directions about Az0+90° ("90°" case

ESC2018-S24-143

A NON-EXTENSIVE STATISTICAL PHYSICS ANALYSIS OF SOME SEISMIC SEQUENCES IN THE IBERO-MAGHREBIAN REGION

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The main topic of this study is to characterize the seismic activity in the studied region by implementing qualitative and quantitative analyses of some selected seismic sequences, including seismic swarms and aftershock sequences. Among of them, three aftershock sequences occurred at Al-Hoceima, in northern Morocco. A clustering analysis of these sequences, located in the last years in the Ibero-Maghrebian region, has been performed using the notion of fractal dimension. Analyses of the temporal variation of the fractal dimensions D_(-2) (T), D_0 (T) and D_2 (T), as well as the spectral slope, have been also carried out in order to characterize them. We also use the concept of Non-Extensive Statistical Physics, denoted NESP, as introduced by Tsallis (2009) in order to study, not only the distribution of the selected sequences, but also to analyze specifically the properties of each one. Some basic methodological tools of the NESP approach have been used to also perform the analysis of the inter-event times distribution between earthquakes, using the q-exponential function, which satisfies the main principle of maximization of the Tsallis entropy. Furthermore, the frequency-magnitude distribution according to NESP concept seems to vary significantly from the classical scheme. The variation with time of the b-value in the Gutenberg-Richter relationship has been derived using the windowing method, and a comparative analysis of the variation in time and in space of the D_2-value is assessed. Taking into account that b-value variations are often used in earthquake forecasting studies, this type of works highlight the importance of fractal dimension researches in seismic sequences. Finally, a positive correlation between the b-value parameter and the fractal dimension D_2 has been obtained, as shown in the following relation D_2=1.36(±0.27)b + 0.59(±0.26) The obtained results in this study indicate that the non-extensive statistical physics approach offers the possibility to investigate and explore complex seismic sequences. It is able to derive important results which highlight the behavior of each seismic sequence and the regional seismicity. Keywords: Earthquake sequences; fractal dimension; NESP approach; b-value; correlation integral Tsallis, C. (2009). Introduction to nonextensive statistical mechanics. Approaching a complex world. Springer Science.

ESC2018-S24-168

USING MULTIPLETS TO FIND SMALL SIGNALS IN BIG DATA

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Numerous catastrophic failure events, e.g. large earthquakes, landslides and volcanic eruptions, occur after multiple sets of smaller repeating earthquakes (multiplets). Such events also occur when no larger event follows. Nevertheless, they have the potential to reveal underlying processes such as the nucleation of large events, or stable repeated slip, and hence could improve probabilistic forecasts of the likelihood of catastrophic events. The problem with finding these multiplets is that they are often small, hidden within the ambient noise, and sometimes only picked up by one seismometer. Here we develop an optimised algorithm to extract a catalogue of multiplets and determine their evolution in different seismic signals. By enhancing the short-time-average/long-time-average (STA/LTA) approach for finding events with a moving cross-correlation window, we discover new multiplets automatically. Subsequent tracking of how these events change through time then allows us to resolve the processes taking place. Data assimilation techniques allows this method to adapt under different conditions, dependent on the type of catastrophic failure involved. Building our algorithm using synthetic data allows us to establish and optimise a reliable method, and to explore the effect of several conditions, e.g. ambient noise. We evaluate the algorithm's success in finding multiplets statistically with hits, false alarms and misses, similar to clinical trials. Our method works significantly more successfully than the conventional STA/LTA approach on its own, with more hits and more accurate pick times, especially when there is a low signal-to-noise ratio. We demonstrate the success of our algorithm in real cases of past earthquake sequences, volcanic eruptions and other catastrophic failure type events. From this, we can: 1) evaluate the evolution of multiplets with respect to the volcanic eruption, 2) identify large earthquakes which have had (or not had) nucleating foreshocks in the form of multiplets, aiding to our understanding of the pre-earthquake mainshock processes, and finally, 3) discuss the prospects of automated real-time assimilation techniques of such data for evaluating the forecasting power of such events in seismic networks.

ESC2018-S24-180

THE PROGNOSTIC ROLE OF FORESHOCK SPATIAL ORGANIZATION

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A crucial issue for seismic forecasting is the search for specific features that allow us to distinguish foreshocks from other earthquakes. Indeed, many foreshock properties can be simply interpreted in terms of normal aftershock triggering. We give evidence that the spatial distribution of earthquakes, occurring before small and intermediate mainshocks, clearly depends on the mainshock magnitude and is independent of the lower magnitude threshold. These properties are found to be a stable feature of regional catalogs from four different geographic regions and conversely cannot be reproduced by Epidemic Type Aftershock Sequence models. Our findings suggest that the area fractured during the mainshock is encoded in the foreshock spatial organization and therefore support the prognostic value of foreshocks.

ESC2018-S24-203

CHARACTERISTICS OF EARTHQUAKE CLUSTERS: APPLICATION TO WESTERN CORINTH GULF (GREECE)

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Earthquake clusters occur as mainshock-aftershock sequences (MS-AS) associated with a strong event called mainshock, or as earthquake swarms (ES) when a distinctive main event is absent. In regions like the western Corinth Gulf, where active deformation is manifested with frequent seismicity bursts, it is important to distinguish MS-AS from ES for providing

information on the physical process of earthquake generation and contribute to the seismic hazard assessment. In this respect, we used a highly accurate earthquake catalog and identified earthquake clusters by establishing certain criteria based on spatio-temporal properties of seismicity. The identified clusters are classified as MS-AS sequences or ES based on the skewness and kurtosis of moment release history in each cluster, the magnitude difference of the two largest events and the occurrence time of the largest event. For MS-AS we found large positive values for skewness and kurtosis contrary to ES that exhibit negative to lower positive values of skewness and lower positive values of kurtosis. The parabolic relationship that is derived between skewness and kurtosis is examined along with its symmetry as an additional indication for distinguishing MS-AS from ES. Additionally, the temporal properties of the classified earthquake clusters are investigated in detail by applying stochastic models (i.e. ETAS) and examining the empirical interevent time distribution. An attempt to associate the triggering mechanism and evolution with the existence of fluids is made, especially in ES, where migration of the epicenters is commonly observed. During their evolution repeating earthquakes (i.e. earthquakes with identical seismograms) are observed, particularly in cases where the triggering mechanism is due to fluid intrusion.

ESC2018-S24-241

SOLID SEISMICITY: SEISMICITY PATTERNS (FORESHOCKS, AFTERSHOCKS, INDUCED SEISMICITY) DESCRIBED USING ANALYTICAL GEOMETRY

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Seismicity spatiotemporal patterns take many forms and have so far been described by different physical processes: e.g., precursory accelerating seismicity by Complexity Theory simulations, aftershocks by rock mechanics experiments, or induced seismicity by poroelasticity. I present the Solid Seismicity Theory in which all of those patterns are defined from geometric operations on a static stress field. In this unifying framework controlled by only 2 physical parameters (background stress amplitude range and event density) and a stress step function postulate, seismicity patterns are represented by so-called "seismicity solids" characterised by the envelope distance r*(t). Analytical solutions are obtained for the power-law behaviour of precursory accelerating seismicity (Mignan, GRL 2012), the linear relationship between induced seismicity rate and injection flow rate, as well as the parabolic front of the induced seismicity cloud (Mignan, NPG 2016), and finally the exponential productivity law of aftershocks (Mignan, NPG 2018).

ESC2018-S24-308

LABORATORY STUDY INTO FRICTIONAL PRECURSORY SOURCE DIMENSIONS AND THEIR RELATIONSHIP TO LENGTH-SCALE DEPENDENT FAULT ROUGHNESS

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In a laboratory direct shear experiment, we formed a frictional fault by pressing together two roughened surfaces of polymethyl methacrylate (PMMA) then sheared it until stick-slip failure. Leading up to critical failure, localised AE 'foreshocks' formed along the faulting surface and were detected using an array of absolutely calibrated piezoelectric sensor (Selvadurai and Glaser, 2015). In this study, we take advantage of the sensor's broadband capabilities.

ESC2018-S24-325

A STUDY ON OFF-FAULT AFTERSHOCK PATTERN AT N-ADRIA MICROPLATE

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The aftershocks mainly occur in zones of increased stress induced by the mainshock. Their spatial pattern, however, can be complex. The analysis of seismic sequences caused by events of moderate magnitude occurred in north-eastern Italy and western Slovenia, in many cases does not show preferential alignments along the mainshock fault plane or indicates that the spatial pattern of the aftershocks can be resolved on a discrete plane. We analysed three well-documented off-fault

aftershock sequences triggered by moderate magnitude events, with MD 4.1, 5.1 and 5.6, occurred in north-eastern Italy and western Slovenia. We investigated the aftershocks spatial features by calculating the fractal dimension and the orientation of planes fitting the earthquake foci with the principal component analysis. The aftershock temporal decay is modelled with a relationship based on the static fatigue process. The off-fault aftershock mechanism is further explored in the context of crustal mechanical heterogeneities and static stress changes induced by the mainshock. The fractal and Principal Component Analysis (PCA) methods allowed to discriminate two phases in time, corresponding to a different spatial distribution of the events. The first phase is characterized by the decreasing of the fractal dimension and by vertically oriented planes fitting the hypocentral foci. The second phase is marked by an increase of the fractal dimension and by the activation of different planes, with more widespread orientation. We interpreted the aftershock pattern within the context of the static fatigue process induced by the mainshock. The dynamic stress step caused by the mainshock promotes sub-critical crack growth along structural inhomogeneities until fracture. The process is favoured by the decreasing of the overburden pressure, the variations of the mechanical properties of the medium and normal stress changes caused by the mainshock.

ESC2018-S24-353

DYNAMICS OF MICRO-EARTHQUAKE MULTIPLETS LINKED TO ACTIVE FAULTS IN THE WESTERN CORINTH RIFT, GREECE

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The western part of the Corinth Rift in Greece is opening at about 15 mm per year, generating one of the highest deformation rates in the world, some destructive earthquakes of magnitude M>6 per decade, and high microseismic activity irregular in space and time. Here, we analyze the complete earthquake archive of the western Corinth Rift, containing about 200,000 seismic sources recorded from 2000 to 2015 by the dense Corinth Rift Laboratory network. Half of them have been accurately relocated using both cross-correlations between pairs of event waveforms and precise differential travel times observed at common stations. The relocated seismicity exhibits well-defined clusters at the root of the main normal faults mainly between 5 and 10 km depth in the middle of the gulf and illuminates thin active structure planes dipping north about 20° under the northern coast. Some seismicity is still observed in the footwall of the main active faults, along the West and East Helike faults. We also built a multiplet database based on waveform similarity taking into account cross-correlation coefficients weighted by signal-to-noise ratios. Short-term multiplets are concentrated in the middle of the gulf along the Kamarai fault system, in a 1-2 km thick layer at 6-8 km depth, interpreted as a highly fractured geological layer. They are often associated to slow seismic migration velocities (about 0.05 km per day) during strong swarm episodes and are thus likely to be triggered by pore pressure variations. On the other hand, most long-term and regular multiplets are located deeper (7-10 km), under the northern coast, within an extremely thin layer (about 200 m thick). They occur at the border of nearly planar structures with low seismicity rate, which we identify as plausible fault planes, and they may be explained by aseismic slip on the fault surface around them. This supports the existence of an immature structure growing downdip towards the north at the base of the active geological layer, which possibly reaches the ductile crust around 15 km depth. The different migration velocities, from several tens of meters per day to several kilometers per day, highlighted during the western 2014-swarms, indicate that both pore pressure and creep diffusion are operating in the fault zone. Finally, we identified two new areas within the central active zone, which may correspond to large scale, locked asperities on active fault surfaces, similar in size to the main asperity broken during the 1995, Mw 6.3, Aigion earthquake.

ESC2018-S24-391

FAILURE FORECASTING IN TRIAXIALLY STRESSED SANDSTONES

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Material failure phenomena such as earthquakes, volcanic eruptions, laboratory deformation experiments, and landslides are often preceded by geophysical precursory signals. These precursory signals have been observed to follow power-law accelerations in spatial, temporal, and size distributions leading up to catastrophic failure. It is believed that modelling these precursors is the key to forecasting these failure events and to effective hazard mitigation. In previous studies, the behavior of geophysical precursors has been modeled using Voight's relation in order to perform 'hindcasts' by solving for failure onset time in a method known as the Failure Forecast Method (FFM) [Kilburn and Voight, 1998; Kilburn, 2003; Bell et al., 2011]. However, performing this analysis in retrospect creates a bias, as we know an event happened, when it happened, and we can search data for precursors accordingly. We aim to remove this retrospective bias, thereby allowing us to make failure forecasts in real-time in a rock deformation laboratory. We triaxially compressed water-saturated 38x95 mm sandstone cores (Pc= 25MPa, Pp = 5MPa, ? = 1.0E-5 s-1) to the point of failure while monitoring strain rate, differential stress, AEs, and continuous waveform data. Here we present the application of the current FFM to our rock failure experiments to gain a statistical distribution of bulk medium properties leading up to failure. We then apply these techniques to increasing fractions of the data-sets to observe the evolution of the failure forecast time with precursory data. We discuss these results as well as our plan to incorporate a Bayesian version of the FFM to mitigate false positives and minimize errors for real-time application. Real-time failure forecasting could revolutionize the field of hazard mitigation of brittle failure processes by allowing non-invasive monitoring of civil structures, volcanoes, and possibly fault zones.

ESC2018-S24-407

ON THE SHAPE OF THE BA}TH'S LAW

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We show that the shape of the distribution of the largest relative magnitude of aftershocks can be derived from the Gutenberg-Richter law and the exponential-type distribution of the number of aftershocks of the relative magnitude above a threshold. The largest magnitude of aftershocks relative the magnitude of the mainshock, according to the well-known B{aa}th's law, in average is about 1.2. Various models interpreted this average value, however, the complete distribution was never obtained in the models. The novelty of our simple model is the exponential distribution of the number of the relative magnitude aftershocks. This distribution is actually observed in the statistics of worldwide earthquakes of Mgid6.5, rather than commonly expected distribution with pronounced non-zero mode. Our model explaines also that the shape of the Bath's law remains unchanged if to consider limited intervals, and the shift in the magnitude is defined by a simple equation, derived from Gutenberg-Richter and Omori-Utsu laws. The calculated model for various intervals perfectly fits the observations. Studying how common is the exponential-type distribution of the number of the relative magnitude aftershocks, we confirm this property for the direct aftershocks in several regions. The research was partially supported by Russian Science Foundation (Project 16-17-00093).

ESC2018-S24-421

DIFFERENT PATTERNS OF AFTERSHOCK SEQUENCES IN THREE RECENT CENTRAL APENNINES EARTHQUAKES

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During the last 20 years, the Apenninic belt (Central Italy) was affected by three seismic sequences: Colfiorito (1997-98), L'Aquila (2009) and Amatrice Visso-Norcia Campotosto (2016-2017). These sequences have lasted for a long time, with a series of moderate-to-large earthquakes distributed over Apenninic-trending segments 40-60 km long. Their closeness in space and time suggested to study their patterns in order to highlight similarities and differences. The

analysis of these aftershock sequences was performed and the migration of aftershocks was studied. Mathematical Morphology and non-parametric statistics were used to reduce the effect of spatial noise. Parametric analysis in time domain and spectral analysis were performed. The results obtained showed evidence of two different types of aftershock sequences. This could be interpreted in terms of the mainshock spatial location and of the geological and hydrogeological properties of the spatial regions involved.

ESC2018-S24-476

INVESTIGATING CHARACTERISTIC PROPERTIES OF EARTHQUAKE NETWORKS FROM HISTORICAL RECORDS IN THE AREA OF GREECE

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The complex networks, mapping the structure of complex systems, and their topological properties, such as small-worldness and scale-free degree distribution have been investigated in geophysics, alike economics and biology. Such non-trivial properties of earthquake networks can be associated with effective information transfer within the network, which may be seen as a distinct dynamic characteristic before main shocks. An exhaustive analysis is performed to identify the small-world and scale-free properties of earthquake networks in the area of Greece, involving the construction of original and random networks. The nodes of the earthquake networks are constructed either by the seismic square cells, with sides of 0.7o and 1.0o, or well defined seismic zones of the study area. Two different approaches are followed to determine the connections in the earthquake network having as nodes the seismic sites or zones: a) the earthquake succession of the corresponding nodes, and b) the significant correlation computed on the time series of seismic activity of thecorresponding nodes. To assess whether the original network exhibits the small-world property the construction of randomized networks is required. For the first approach for network connections, the connections in the randomized networks are derived by randomization schemes on the original connections. For the second approach randomization schemes on the time series are used, found to give more appropriately randomized networks. Specifically, simulations on multivariate time series, for different settings of their length and number of variables, generated by dynamical systems as well as stochastic processes, maintaining or not the small-world connectivity structure, reveal that the approach of the randomization on the time series is better than the approach performing the randomization on the original network connections. The seismic data are taken from a catalog comprising earthquakes occurred during the period 1845-2017 in the territory of Greece, using different magnitude thresholds. For each of the earthquake networks formed for different magnitude thresholds, type of nodes and connections, the metrics for characterizing the small-world and scale-free properties are computed. The results overall suggest that the earthquake networks lack the scale-free property and exhibit a small-world structure when the random networks are constructed by time series, independently of the type of nodes, i.e. seismic cells or zones. Acknowledgments: The financial support by the European Union and Greece (Partnershi Agreement for the Development Framework 2014-2020) under the Regional Operational Programme Ionian Islands 2014-2020, for the project "Telemachus-Innovative Operational Seismic Risk Management System in the Region of Ionian Islands" isgratefully acknowledged.

ESC2018-S24-481

MARKOVIAN ARRIVAL PROCESS MODELING OF SEISMICITY PATTERNS IN CORINTH GULF, GREECE

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A detailed description of the time-varying earthquake behavior in Corinth Gulf (Greece) area is attempted. The Markovian Arrival Process (MAP) is applied aiming to reveal and quantify distinct seismicity phases due to variations in the earthquake occurrence rates. The MAP is a counting process, that allows for transitions between the hidden states of a Markov process, and in each state a different level of seismicity rate is assigned. Akaike and Bayes information criteria

are used for identifying the number of phases, the model parameters are estimated via the EM algorithm, and the most likely sequence of the states under which the observations occurred is calculated through a local decoding algorithm. The study area is divided into its western and eastern parts, in order to investigate possible variations of the earthquake occurrence rates and interevent times. A quantitative evaluation of the clustering properties is implemented, for detecting the optimal threshold above which a strong clustering with long range dependencies is observed. Concerning the eastern part, data analysis demonstrates that the earthquake sequence is explained by the four-state model while the seismicity of the western part can be described by three states. Goodness of fit tests suggest that the proposed models approximate well the physical process. The hidden states can capture the behavior of active seismic periods with main shocks-aftershock sequences, and periods of seismic quiescence. A mark (magnitude interval) in each arrival (earthquake) is further assumed in order to investigate the associations between the earthquake frequencies of different magnitude ranges. The process, called Marked Markovian Arrival Process (MMAP), is applied for the first time for the description of the seismicity patterns in the study area which accommodates intense seismic activity, a characteristic example being the 1981 Alkyonides seismic sequence of the eastern part with three main shocks of M≥6.3. The analysis is performed on synthetic earthquake catalogs that replicate the temporal behavior of the earthquake sequence. After the magnitude classification, we quantified a relation of main shock occurrences to smaller ones, through the computation of correlations and covariances between the seismicity rates of different earthquake magnitude intervals. The applied models, significantly contribute to the temporal description of seismic activity, since they detect the number of seismicity phases that characterize the two subareas, and statistically reveal the earthquake interactions of different magnitudes regarding the occurrence rates. The financial support by the European Union and Greece (Partnership Agreement for the Development Framework 2014-2020) under the Regional Operational Programme Ionian Islands 2014-2020, for the project "Telemachus – Innovative Operational Seismic Risk Management System in the Region of Ionian Islands" is gratefully acknowledged.

ESC2018-S24-493

SPATIAL FEATURES OF EARTHQUAKE CLUSTERS INVESTIGATED BY DIFFERENT APPROACHES

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Earthquake clustering is a prominent feature of seismic catalogs, both in time and space. Several methodologies for earthquake cluster identification have been proposed in the literature with at least a twofold scope: (1) characterization of the clustering features and their possible relation to physical properties of the crust; (2) declustering of earthquake catalogs which, by removing events temporally and spatially dependent on the mainshocks, allows for spatio-temporal analysis of the background seismicity. Nevertheless the application of different (de)clustering methods may lead to diverse classifications of earthquakes into main events and secondary events; consequently, the definition of mainshock is not univocal, but strictly related to the different physical/statistical assumptions underlying each method. Therefore we consider different declustering techniques to investigate classification similarities which might provide strong support for some clustering features, and classification differences which might highlight strength and lack of the clustering methods. The comparative analysis of earthquake clusters is carried out for a sequence of earthquakes occurred in North-Eastern Italy, as reported in OGS catalog since 1977. In this area only low-to-moderate magnitude events have been recorded during the last decades, despite its high seismic hazard attested by at least eight historical destructive earthquakes occurred since 1348, the most recent one being the 1976 May 6 M6.4 earthquake, located in the Julian Prealps. Hence, a further aim of the clustering analysis is to provide a quantitative basis to understand the role of moderate size earthquakes in the framework of regional seismicity. Two clustering techniques are applied: the nearest-neighbor approach (Zaliapin and Ben-Zion, 2013) and the stochastic declustering approach (Zhuang et al., 2004). Both

methods can be satisfactorily applied to decompose the seismic catalog into background seismicity and individual sequences (clusters) of earthquakes; moreover, they are data-driven and allow studying the internal structure of the clusters. The nearest-neighbor (NN) approach is based on the nearest-neighbor distance of events in the space-time-energy domain (Baiesi and Paczuski, 2004), where the distance between event i and event j is the product of (1) their inter-occurrence time, (2) their hypocentral distance up to the fractal dimension of the earthquake hypocentre distribution, and (3) the frequency of the magnitude of event i as given by the Gutenberg-Richter law. The histogram of the distances between every pair of events i and j clearly shows a bimodal distribution that can be approximated as a mixture of two Gaussian distributions, one associated with the Poissonian background activity and the other with the clustered populations. The nearest-neighbor method has only two parameters, fractal dimension d and b-value, that are robustly identified by the Unified Scaling Law for Earthquakes (USLE) method (Peresan and Gentili, 2018). The stochastic declustering approach (SD) is based on the space-time epidemic-type aftershock sequence (ETAS) model (Ogata, 1998), a branching point process controlled by a hazard function conditional on the observation history: background earthquakes independently occur at constant Poisson rate, triggering other events with a spatio-temporal decay modelled by the Omori-Utsu law. By the thinning simulation procedure for point processes, the probability that an event at any time t is independent or triggered by previous earthquakes is calculated. Based on these probabilities, the whole process stochastically splits into key sub-processes: the background process (i.e. the declustered catalog), and the cluster processes triggered by each background event. The estimation of ETAS parameters is an iterative algorithm that simultaneously estimates the background rate by a variable kernel method, the model parameters by the maximum likelihood method, and the branching structure obtained by the thinning procedure (Zhuang et al., 2002). A preliminary comparison of results from the two methods shows that the cluster structures produced by NN and SD approaches have comparable trend in terms of spatial extent of seismic clusters. The detected clusters can be represented as topological trees. For large sequences, trees obtained from the SD method show a more complex internal structure than trees obtained by the NN method. The greater complexity might reflect the basic features of the SD method, in particular the multilevel triggering property of the ETAS model for which each event is able to generate offspring. Based on the internal structure of the trees detected by NN method, two geographical areas can be recognized. Specifically, burst-like sequences are associated with the north-western part and swarm-like sequences with the south-eastern part of the study region. The territorial heterogeneity of earthquakes clustering is in good agreement with spatial variability of scaling parameters identified by the USLE method, the fractal dimension in particular.

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ESC2018-S24-572

SEISMOTECTONIC PROPERTIES OF THE CENTRAL IONIAN ISLANDS, MICROSEISMICITY ANALYSIS IN CORRELATION WITH THE RECENT STRONG EARTHQUAKES

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The tectonic setting of the central Ionian Islands is dominated by the right-lateral, strike slip faults of the Kefalonia transform fault zone (KTFZ), which consists of two main branches along the western coastlines of Kefalonia and Lefkada Island, respectively, and is characterized by high seismic activity. Since 2003, four strong (Mw > 6.0) earthquakes occurred in the area, two in Lefkada (on 14/08/2003 with Mw 6.2 and on 17/11/2015 with Mw 6.5) and the Kefalonia 2014 doublet (on 26/01/2014 with Mw 6.1 and on 03/02/2014 with

Mw 6.0) causing significant damage. Benefiting by a dense local seismic network, part of the Hellenic Unified Seismic Network (HUSN), manual picking of microseismicity is being made systematically since September 2016, resulting in a catalog of about 9500 data with magnitudes ranging from ML = 0.0 to ML =4.8. The earthquakes were relocated using station residuals and the double difference technique. The spatial and temporal distribution of the relocated earthquakes and cross sections, reveal the fault complexity in the area. In order to identify the properties of active smaller fault segments and correlate them with the properties of the main faults that produced the strong earthquakes, focal mechanisms of earthquakes throughout the KTFZ were calculated and examined along with those of the main shocks. The calculated focal mechanisms are correlated with the geodynamic and tectonic features of the area. The interaction of strong earthquakes was investigated by calculating the static stress changes and by examining the distribution of relocated epicenters from the catalog. This work has been supported by the project “HELPOS – Hellenic System for Lithosphere Monitoring” (MIS 5002697) which is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund).

ESC2018-S24-592

A NON EXTENSIVE STATISTICAL MECHANICS APPROACH INTO THE PHYSICS OF PRECURSORY ACCELERATING SEISMICITY

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The risk associated with the energy release of the large earthquakes inspired scientists to investigate the various preseismic indicators. One of the precursory phenomena is relied on the hypothesis that during the large earthquake preparation, there is an interval where an accelerating seismic release is observed. The increase in the cumulative energy has been described by a power law time to failure relation. Aiming to examine the seismic energy conservation mechanisms occurred on the stress loading process, a theoretical framework which is depended on the non-extensive statistical physics is discussed. The merged applications of the first principles approach as well as the Tsallis entropy ideas in near the time of failure conditions on a hierarchical distribution fault system permits to derive a time-to-failure power-law of the cumulative energy functionals with a common critical exponent m(q) appears. The common critical exponent is a function of the non-extensive entropic parameter q, which describes the existence of the acceleration-deceleration seismicity patterns on the fault system. The concluding remarks and derived empirical laws, support that the cumulative precursory parameters are related with the seismic energy supplied to the fault system and the size of the precursory volume. ACKNOWLEDGMENTS: This work is supported by the project HELPOS (MIS 5002697) which is implemented under the Action “Reinforcement of the Research and Innovation Infrastructure”, funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the EU.

ESC2018-S24-618

COMPILATION OF EARTHQUAKE CLUSTER CHARACTERISTICS IN EASTERN MARMARA SEA

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This study aims to look for seismological footprints for the inferred lateral variations of stress release mechanisms in Eastern Marmara Sea (Turkey). Detecting and analyzing spatio-temporal changes of the seismic activity occurring across the fault zones is the main goal. In this context, general characteristics of earthquake clusters, namely how they extend in time and space are considered. Lowering down the magnitudes of the detected earthquakes is the primary prerequisite for this study. Particular emphasis is given to resembling events which occur in earthquake clusters. In this frame, a systematical search is carried out using array based cross-correlation method. Each cluster has been analyzed

individually from two perspectives; in terms of number of earthquakes and duration time of the activities. Variations of these two properties on EW and NS directions are discussed in relation to well defined major fault lines. The number of earthquakes in each cluster is more intense in the east on the Cinarcik Basin compared with respect to the west (both the foreshocks and the aftershocks). In addition to that, events that have the most intense activity are the ones closer to the main fault. Secondly, when duration times are considered, a difference between the east and west in terms of the decay rate is observed. On the east, both the foreshock and aftershock sequences last longer in duration and vice versa. In parallel to the former case, the largest durations occur once again on the locations which are closer to the main fault. In conclusion, on the east, close to the segments which correspond to the Cinarcik Basin, earthquake clusters include higher number of events, both foreshocks and aftershocks, extending over a longer time period. Observations imply that earthquake activity is triggered more easily and last longer. In contrast, on the west, number of events is lower and occurs in shorter time. Moreover, both the number and duration of seismic production size are higher as we get closer to the main fault. This behavior is discussed in the context of fault maturity, rheology and stress distribution. Finally, a classification methodology is proposed for differentiating between different behaviors of seismic clusters. Close inspection and compilation of these properties over a long time span might in turn be used to detect signs of atypical behavior which may relate any other hidden process such as slow deformation.

ESC2018-S24-661

HIGH-RESOLUTION IMAGING OF SEISMICITY PATTERNS PRIOR TO MICROEARTHQUAKES IN SWITZERLAND

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Earthquake sequences are a typical feature in Switzerland. Each sequence shows a different spatio-temporal occurrence behavior and many of them can roughly be classified into mainshock-aftershock, foreshock-mainshock-aftershock or swarm-like sequences. Yet, the reason for their different behaviors is not fully understood and it was mostly not possible to resolve clear patterns in the seismicity of individual sequences, which is needed to understand the processes behind them. It is therefore important to get a better knowledge of foreshock occurrences – which is an essential component for the understanding of earthquake nucleation – by collecting high-resolution data of earthquake sequences and to analyze in more detail how different geological and seismotectonic settings as well as external forces affect seismicity patterns and earthquake nucleation in general. Immediate foreshocks are the most direct observation of earthquake nucleation. In the past decades, earthquake nucleation has been studied intensively on the centimeter scale in laboratory experiments. Contrarily, for real earthquakes only a few high-resolution observations of their nucleations are available today – mainly limited to magnitudes above M4. Due to the big observational gap between laboratory and field scale, it is still not fully understood if and how results can be transferred between the two different scales. Here we present that rupture nucleation phenomena – as observed on the laboratory scale – can also be observed in detail on the microearthquake scale in well-monitored earthquake sequences with fault dimensions that links the scales of previous observations (laboratory vs. large earthquakes). Our results highlight the potential of our approach to study earthquake nucleation at the field scale for a large number of natural and induced earthquake sequences in well-monitored areas, like Switzerland. Our analysis workflow combines several well-established seismological analysis techniques: We start from the routine catalog of the Swiss Seismological Service (SED) and perform a matched-filter analysis to detect events several orders of magnitude below the SED catalog detection threshold. The enhanced catalog is then analyzed statistically and strong-enough events are located using the double-difference method. The potential of our analysis workflow was recently demonstrated by the analysis of the earthquake sequence of Diemtigen in Switzerland in 2014 and 2015 where we were able to detect and analyze foreshock phenomena for events with magnitudes between ML2.7 and ML3.2. Each immediate foreshock sequence is linked to a decrease in the b-value and a subcritical growth of the foreshock area before the main events. Based

on these results, we plan to perform systematic high-precision analysis of several earthquake sequences with main shock magnitudes ML>=2.5 that occurred in Switzerland in the last 15 years. This would make it possible to not only develop a systematic classification of seismicity patters in Switzerland and how they are linked to seismotectonic and geological settings or source depths, but also to investigate the long-term behavior, driving mechanisms and the influence of external forcing.

ESC2018-S24-666

FOUR INDEPENDENT ANOMALIES FROM THE GENERALIZED VICINITY OF A MAJOR EARTHQUAKE

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The detailed examination of a regime of fore- and aftershock sequences is complicated by an insufficient number of seismic events taking place in the vicinity of individual large main earthquake. To overcome this deficit of data the method of construction of a generalized vicinity of a large earthquake (GLEV) was suggested. This method is based on the scaled summation of data from a great number of fore- and aftershock sequences of individual main earthquakes. Summation of data of fore- and aftershock sequences of 300, 500 or 1000 strongest earthquakes is performed in most cases. Different earthquake catalogs were used to construct such generalized space–time vicinities, and the investigation of the typical behavior of seismicity in such summed vicinities was carried out. In result the typical regime of fore- and aftershock sequences, and a number of other anomalies were described in more detailes than it was possible without the use of the GLEV method. Among others the specificity in the regime of earlier aftershocks was confirmed and examined in more details. It was shown also that fore- and aftershock cascades are accompanied by anomal decrease in apparent stress values a, by an increase in relative contribution of low frequency range of earthquake spectrum, an increase of homogeneity of stress-strain state, a decrease in the b-value, and an increase in the mean magnitude of earthquakes. Wherein all these anomalies increase with approaching of the moment of the generalized main shock as minus logarithm of the time interval remaining from occurrence of the generalized main shock. The anomalies in GLEV can be noticed about one hundred days before the main event occurrence. The character of the mentioned anomalies agrees well with results obtained in laboratory studies of acoustic emission (AE). Most of the revealed anomalies are those expected during development of a common type instability. All these anomalies can be treated as non-specific anomalies. Only one earthquake-mechanism-specific precursor was found. The decrease in mean earthquakes depth occurring in GLE vicinity presumably provides an evidence of the deep fluid involvement in the process. The decrease in the mean depth value indicates presumably the temporal development of a very high permeability arising in connection with (micro)fracturing developing with a strong earthquake approaching. The obtained this way estimations of permeability are very high, but they agree with the maximum permeability values within the Earth's crust obtained by other authors. The problen arises which of the revealed anomalies are independent and which of them have a secondary character. It result of the analysis it was found that majority of the anomalies mentioned above have a secondary character and are connected mainly with an increase of a mean magnitude of earthquakes and a decrease in a number of weaker earthquakes in the GLE vicinity. And this decrease in a number of weaker events is hardly connected with their incomplete registration. Moreover, this behavior was found to agree well with laboratory data on a development of a failure in metals. In result, four independent anomalies developing with approaching of a moment of the generalized main event were found in GLEV. There are power-law increase in a number of foreshocks and aftershocks, an increase in a mean magnitude of earthquakes, a decrease in their mean depth, and a homogenezation of the stress-strain state. The latest three anomalies increase with aproaching of moment of the main shock as minus logarithm of the time interval from the main shock moment. In the most cases the beginning od anomalies can be noticed in GLEV about one hundred days before the generalized main shock. The work was supported by the Russian Foundation for Basic Research (project no. 17-05-00351).

ESC2018-S24-701

THE 2005 VOLCANO-TECTONIC EARTHQUAKE SWARM IN THE ANDAMAN SEA IN VIEW OF NON EXTENSIVE STATISTICAL MECHANICS.

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In the past years the Andaman sea region repeatedly became a site of shallow earthquake swarms followed distant mega earthquakes by days to weeks. The Mw 9.1 December 26, 2004 Sumatra-Andaman earthquake was followed by an earthquake swarm delayed by 30 days, respectively occurred beneath distinct seamounts and seafloor ridges. Previous reports suggest that this earthquake swarms resulted as a consequence of magma unrest induced by static and/or dynamic stress change following the distant Sumatra-Andaman mega earthquake, indicating a criticality in the condition of magma reservoirs beneath the Andaman sea. In the present work the aforementioned criticality as expressed in seismicity patterns, is viewed in terms of non-extensive statistical physics, which is based on the definition of Entropy proposed by Tsallis (2009). We result in a double-slope frequency –magnitude distribution which interpreted as proposed by Vallianatos and Sammonds (2013) where the medium size events corresponds to tectonic fracturing mechanisms, while the higher one to a magma induced hydraulic fracture mechanism. In addition the interevent time distribution is discussed resulting to a q-exponential distribution which suggests a sub-additive system.

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ACKNOWLEDGMENTS

This work is supported by the project HELPOS (MIS 5002697) which is implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the EU.

ESC2018-S24-704

A NON EXTENSIVE STATISTICAL PHYSICS STUDY OF KATLA, GODABUNGA AND EYJAFJALLAJOKULL VOLCANIC SEISMICITY (ICELAND) IN THE PERIOD 2000-2010.

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Iceland is one of the most active volcanic areas of the Earth. In this work we studied the evolution of seismicity in the period 2000-2010 for the Katla, Godabunga and Eyjafjallajokull volcanoes using the temporal characteristics of the non-extensive frequency–magnitude distribution of earthquakes along with that of inter-event times . Our analysis is based on non-extensive statistical physics (NESP) based on Tsallis entropy. We performed the NESP analysis of the three Icelandic volcanoes (Katla, Godabunga and Eyjafjallajokull) and we calculated the temporal evolution of q_M and q_T indexes of non-additivity, which are related to magnitude and inter-event times distribution, respectively. Our analysis indicate that NESP model is suitable to describe the behavior of complex volcanic systems. Our calculations suggest that during the eruption phase of Eyjafjallajokull, q_M=1.48 and q_T=1.60 values higher than that observed in the other two volcanoes and significantly greater from that estimated for the pre-eruption phase. Summarizing , we conclude that Icelandic volcanic seismicity presents a complex correlation and the application of non extensive thermodynamics could be used to describe the characteristics of its complexity.

ESC2018-S24-717

SPACE-TIME CLUSTERING AND SOURCE CHARACTERISTICS IN THE CRUSTAL SEISMICITY IN FRONT OF THE SOUTH-EASTERN CARPATHIANS ARC BEND

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The South-Eastern Carpathians Arc bend in Romania is the most seismically active segment of the entire Carpathians orogen. The seismicity here is dominated by the Vrancea intermediate-depth source, located in a narrow focal volume embedded in the mantle (about 60 to 180 km depth). The Vrancea source represents one of the well-defined intermediate-depth seismic nests in the World (other similar nests are located in Bucaramanga – Colombia and Hindu Kush – Afghanistan). The seismicity in the overlying crust is significantly less intensive and more dispersed in space as compared with the seismic activity in the mantle. It overlaps but at the same spreads beyond the epicentral area of the subcrustal events, mostly eastward of the Carpathians Arc bend. Although it looks to a certain degree decoupled from the tectonics in the mantle, we can expect this activity to be in connection with the complex post-collisional processes driven by the slab-pull beneath Vrancea and intraplate folding in the foredeep area. The goal of the present work is to investigate in detail the clustering and source scaling properties of the recent seismicity (after 2010) developed in the crust in front of the South-Eastern Carpathians Arc bend, between the Trotus and Intramoesian faults. A few representative earthquake sequences were recorded during the study time interval. The most important earthquake sequence occurred close to Marasesti city, with the main shock of magnitude Mw = 5.4 triggered on 22 November 2014 at 19:14 at the bottom of the crust (h = 41 km). According to the Romplus catalog (Oncescu et al., 1999, updated), it is the largest earthquake ever recorded in the area both in the historical and instrumental times. Following the main shock, the seismic activity rapidly developed over an extended area in front of the South-Eastern Carpathians Arc bend. The area of disturbed activity exceeds by far the area expected to scale the main shock size. Unusual migrations were induced both toward SW (reaching 30 km distance from the epicenter within first three hours after the main shock) and NE. Both area and time duration (about six months) of the perturbed seismicity following the shock of Marasesti earthquake exceeds by far the scales usually observed for earthquake sequences of moderate magnitude. We apply cross-correlation analysis together with empirical Green's function (EGF) deconvolution and spectral ratios techniques to investigate seismicity clustering properties and to optimize the source parameters determination. At the same time, we applied inversion techniques to retrieve the moment tensor solution for the largest shocks. For EGF and spectral ratios applications, we associated to the main event many co-located events, selected according to the requirements for empirical Green's functions. The source parameters are estimated as mean values for all the available earthquake pairs. Source clustering and scaling properties and focal mechanism are investigated and discussed in terms of the regional seismotectonics and comparatively with the source scaling relationships for the Vrancea intermediate-depth earthquakes.

ESC2018-S24-722

A MODEL FOR THE SEISMIC ASSOCIATED ACTIVITY BASED ON STATISTICAL ANALYSIS

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The recurrence time theory for mainshocks, as well as Omori's law for aftershocks are briefly reviewed. It is shown how the Gutenberg-Richter frequency-magnitude distribution (or equivalently the earthquake energy distribution) and time recurrence law of the events can be related to specific characteristics of the seismogenic source. An approach for short-term earthquake prediction is put forward herein, based on the statistical analysis of the time-magnitude distributions of the earthquakes. The method uses the general n-point correlation functions in statistical analysis. It is shown that the aftershock activity is characterized by an energy-time distribution with a long tail extinguishing slowly in time. Such Omori-type power-law distributions may originate in a self-replication process underwent by an original, generative distribution of exponential type, resulting in frequency-magnitude distributions of the aftershocks, similar to Gutenberg-Richter law. The generated distributions of the aftershocks have been analyzed using the Båth's law. The statistical analysis of the involved distributions functions may provide information on the time and size patterns of earthquake occurrence if the statistical data set is large enough.

ESC2018-S24-834

COMPARATIVE STOCHASTIC MODELING OF THE AL HOCEIMA, MOROCCO, AFTERSHOCK SEQUENCES IN 1994 (MW 6.0), 2004 (MW 6.4) AND 2016 (MW 6.3)

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In this study, a stochastic modeling of the three aftershock sequences occurred at Al Hoceima, Morocco, starting on May 1994 (Mw 6.0), February 2004 (Mw 6.4) and January 2016 (Mw 6.3) has been carried out. A version of the restricted trigger model, named RETAS, has been used to perform the temporal analysis of the three selected sequences. The conditional intensity function of the RETAS model is similar to the Epidemic Type Aftershock Sequence (ETAS) model, with the restriction that only aftershocks with magnitude greater than or equal to a certain threshold magnitude (Mth) can trigger secondary events. Varying the threshold magnitude, some variants of the RETAS model have been examined, which ranges from the modified Omori formula (MOF) to the ETAS model, including such models as a limit cases. The best fit models identified, based on Akaike Information Criteria (AIC) and for each of the three sequences, differ from one to the other. The obtained difference suggests that, although the activated faults are close together (in the range of 10 to 20 km), their stress regimes could be different. Furthermore, a stochastic model is proposed to analyze the Benioff strain release after a strong earthquake. The model is developed following a compound Poisson process, and contours the evolution of strain release during the aftershock sequence following the main shock occurrence. The suggested model has been applied to our data. Initially, the temporal evolution of the aftershock decay rate was modeled by a RETAS model, and after that, the best fit model recognized is integrated into the strain release stochastic analysis. The applied stochastic model of Benioff strain release empowers a more detailed study by detecting possible deviations between observed data and model. The comparison between the real values of the cumulative Benioff strain release and the expected modeled ones shows some deviation at the beginning of all the three sequences. This shows that it happens large aftershock clusters at the beginning of the sequence immediately after the occurrence of the main shock, more than if their occurrence could be completely aleatory. Strain release spatial analysis reveals release patterns, changing during each aftershock sequence.

ESC2018-S24-844

STOCHASTIC MODELLING OF FLUID-INDUCED SEISMICITY

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The substantial role of high-pressure fluids in the seismogenic process has long been recognized. Fluids can alter rock mechanical properties through fluid pressure and chemical reactions so that they play an integral role in lithospheric geodynamics. Chemical reactions inside the rock mass can reduce rock strength, while increased pore-pressure can reduce the effective normal stress along critically stressed fault zones triggering earthquakes. The key role of high-pressure fluids in the seismogenic process has been documented in many case studies, including large to mega-earthquakes, earthquake swarms and industrial-induced earthquake sequences, associated with fluid or gas injections and extractions from the Earth's crust, or the impoundment of water reservoirs. Although the failure condition of a fault in the presence of high-pressure fluids is well understood, a complication emerges from the diffusion of the pore-pressure triggering front into the crystalline basement that can trigger earthquakes at great distances away from the initial site of the pore-pressure perturbation and at time scales that may vary from days, up to months or even years. Such earthquakes can ever occur in zones of low deformation, posing a higher seismic risk than the one expected in the conventional hazard models. Mitigating the hazard associated with fluid-induced seismicity requires a detailed understanding of the physical mechanisms involved and the development of efficient models

that can describe the complex propagation of the pore-pressure triggering front in the crust. Pore-pressure diffusion in the subsurface is fundamentally a nonlinear process, associated with the highly heterogeneous and multi-fractured crust that produce anisotropic diffusivities that vary both spatially and temporally by several orders of magnitude. In addition, the exact dynamics in the Earth's crust are generally unknown such that the occurrence and evolution of fluid-induced earthquakes cannot be forecasted. To overcome any assumptions and uncertainties related to the in-situ conditions in the seismogenic crust and to account for the wide range of spatial and temporal scales that might be present in earthquake diffusion, we consider a stochastic framework that generates the key features of the process. Within this framework, the Continuous-Time Random Walk (CTRW) model is well-established for modeling diffusion phenomena in complex heterogeneous media, where normal diffusion equations are no longer applicable. We develop the CTRW model to describe earthquake diffusion and test its efficiency in fluid-induced earthquake sequences, either associated with industrial activities and the stimulation of geothermal reservoirs, or with naturally occurring earthquake swarms due to pore-pressure diffusion in the crust. The results of the analysis indicate anomalous earthquake diffusion and the slow migration of seismicity away from the site of the initial pore-pressure perturbation according to a subdiffusive process. Within this context, the spatiotemporal scaling properties of the induced earthquakes show broad distributions with asymptotic power-law behavior, indicating non-Poissonian behavior and correlations in the evolution of the induced seismicity. We further combine the CTRW model with fractional kinetics and the fractional diffusion equation to provide an analytic description of earthquake progression with time. The results indicate that the CTRW model and the fractional diffusion equation can efficiently be used to model anomalous earthquake diffusion in the highly heterogeneous crust.

Acknowledgements

G. Michas acknowledges financial support from an AXA Research Fund postdoctoral grant.

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SESSION 25

ESC2018-S25-332

CHARACTERIZATION AND APPLICABILITY OF AN OCEAN BOTTOM SEISMOMETER ARRAY TO CALCULATE THE SLOWNESS VECTOR FROM INCOHERENT SEISMIC WAVES

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The use of land seismic arrays has been broadly used to calculate the apparent slowness and backazimuth of the seismic waves. For many reasons, the use of conventional array techniques by Ocean Bottom Seismometers (OBS) is a challenge but, it gives an important Earth structure information from the survey area. In this research, we have deployed a 70 km aperture array formed by 5 OBS in the Cape Saint Vincent area. Against all odds, We have been able to obtain seismic wave parameters for regional earthquakes by using this incoherent array (array aperture much larger than expected wavelength).In order to obtain the slowness vector, we have implemented two techniques. On the one hand a multitaper spectrogram time domain beamforming and on the other one a Frequency-Wavenumber (F-K) over the lowpass filtered waveforms from the Continuos Wavelet Transform (CWT). Finally, it will be shown some example of this applicability either in teleseism cases and local earthquakes. The results will be discuss taking into account the ambient noise clock correction and the 3D model for the Cape Saint Vincent area.

ESC2018-S25-416

SEISMO-ACOUSTIC SIGNALS OF THE BAUMGARTEN (AUSTRIA) GAS EXPLOSION DETECTED BY THE ALPARRAY SEISMIC NETWORK

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On December 12, 2017 a devastating release and combustion of gas occurred at the Baumgarten gas hub in Eastern Austria, which is a major European distributor for natural gas near the city of Vienna. The incident caused one fatal casualty, left over 20 people injured and led to a temporary increase of natural gas price by more than 80% in several countries in Europe. We have detected the resulting seismo-acoustic signal on over 20 permanent and temporary broadband seismic stations at distances between 30 and 180 km from the gas hub, most prominently in the 2-4 Hz range. Two distinct phase arrivals correspond to acoustic waves traveling through the troposphere and stratosphere. The passing of a cold front shortly before the explosion has introduced several temperature inversions at low altitude and acoustic waveguides within the troposphere that facilitated our infrasound detections at distances as close as 50 km from the source, in addition to the commonly observed stratospheric reflections. 3D acoustic raytracing using temperature and wind speeds from the forecast model of the European Center for Medium Range Weather Forecast (ECMRW) has allowed to precisely relate the spatial distribution of our detections with calculated surface bouncing points of infrasound rays. This has provided a precise and independent estimate of the origin time of the accident, to be used in forensic investigations. In addition to the acoustic signal we find evidence for weak seismic phases on the stations closest to the gas hub, yet the sudden release of gas above the surface generated acoustic waves more effectively than seismic waves. After the first explosion signal, we also detect a prolonged coda of elevated noise, which is probably due to ongoing gas release and/or the extended fire from the escaping gas.

ESC2018-S25-417

SEARCHING FORE- AND AFTERSLIDES OF GRAVITATIONAL MASS MOVEMENTS

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Environmental seismology is an emerging field with strong implications for better understanding and mitigating natural hazards. Continuous real-time records of seismic stations allow the precise

detection of rapid gravitational mass movements such as rockfalls and landslides on various scales – from local slope monitoring to regional or global detection of large-scale events. Especially when compared with classical detection methods for wide-area coverage, such as remote sensing, seismology has the advantage of providing continuous records with precise time stamps. The seismic waves generated by rapid mass movements enable us to study e.g. repeated failures of a slope with a temporal resolution that opens up new possibilities: E.g. we can discriminate subsequent events from the same source region, such as potential foreslides and afterslides, which might otherwise be registered as just a single failure, or with insufficient timing precision. In this study we analyze seismic records obtained from permanent and temporary seismic networks in the Alps and search for fore- and afterslides around the catastrophic 2017 Piz Cengalo, Switzerland rockslide and a series of rockfalls in the Glockner Group, Austria that have occurred in October 2017.

ESC2018-S25-557

SEISMIC ARRAY OBSERVATION AND ANALYSIS OF ATMOSPHERIC EXPLOSIONS IN TAIWAN

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Dense seismic stations have deployed in Taiwan for seismic activity monitoring. However, different type atmospheric explosions have been recorded by those seismic stations. The first completely recorded atmospheric explosion was related to a large chemical explosion at the Taipei metropolis on April 22, 2011. During this accidental explosion, clear seismic waves accompanied air compression signals were recorded by a broadband seismic array. A possible shock wave signal was recorded at the nearest by strong motion station. Those records provided us an opportunity to study the excited acoustic signals across Taipei basin and interaction with high rise building. On December 5, 2013, another unknown large sound was heard and reported as mysterious explosion in a wide area of northern Taiwan. The explosion has been well recorded by many seismic stations in northern Taiwan. Based on array process of seismic signals, we have identified three major seismic signal groups of this explosion and related to three events in sequence. This explosion sequence has been interpreted as a meteorite explosion with flight trajectory across northern Taiwan from southeastern to northwestern direction. Both events and other reported explosions were not well routinely identified but with large social impact and potential natural hazards. In this report, we presented that limited infrasound stations in northern Taiwan have recorded those atmospheric explosions well also. In further, join seismic and infrasound stations, a new type monitoring network can be constructed to routinely monitor atmospheric acoustic signals in Taiwan.

ESC2018-S25-570

JOINT SIGNAL DETECTION AND PARAMETER ESTIMATION IN SEISMIC ARRAYS

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The robust detection of an incoming seismic wave and the estimation of the wave's slowness vector constitute the two most fundamental tasks performed by seismic arrays, stemming from their beamforming capabilities. Conventionally, the detection and estimation problems are addressed in a sequential fashion, whereby first an incoming phase is detected by means of a signal detection method and then, the parameters of the detected wave are estimated by using a suitable parameter estimation technique. Typically, automatic signal detection in seismic data is performed by using waveform-based techniques such as STA/LTA that are widely used for event detection in conventional seismic networks. The main difference is that in arrays, signal detection is performed on enhanced beams instead of single traces. A notable exception to this rule is the PMCC technique where signal detection is based on the consistency of estimated time-delays between the array elements. On the other hand, the solution of the parameter estimation problem is based on beamforming either in the frequency or in the time domain, with the frequency-wavenumber (or f-k) analysis constituting the most popular estimation technique. In this work, we re-formulate the detection and estimation

problems into the general problem of sensing potential changes in the array's state, which is summarized by the set of time-delays that exist between the signals from the array elements. Assuming a plane-wave model and a constant apparent velocity, we show that by combining pairs of station-pairs, the available time-delays (which are estimated via cross-correlation) can be translated into a set of estimates of the angle Φ that corresponds to the path followed by the incoming wave (Φ lies in the interval [0,180] degrees). It should be noticed that the number of Φ estimates for an array with K elements is equal to the 2-combinations of the 2-combinations of K. For example, in the case of the ARCES array in Norway with 25 elements, we obtain (at each time instance) 44.850 estimates of Φ. In the case of an incoming wave, the estimated time delays should be consistent with the structure of the array, leading to consistent Φ estimates. In the absence of a signal, the estimated delays are random and accordingly, the Φ estimates are uniformly distributed in the interval [0,180]. Thus, the detection problem in seismic arrays can be formulated as the problem of deciding between the two hypotheses of random vs consistent Φ estimates, by comparing the observed distribution of Φ to its theoretical distribution in noise. The Kullback-Leibler divergence is used to measure the distance between the PDFs. When a signal is detected, the obtained Φ estimate can be combined with the set of pairwise delays for the closed-form estimation of the wave's parameters. Since a structured set of delays can only be caused by a signal affecting the entire array (or at least most of its elements) the solution of the hypothesis-testing problem at hand should yield very robust decisions. Additionally, its solution is insensitive to specific noise models or changes in noise conditions (as long as correct delay estimates are obtained). Moreover, contrary to STA/LTA, the proposed technique works equally well with emergent signals. The results obtained from the application of the technique to datasets of real signals from the ARCES array have been very promising and confirm our conclusions. Finally, it must be noted that despite its increased computational complexity, the proposed technique remains within the realm of real-time implementation.

ESC2018-S25-709

REVEALING THE PRESENCE OF THE P-WAVE GENERATED BY WEAK SEISMIC SOURCES WITH COMPLEX FOCAL MECHANISM USING SURFACE ARRAY DATA

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We present the multichannel signal processing technique aimed on the robust (to noise) detection andparameter estimation of weak seismic source signal using surface array observations. Considered problembecame recently popular due to necessity of microseismicity monitoring of dangerous industrial or natureobjects such as mining workings (Maochen, 2005), volcanic zones (Droznin et al., 2015), hydrocarbon andhydrothermal deposits (Eisner 2010; Cros et al. 2017). Such monitoring includes registration procedure (withspatially distributed array sensors) and seismic data processing with further interpretation and decisionmaking about possible threats or hazard estimation. Automatic processing of seismic arrays records allows us to solve two different tasks of microseismicmonitoring. First task is detection of weak seismic signals observed against background seismic noise. Secondtask is the parameter estimation of seismic source such as coordinates, moment tensor (radiation pattern) orp-wave slowness (arrival direction). Obviously, these two tasks are closely connected, because estimation ofsource parameters can be produced only over the time interval where the source signals are observed. As it is discussed earlier (Kushnir et al., 2014) in the practice of microseismic monitoring engineers encounterswith problem of low signal to noise ratio (SNR) and complex focal mechanism of seismic source. In this casemost of standard beamforming techniques, for instance seismic emission tomography (Duncan et al., 2010),become unsuitable to estimate seismic source parameters with required precision. Moreover low SNR valuedoesn’t allow us to detect source signals in array observations with well-known STA/LTA algorithm. We developed multichannel detection algorithm which estimates coherence measure of multidimensionalsignal in the quite short time interval of array records. The main concept of this algorithm based on

thesingular values estimation of the matrix power spectral density (MPSD). Theoretically, MPSD is assumed to besingular and its rank is equal to unity in case when we observe the mixture of p-wave source signal andseismic noise. Detection of p-waves requires the probabilities of false alarm and true detection. In practice,these probabilities is always can be evaluated via Monte-Carlo method using rather long intervals of «pure»seismic noise records. The phase-based robust beamforming algorithm (Kushnir and Varypaev, 2017) of p-wave slowness estimationis presented. This algorithm can be applied to the detected time intervals for the further seismic eventsrecognition under the rough assumption of plane wavefront. Proposed algorithms were applied to the real seismic records of the small aperture array. The main purposewas to investigate the local seismic activity induces by industrial mining explosions. During 20 hours of seismicrecords we have found strong (local mining explosions) and weak seismic events. In some cases the complexfocal mechanism of weak events was established. Using the statistically optimal multichannel filter (Capon,1969) the similarity of seismic source signals was shown in the frequency range from 15 to 30 Hz up to a sign.This filter also shows that the time duration of the identified weak source signal is sufficiently short (about 0.14s.) and its form is very similar to well-known ricker-wavelet function (Bording, 1996). Time distribution analysesof the recognized weak seismic events attests about the relaxation of the earth medium after miningexplosions, what is consistent with the common model of the aftershocks appearing after the mainshock. This work was supported by Russian Science Foundation (Grant No. 16-17-00095), by scientific program ofRAS (N56) and by the Russian Foundation for Basic Research (project no. 18-05-00923).

ESC2018-S25-768

A CONSISTENT AND UNIFORM RESEARCH EARTHQUAKE CATALOG FOR THE ALPARRAY REGION

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To improve our understanding of the seismotectonics and the seismic hazard in the greater Alpine, a homogeneous earthquake catalog in terms of location and magnitude is needed. This requires merging of waveform data of many regional and national seismic networks. AlpArray initiative (www.alparray.ethz.ch), with its AlpArray Seismic Network (AASN), provides unprecedentedly uniform station coverage for the region with more than 650 broadband seismic stations, 300 of which are temporary. The AASN operates since January 2016 and is expected to continue until the end of 2018. We make use of this unprecedent large-scale dense array to: i) consistent and precise hypocenter locations and ii) provide preliminary but uniform magnitude calculations across the region. For this study, we collected the first two years of data (2016-2017) from more than 1000 stations (>15TB of data) and we systematically checked the data and metadata quality. Our workflow is based on the iterative use of automatic P-wave pickers, detection and nonlinear location algorithms with a high-quality re-picking approach finally providing consistent phase arrival times in combination with a picking quality assessment. First, we detect events in the region in 2016/2017 using the STA/LTA based detector of the SeisComP3 monitoring system in off-line mode. To minimize the impact of erroneous automatic triggers on the location, the initial automatic hypocenters are derived by the Equal-Differential Time (EDT) algorithm implemented in the NonLinLoc location software. In addition, a quality-score is determined for each automatic origin and the one with the highest score is the preferred solution for the event. Among the detected events, we select 50 geographically homogeneously distributed events with magnitudes >2.5 representative for the entire catalog. We manually pick the selected events to establish a consistent P-phase reference data set, including arrival-time time uncertainties. The reference data, are used to adjust the secondary, high-quality automatic post-pickers and to assess their performance. The first post-picker is an iterative phase picker, searching for the most likely first-arrival P-onset of the seismogram. This pick is used as initial pick for the secondary post-picker, the advanced MannekenPix (MPX) algorithm. The MPX picker provides consistent and reliable automatic first

arrival P picks together with a pick-quality estimate. Subsequently, high-quality automatic picks of all well-locatable earthquakes are used to calculate a minimum 1D P-wave velocity model for the region with appropriate stations corrections. Finally, all the events are relocated with the NonLinLoc algorithm in combination with the updated 1D model. We compare our locations with existing earthquake catalogs (ISC, EMSC, national catalogs). The proposed procedure represents an important step towards the uniform earthquake catalog for the entire greater Alpine region using the AASN and could applied to different region around the world.

ESC2018-S25-781

MICRO-SEISMIC ARRAYS DETECTION THROUGH FREQUENCY-WAVENUMBER SPECTRUM ANALYSIS

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Since 1960s, seismic arrays represent a powerful tool to study the global earthquakes and the small scale structure of the Earth's interior. These instruments are capable to lower the magnitude threshold of earthquake detection or nuclear explosions improving the signal-to-noise ratio of recordings. For this ability, several seismic arrays were designed with different geometry and configuration and were installed worldwide to detect and to discriminate between nuclear and natural earthquakes, as well as to study the interior structure of the Earth. At the same time, several and specific array technique were proposed to process the array data showing a common capability to measure the slowness and back-azimuth of the incident wave-front and to locate the seismic source by a single array signal measurement. In this work, we exploit the array capability of enhancing by signal-stacking the seismic signals respect to ambient noise and we propose a new method for earthquake detection and location of micro-seismicity. The method uses the frequency-wavenumber (fk) analysis to separate the coherent signals from noise in the continuous recorded signal and search for the best parameter combinations of slowness and back-azimuth that produce the highest amplitude of the summed signals. This f-k analysis is performed on a short time sliding window that is shifted along the raw data with a constant step size. Then, the results of this analysis are combined to define a characteristic function that is used to detect and to locate the identified seismic signals. We designed a field experiment in the Irpinia region (Southern Italy) with seismic micro-arrays and tested the performance of the proposed algorithm to detect natural micro-seismicity. In particular, the experiment consisted of deploying three seismic arrays at few tens of kilometers distance installed nearby the main fault segment activated during the Ms 6.9 Irpinia earthquake in 1980. Each array is made up of seven 3C stations, small aperture (few hundred meters) and irregular geometries. The natural seismicity of the area occurs occasionally in small seismic sequences, with magnitude (Ml) ranging between 0.5 and 1.6. Through the proposed f-k earthquake detection method, we analysed the recorded data at each array and for each detection we estimated the apparent velocity and back-azimuth of the incoming wavefront. Then, combining the information of the three arrays, we tried to triangulate the epicentre for a better estimate of the earthquake location. The results of the experiment are compared with the earthquake locations derived by ISNet, the local operating seismic network that monitors the Irpinia faults system. We discuss our preliminary results and the performance of the new fk-earthquake detection algorithm to monitor the micro-seismicity using seismic micro-arrays as valid tool to complement standard seismic networks for studying natural and induced seismicity.

ESC2018-S25-854

TWO TEMPORARY SEISMIC ARRAYS IN THE HIGH ARCTIC

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The goal of the CalvingSEIS project is to produce high temporal resolution, continuous calving records for the glaciers in Kongsfjord, Svalbard, and in particular for the Kronebreen glacier laboratory. Through innovative, multi-disciplinary monitoring techniques combining fields of

seismology and bioacoustics, individual calving events were detected and located autonomously, and methods to quantify calving ice volumes directly from the seismic and acoustic signals have been developed. Results of this project are presented by Köhler et al. (S12 Seismological and structural studies in Polar regions and the cryosphere). One element of the seismic monitoring was the installation of a temporary, 8-element seismic array west of Ny-Ålesund in Kongsfjord, Svalbard, between 9 April and 4 September 2016. The 3C sensors of the array consisted of 4.5 Hz geophones and Data CUBE recorders of the German pool of mobile stations (GIPP). A second temporary, 3-element array was running with same equipment close to the permanent seismic station KBS. These seismic arrays not only recorded calving events at the glaciers around Kongsfjord, but also regional seismicity from e.g., the Knipovich Ridge, which at its shortest distance is situated only about 100 km away from Ny-Ålesund. In this study, the capabilities of these geophone arrays to monitor the regional seismicity will be investigated by comparing their records with NORSAR's automatic and analyst reviewed bulletins.

ESC2018-S25-1069

ADVANCES IN ARRAY BASED STUDIES OF SEISMIC SOURCES SMART SEISMIC NETWORKING

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Smart seismic hardware which offer simple interface and advanced on-board processing can aid the implementation of seismic array networking. Limitations in communication infrastructures and seismic instrumentation causes difficulties for network operators to install an efficient and accurate seismic network capable of handling the requirements of low latency transmissions and reliable event triggering. Configurable voting technology within a seismic network can eliminate false positives. Using Guralp's latestdigitiser technology, individual stations within the network can be assigned as 'masters' and others as 'slaves'. The slave stations send triggered data packets to the master stations for a decision on an action. The master station can consult the reliability of each station by weightings given to every station on the network. A station installed in an environmentally noisy site may be weighted lower than a vault installation in a remote quiet site. If a master station calculates a high scoring event an action can be issued. The action could be issuing as an alarm, or transmission of the triggered event data.This approach allows networks to be scalable and robust by increased network redundancy and reducing false positives. If an event is identified Common Alert Protocol (CAP) can be used to distribute the event data. CAP is the XML based data format used for exchanging and describing public warnings and emergencies. A warning message can be disseminated simultaneously over many warning systems to many applications. When trigger conditions are met the Guralp digitiser can send a signed UDP packet to a configured CAP receiver which can then send the alert via SMS, e-mail or CAP forwarding. The forwarding CAP message can be sent to multiple destinations. This allows for a hierarchical approach where the single station (or network) parameters can be streamed to another station, or data centre, or both, so that there is no one single point of failure. Guralp Data Interchange, (GDI) is a packetized data transmission protocol used by Guralp hardware which allows seismic waveforms to be transmitted sample by sample, as they are acquired by the instrumentation. To reduce delay time (latency), GDI adapts the size of the data packets it sends to suit the bandwidth available in the network. This means that transmission time is absolutely minimised, well suited for EEW networks. The latest Guralp digitiser technologies can issue triggered event details and alerts with ultra-low-latency, averaging just 40-60ms latency from system triggering to issuing an alert. The next challenge for network operators is the transmission methods between the network and to a central datacentre or 'master site'. The Guralp solution offers network operators simple, configurable seismic hardware which can enhance triggering reliability and reduce network latency.

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SESSION 26

ESC2018-S26-439

BQUAKE: SEISMIC RISK MODELING ON WEBGIS

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Although in Portugal there is no recent memory of catastrophic seismic events, it's a fact that both Continent and Azores Islands are in an area of the planet prone to such events. Examples are for the Continent in the years 1531, 1722, 1755 and already in the 20th century, 1909 and 1969 - those still in the memory of the older generations. For the Azores Islands those of 1522, 1757, 1841, 1926, 1972, 1980 and 1998 were the most significant ones. Seismic risk modeling is a process that relies on predicting the ability of the soil to vibrate. Modeling damages of seismic risk differs from the previous one, since it implies to analyze the behavior of the building, due to this same vibratory action and, consequently, it is important to estimate the effects on the population. Thus, a seismic risk simulator model is proposed – bQuake – which allows to define (or choose) an epicenter and magnitude and then obtain results on the damages inflicted to the building stock, affected roads (availability) and potential victims. Data from the 2011 Census for housing and population are used and the soil type is estimated from the topographic relief. Seismic intensities are calculated for each census block, based on most recent attenuation laws developed for the Continent and Azores, and then damages in the building are estimated using fragility functions based on the vulnerability of each typology of the building stock, in a total of 150 different classes (elements collected from the existing literature). Road availability is estimated from the amount of debris caused by damages on buildings and potential victims are classified from slight injuries to dead. bQuake runs in a webGIS environment (personal computer, tablet or smartphone) and relies heavily on a spatial relational database and client-server architecture. Several programming languages are used in order to optimize processes and processing times. From the definition of the epicenter to obtaining results (geographical representation, statistics or export to Excel) the average time is less than one minute for a given region of the territory. The paper illustrates the results for the case of the earthquake of 17 December 2009, a mild M6, 100 km SW of San Vicente.

ESC2018-S26-498

NUMERICAL SIMULATION OF SURFACE WAVE SCATTERING ON A SINGLE RELIEF HETEROGENEITY

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When geophysical works performed on various objects, the influence of the relief on the results obtained is usually neglected. If the length of the sounding wave is much greater than the typical size of the relief feature, then such an assumption may be justified, however, for many objects, these dimensions can be commensurable, therefore, it is necessary to take into account the distortions associated with the relief. Unfortunately, it is very difficult to analytically do this, so we used numerical methods to determine the features of scattering of surface waves. Numerical simulation in Comsol multiphysics 5.3a [1] is carried out. For this purpose, a universal model has been developed that can be used to calculate the field of surface acoustic waves (SAW) propagating along curvilinear boundaries of arbitrary shape. The approach used in the model for constructing local finite element meshes allows to automatically select the optimal number of elements for different model parameters. Scattering of SAWs on the features of the relief in the form of a Gaussian and a cone is simulated. The coefficients of amplitude variation of various wave components are calculated as a function of the distance to the center of the relief feature and the ratio of the characteristic relief dimension to the wavelength (K). These results are useful in geophysical studies using methods based on amplitude information (for example, the Nakamura method or the method of microseismic sounding [2, 3]). The coefficients of transmission, reflection, and transformation into volume waves are calculated for the scattering of SAWs on the features of the relief, which shows that the waves are most strongly scattered, for which the coefficient K lies in the range 0.07 -5. A distribution of the total SAW energy is constructed near the singularity of the relief with the spectrum corresponding to the real earthquake, from these data the most seismically safe zones with the minimum energy are determined. A dispersion analysis of the SAWs near the relief feature was carried out, it showed that surface-wave tomography methods directly near the relief

feature can have errors over a wide range of frequencies. Analysis of the propagation times of surfactants between two fixed points on different sides of the relief feature showed that for many coefficients K the effective propagation velocity of the SAW exceeds the velocity of the Rayleigh wave in a homogeneous half-space. This is due to the fact that at a certain coefficients K, the SAW is converted into a body wave and back, so the wave travels at a high speed part of the path. A numerical calculation of the surface wave fields propagating along curvilinear boundaries simulating real geophysical objects: the mud Jau-Tepe volcano and the Elbrus volcano. These objects have a different ratio between the characteristic width and height - 0.17 for Jau-Tepe and 0.3 for Elbrus (for the case considered earlier, this coefficient is equal to 1), but nevertheless, the change in the amplitude of the surfactant reaches 20-50% , therefore the results obtained in the project must be taken into account when performing real geophysical work, such as in the field survey of the Elbrus volcano on microseismic sounding technology performed with our participation [4]. The constructed depth profile through this object reflects the internal structure of the volcano and coincides with the part of the region of maximum changes in the amplitude of the surfactant. The study of the relief in the form of a depression showed that in this case the SAWs are scattered more efficiently and most of the energy is converted into bulk waves. It is shown that the relief exerts several times a stronger influence on the scattering of SAWs in the case of the addition of a liquid half-space. This is due to the fact that the main energy of the Stoneley wave is concentrated in the liquid, and in a layer of higher power than for the Rayleigh wave, so the energy concentration near the center of the relief feature is stronger in the presence of a liquid half-space. The research was carried out with the support of the Russian Foundation for Basic Research, the project 16-35-60109. References

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ESC2018-S26-785

IMPLEMENTING OPEN-SOURCE/FREE SOFTWARE FOR MALTA SEISMIC NETWORK

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The broader region of Malta comprises a small archipelago, with a land mass covering a total area of 316 km2 in the Sicily Channel, located between Sicily, Tunisia and Libya. Local seismicity occurs mainly offshore and is considered to be low when compared to the seismicity of other regions in the Mediterranean such as Italy or Greece. Historical records, however, indicate that Malta is susceptible to stronger shaking powerful enough to damage buildings, caused by active nearby tectonic structures like Sicily Channel rift zone, eastern Sicily's Malta Escarpment, even as far away as the Hellenic arc. Urbanization of new regions and development of new building typologies has made seismic hazard assessment for the region very important. For this reason, and to achieve better earthquake detection and evaluation, recently the Malta Seismic Network was enhanced and now comprises 6 broadband stations. In this presentation we illustrate results from the implementation of open-source/free software, from data acquisition and processing, to earthquake source determination and re/location. The benefits of using such software and also the drawbacks are further analyzed.

ESC2018-S26-825

AMBIENT NOISE PIPELINE FOR COMPUTING SURFACE WAVE DISPERSION CHARACTERISTICS

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Ambient noise tomography is one of the most exciting current research in seismology today. In summary, the analyses of ambient oscillations have the capability of determining 1) the Earth's interior in the absence of earthquake sources; subsurface changes over time; and the dynamical

characteristics of ocean induced phenomena. Surface wave tomography using ambient noise, relies of the measurement of dispersion characteristics. Christopher will detail the seismic data processing pipeline currently employed at the Sicilian regional scale for the extraction of surface wave dispersion curves.

ESC2018-S26-894

FREE SOFTWARE LICENSES AND THE IRIS LIBMSEED UNPACKDATA.C INCOMPATIBILITY IN OBSPY

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People often ask us what license we recommend they use for their software and non-software projects. We will address not just the technical questions; but also the moral, ethical, social, and political aspects of a freedom respecting digital society. In a digital society, tools citizens control serve their interests; but if someone else controls them, they serve their own. Part of the problem is that today we understand censorship but have not adapted public discourse to the realities of the digital age, which is being driven by subtler forms of control imposed by ownership of information. One such ownership expansion proposal, namely the European Union Directive on Copyright in the Digital Single Market, was defeated during the plenary session of the European Parliament (5 July 2018) in Strasbourg. Consequently, the European Parliament, the European Commission the Council of Ministers, and the JURI Committee Members (the committee assigned with drafting the rules on European jurisdiction) proposing the surveillance and digital control mechanisms embedded within the directive today face adverse public judgment. Freedom under distribution is paramount for works designed to do practical jobs, particularly in Computational Seismology. The 2016 ObsPy-IRIS Incompatibility of Software Licenses exposes the problems that can be encountered when merging infrastructural code under various different software licenses. In general we say that several licenses are compatible if there is a way to merge code under those various licenses while complying with all of them. Such combinability, or the absence of it, is a characteristic of a given set of licenses. The set of licenses also controls which license is required for the combined program. The libmseed story will then be followed by a comparison between software licenses. We can then start addressing particular practical problems such as the distribution of seismological and geodetic data, and the provision of infrastructural hardware and software products, together with the appropriate analysis and simulation source codes favourable to free software; namely the criterion defined by the respect of user's freedom and community. We will also strive to have sufficient time for questions.

ESC2018-S26-959

GLOBAL HYBRID INSTASEIS-FRAMEWORK FOR HIGH-FREQUENCY 3D WAVEFIELDS

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Earth structure is multi-scale, yet capturing such a broad range of complex heterogeneities with seismic wave propagation is computationally prohibitive. To bridge the gap between complexity and computational cost, we present an Instaseis-based (van Driel et al. 2015, www.instaseis.info) framework for injection type hybrid methods on a global scale. Such techniques represent the bulk background medium as a sparse or smooth structure that accounts for source and path effects, and optimally honour complexities in the model to resolve local scattering where necessary. The modified Instaseis interface allows to couple the global wave-propagation solver, AxiSEM (Nissen-Meyer et al. 2014, www.axisem.info) with an arbitrary local three-dimensional solver of choice, and thus embed a heterogeneous 3D domain within a spherically symmetric Earth model. Thanks to reasonable computational costs (10k CPU hours) and storage requirements (a few TB for 1Hz waveforms) of Instaseis databases, the framework provides coupling of 3D wavefields that reach the highest observable frequencies in global seismology. Since those databases act as a once-and-for-all solution to wave propagation in spherically symmetric models, the framework provides flexibility with respect to parameter alterations, such as modifications in source properties (radiation patterns, source-time function), in the source-receiver geometry, and in

local domain dimensions and location (including regions around the source or receivers) without the need of re-running the global simulation. SPECFEM3D_Cartesian (Komatitsch and Tromp 2002, www.geodynamics.org) has already been incorporated into the framework, with other local 3D solvers to follow. Possible applications include near-source structures and their influence on earthquake or explosion source estimates, characterisations of large finite ruptures, resolution limits of heterogeneous structures at depth, SV-SH conversions in the deep mantle, and hybrid inverse modelling.

ESC2018-S26-1058

A PRACTICAL APPROACH FOR THE SELECTION OF THE CORNER FREQUENCY OF HIGH-PASS FILTERS IN PROCESSING EARTHQUAKE RECORDS

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Processing of strong ground motion (SGM) records is an important step in earthquake engineering, because a large number of external factors, such as instrument noise, tide, wind, human activities etc. can alter the frequency content of records. Velocity and displacement time histories, which are obtained by integrating acceleration time histories, may have low frequency drifts due to above factors, which are usually not noticeable in acceleration records. To eliminate these low frequency drifts from data, de-trending, baseline corrections, and high pass filtering are required. The appropriate corner frequency of the high-pass filter is generally identified by visual inspection of the calculated velocity and displacement time histories. This frequency may be different for records from different stations, even when they are from the same earthquake. The directivity of seismic waves and the site characteristics at the station require that the high-pass filter selected should be record-specific. When large datasets are considered, the visual inspection approach to select the high-pass filter would be time consuming and not practical. In such cases, the common practice is to use the same high-pass filter for all the records. This study proposes a practical and fast methodology to select the corner frequency of high-pass filters when processing a large number of earthquake records. A semi-automated and a fully automated algorithms are presented. Both routines filter records through a range of high-pass filters. After each filter, the corresponding displacements are calculated by double integration and a straight line is fitted to the displacement time histories via least-squares approximation. The filter that results in a straight line fit with a slope closest to zero is taken as the optimal high-pass filter. The semi-automated routine enables a visual check of the changes in the slopes of straight lines, whereas the fully automated routine returns the corner frequency of the optimal high-pass filter directly.

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SESSION 27

ESC2018-S27-233

THE GEONET PROJECT: 7-TH YEAR OF SEISCOMP3 GEOHAZARDS MONITORING IN NEW ZEALAND AND ITS FUTURE

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GeoNet is a project to build and operate a modern geological hazard monitoring system in New Zealand. This project is the result of a partnership, established in 2001, between EQC (Earthquake Commission, New zealand) as investment manager and GNS Science as technical manager. The Geonet project adopted the seiscomp3 software suite as an operational tool in June 2012 to succeed the CalTech-USGS-Seismic-Processing (CUSP) system. The CUSP system developed in the late 1980's relied on a seismologist to review each and every earthquake from 1987 to 2011 in New Zealand. Since 2012, GeoNet is using SeisComP3, which fully automates the location of earthquakes, eases the event analysis for the seismologists and produces automatic and manual outputs in minutes available in quasi real time to the public, and the engineering and research community. New Zealand is located on a complex and active plate boundary and all along the 7 years of monitoring geohazards, Geonet ran, maintained and probed the seiscomp3 operational monitoring system and its seismological network in a context of intense activity with several large regional and local events with roughly a M6 earthquake once a year inland, up to a latest magnitude 7.8 in 2016. This "field" experience in the context of a daily event monitoring and of emergency response lead Geonet to improve, develop and question many aspects of the operational seismic monitoring in collaboration with the Seiscomp3 developers, the user community, the researchers, the duty officers and analysts and the diverse GNS/Geonet teams in charge of the instrumentation, network, computer systems and data collections. We will shortly describe our past experience and present the possible foreseeable future integrating more capability of the seiscomp3 system in the framework of an enhanced geohazards monitoring project for the years to come. Geonet project http://geonet.org.nz.

ESC2018-S27-313

USAGE OF SEISCOMP3 ON A LOCAL SCALE - THE HESSIAN EARTHQUAKE SERVICE IN GERMANY

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The earthquake activity in the federal state of Hesse in Germany, Central Europe, is monitored by the Hessian Earthquake Service situated at the Hessian Agency of Nature Conservation, Environment and Geology in Wiesbaden. The Hessian Earthquake Service operates in total 12 short period, one broadband and three strong motion stations (all permanent stations). Additionally, seven broadband stations are temporally used in the southern part of the state of Hesse, as well as other stations of surrounding institutions. Considering all additional stations the Hessian Earthquake Service uses data of about 50 stations. The earthquake activity in the state of Hesse is mainly concentrated on the southern part of the federal state, where numerous weak earthquakes below the perception threshold are registered. In addition, however, perceptible and sometimes even damaging earthquakes remind the population that the Upper Rhine Graben has not completely come to rest tectonically. The Hessian Earthquake Service established the usage of SeisComP3 as the basic data management and data analysis tool in 2012. Since then multiple changes have been made and implemented in the system to solve local challenges. Data management, data examples and challenges in SeisComP3 on a local scale will be shown, as well as our implemented routine procedures. Besides the standard SeisComP3 tools the Hessian Earthquake Service uses functions like scanloc (for a better detection and localization procedure) or sigma (for strong motion analysis).

ESC2018-S27-530

REAL TIME ESTIMATION OF PEAK GROUND-MOTION PARAMETERS USING AN ADVANCE PROCESSING SYSTEM

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The seismic survey of Romanian territory is performed by the National Institute for Earth Physics (NIEP). After successive developments and upgrades the seismic network operated by NIEP has installed at present over 100 seismic stations and two seismic arrays which cover the whole territory of the country. All the stations are equipped with velocity sensors while most of them are collocated with accelerometer sensors. The seismic network is designed to monitor the seismic activity of Romania which is dominated by intermediate earthquakes from the Vrancea area. The processing software used by the National Data Center are Antelope and Seiscomp3. The program used for the automatic real-time locations in this study is Seiscomp3. Seedlink which is a part of Seiscomp3 is used for data acquisition in real time and also for data exchange. We created a database with events selected from Romplus earthquake catalogue. The events were chosen according to magnitude, depth and number of used stations. After accurate locations of events are obtained, we moved to the next step to calculate peak ground acceleration (PGA), peak ground velocity (PGV) and pseudo absolute elastic response spectrum (PSA). Multiple playbacks were made to obtain realistic results, results that will be implemented in real time. To facilitate easier access to all this information NIEP has developed a web application that uses the data stored in the database to display earthquake information, like location, magnitude and depth in real time. The web application will display in real time the PGA, PGV and PSA values per station after a local event has occurred. The calculated values are compared with different analysis system.

ESC2018-S27-576

SEISCOMP3 AS THE SWISS ARMY KNIFE OF THE NATIONAL SEISMIC NETWORK OF SWITZERLAND

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When the Swiss Seismological Service (SED) first evaluated SeisComP3 (SC3) as a candidate of its new real-time seismic processing system, it was not much more than a concept on paper, with some initial implementation in the framework of the German-Indonesian Tsunami Early Warning project – quite different from the tasks to monitor the typical magnitude 1-4 events of the moderately seismic active Alpine region of Switzerland. However, the idea of a modular system operating on a common, quakeML-compliant data model, a configurable inter-module messaging, and a standard SQL backend database was so appealing that the SED decided to take the challenge of customizing the setup and adapting the software to monitor seismicity at local to regional scales. In 2012, SC3 went operational in Switzerland. The SED extensions included the Baer-Kradolfer postpicker, a local-magnitude module providing ML calibrated for Switzerland and the NonLinLoc algorithm as secondary locator allowing 3D models used for hypocenter determination. In addition, we developed new import routines for merging custom event messages from neighboring agencies, a high-availability setup and a highly configurable alerting system with regional sensitivity, quality thresholds and authoritativeness rules. In the following years, modules for waveform parameterization (ShakeMap compatible) and earthquake early warning (a SC3 implementation of the Virtual Seismologist algorithm) were added, as well as interfaces for custom origin quality metrics used in scevent and for SED alarming thresholds. The database was extended to store the Earthquake Catalogue of Switzerland (ECOS), including historical earthquakes back to the Middle Ages. We also developed new complementary data schemes for station description, site characterization, and management of instrumentation equipment. Current efforts focus on improving SC3-monitoring for induced micro-seismicity associated with e.g. geothermal injection experiments. This requires enhanced resolution in time and space of detections and locations (in the order of few seconds and few hundred meters). To this aim, a new event detector based on template matching and a near real-time double-difference relocator are presently developed. Another project deals with the development of a decision-module for early-warning purposes. Modules are developed partly in-house, partly with external partners or on contract by gempa. This contribution gives an overview of our current SC3 implementation,

alongside with the status of new developments and the availability of all modules in use at the SED.

ESC2018-S27-798

LESS THAN 10 YEARS SEISCOMP3 AT KNMI

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In this contribution we will give an overview of ow SeisComP3 and its components are leveraged in daily data center operations for the Netherlands national seismic archive (KNMI) and part of the European Integrated Data Archive (EIDA; ORFEUS Data Center). Starting a little less than 10 years ago, still using home-grown software and having an event based archive, it was time for a change. Knowing part of the software, as seedlink and slarchive were already in use, and having seen the capabilities of seiscomp in Erice, the choice was made for SeisComP. Data acquisition at KNMI and ORFEUS Data Center begin with a seedlink connection to either another remote seedlink chain server or physical station. Data is continuously being archived using the slarchive module. For derived products and data distribution, in nearly all cases an open-data policy is enforced. Both parties employ the FDSNWS server modules that provide standardized access for users to our seismic data archives as well as internal review and research processes. The strong motion module scwfparam powers the Rapid Raw Strong Motion (RRSM) portal and is running in background. For ODC, the processing pipeline is triggered by an event emitted by the EMSC web socket and dispatched to SeisComP3. Data acquisition is done through Arclink & Arclinkproxy for the collection of data from all EIDA stations. When a single federated FDSNWS entry point to EIDA exists we will make changes in the configuration to reflect this improvement. The KNMI runs an identical service for national events. In total 3 separate pipelines monitor all seismicity in the Netherlands and its surroundings, including the Dutch Caribbean area For management of instrument metadata we use SeisComP3 for inventory modifications, e.g. conversion between dataless SEED, StationXML, and SC3ML. In addition, we have developed and run components that communicate with the Seedlink module over its native protocol. This allows us to leverage technologies such as web sockets and stream data to browsers to show live waveform acquisition, and display channel latencies in real time.

ESC2018-S27-822

CENTRAL GERMAN SEISMOLOGICAL NETWORK AND SEISCOMP3 -- REAL TIME ALERTING FOR EVENTS CLOSE TO THE THRESHOLD OF HUMAN PERCEPTIBILITY

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In Central Germany seismological monitoring by continuously operating digital seismic stations started in 2000 by the installation of station WERN close to the swarmquake area of Vogtland/NW-Bohemia. In the following years the geological state authorities of Saxony, Thuringia and Saxony-Anhalt started funding a network that now consists of a total of 36 stations, which constitute the Central German seismological network. The network is run and maintained by coordinated efforts of the Universities of Leipzig, Jena, and Freiberg. Together with stations from neighbouring networks in Germany, Czech Republic, and Poland the data center at Leipzig University receives near real time data of 68 stations to monitor tectonic and induced seismicity in Central Germany and produce quick alerts for events of magnitude 2.5 and above; for a small mining district this threshold is lowered to magnitude 2.0. Traditional manual data analysis is done to verify the automatic alerts and to produce a local bulletin with a magnitude of completeness of Mc = 0.5. Natural seismicity in Central Germany is dominated by swarm earthquakes in NW-Bohemia/Vogtland (Czech Republic/Germany). One of the prominent results of the last decades additionally shows a S-N elongated seismologically active zone between the swarm quake region in the South and the cities of Halle and Leipzig in the North. The largest instrumentally observed earthquake occurred on Dec 21 1985 near Nový Kostel (Mw = 4.7). Two prominent earthquakes truck the metropolitan region of Halle/Leipzig on

April 29 2017 (Mw = 2.8) and Apr 16 2015 (Mw = 3.2). Automatic data processing in the data center is mostly done by SeisComP3 (SC3) software developed by GFZ German Research Centre for Geosciences, Potsdam, Germany, complemented by modules from gempa GmbH, Potsdam, Germany for enhanced monitoring of local earthquakes. SC3 with SeedLink is used for data acquisition, real time data transmission, collection, storage and provision of miniSEED data to other users or data centers. SC3 with gempa modules provides near real time event detection, location and magnitude determination, and issues alerts in case of significant events. Automatic alerts are sent by SMS and e-mail to state authorities and other interested institutions, and are published on the website http://antares.thueringen.de/cadenza/p/autoevent_tablong_site. Automatic alerts are verified by seismologist and corrected or removed in case of false detections or quarry blasts. The low alerting threshold of Ml = 2.5 originally led to a considerable number of false alerts. Sources of false alerts are location errors, overestimation of magnitudes, and missing discrimination of quarry blasts and mining induced events. In close collaboration with gempa GmbH we were able to reduce the number of false alerts by a bundle of fine-tuning of parameters and tailored developments of SC3 modules like: tuning of P- and S-pickers to increase the number of usable picks, tuning of SC3-module SCEVAL to suppress false alerts, tuning of SC3-module SCANLOC to increase accuracy of picks and speed up picking, most useful during earthquake swarms with short inter-event time spans, locally adapted configuration of SC3-module SCRELOC with respect to localization routines and velocity models. We will give an overview over these developments and demostrate the performance by means of a small earthquake swarm near Nový Kostel in July 2017, providing automatic detections down to a magnitude of completeness of Ml = 1.8.

ESC2018-S27-824

EEW IN SC3 - FINDER AND VIRTUAL SEISMOLOGIST

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Numerous methodologies for Earthquake Early Warning (EEW) exist and have been hardened into production-level software at many networks. Mostly, these implementations are standalone programs independent of the operational earthquake monitoring systems that provide network locations within minutes of an earthquake. Therefore, to manage such an EEW infrastructure is ressource-expensive and most tasks, just as streaming / managing metadata / archiving performance / staging playbacks need to be implemented differently in each environment. This means operating EEW becomes a major effort requiring significant resources, which hampers networks to evaluate their readiness for EEW and demonstrate EEW to potential end-users. The SED has been developing methods and open-source software for Earthquake Early Warning for 10 years. The seismic network at SED migrated to SeisComP3 (SC3) for automated seismic bulletin generation in 2012. Since then, all software for EEW are developed as modules within an SC3 framework. In this presentation, we describe the Virtual Seismologist (VS) and Finite-Fault Rupture Detector (FinDer) methodologies and show how they are integrated into SC3. VS is a traditional approach that builds on existing SC3 detection and location modules for point-source models. FinDer matches growing patterns of observed ground motion with modelled templates to identify line faults, and hence can infer on-going finite-fault rupture in realtime. Together these methods can provide EEW for all event dimensions from moderate to great, if there is a high quality, EEW-ready, seismic network in place. We also describe the desktop EEW Display tool (EEWD) that receives and displays EEW messages and can be used to demonstrate EEW. The EEW package in SC3 is deployed for testing in various places including Switzerland, Central America and Chile. We summarise performance in key events. Providing our open-source modules within SeisComP3 means operators interested EEW that operate SC3 can easily evaluate the potential for EEW in their network - a single agency can operate both the traditional monitoring and EEW using a minimum of resources.

ESC2018-S27-851

BUILDING A SEISMICITY CATALOGUE FOR MARS USING SEISCOMP3

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The InSight SEIS experiment, which will deploy a seismic station on the surface of Mars, will start returning data in late 2018. SEIS includes one short period and one very broadband sensor. The Marsquake Service (MQS), led by ETH Zurich, is responsible for initial analysis of the data. The MQS team will attempt to identify all seismic activity on the planet, provide locations, characterise the events, and if possible distinguish meteorite impacts from tectonic events. This encompasses providing a complete event catalogue for Mars at all distance and magnitude scales, using a single station. In preparation for the data return, a suite of methods that independently constrain distance and back-azimuth have been developed. These algorithms employ 1D and 3D velocity models, which we expect will be updated constantly during the mission as more events are recorded and analysed. In collaboration with gempa, the MQS group has built on the SeisComP3 framework to create a new single-station location platform with new modules and GUIs. This presentation will describe the methods we will use for building seismicity catalogue for Mars, and demonstrate our framework for producing and managing the catalogue.

ESC2018-S27-937

SEISCOMP3 - WHERE ARE WE NOW?

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In 2008, SeisComP3 (SC3) was for the first time released as an open software package to the scientific community. Building upon existing waveform data infrastructures like SeedLink and ArcLink, SC3 was originally designed as a software to automatically detect, locate and quantify large earthquakes on a regional to global scale. A suite of sophisticated interactive and non-interactive graphical user interfaces was developed for SC3, which allows to conveniently control the earthquake processing, with special emphasis on addressing the requirements of tsunami warning centers. However, SC3 was subsequently adopted also by many regional to local networks. Over the years, in fact, numerous new modules were developed and added to the SC3 distribution, many of which meant to accommodate the needs for smaller networks. For instance, full support for NonLinLoc was added as an option to locate earthquakes. Significant progress has been made to include earthquake early warning functionality to SC3. ShakeMaps can be generated directly from SC3. Besides its earthquake monitoring capabilities, SC3 also includes a powerful modules that support seismic data center operations. De-facto standards like SeedLink and ArcLink and, more recently, the addition of the full suite of FDSN webservice allow easy exchange of seismic waveforms and parametric earthquake data. In this presentation we summarize the evolution of SC3 into a popular, end-to-end, now fully open-source software package. We will take stock of the last 10 years of SC3 development, management and licensing. We will provide an overview of where SC3 stands now, what the major challenges of the near future are and how we plan to make SC3 future proof for the next years.

ESC2018-S27-1036

SEISCOMP3 OPEN SOURCE DEVELOPMENTS FOR USA TSUNAMI WARNING

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As SeisComP3 as an open-source project has grown in popularity in recent years, there has been the opportunity for 3rd party developers to augment SeisComP3 both with direct modifications and by integrating external tools and libraries with the core SeisComP3 systems and infrastructure. As a result of the success and popularity of SeisComP3, it was selected as the back-end processing system for the new Tsunami Warning System by NOAA/National Weather Service in the USA with the need to have all software components be open source. ISTI presents here a summary of the open source software components that were paid for by the US

Government and have recently been contributed back to the SeisComP3 community. These modules include a Moment Tensor Processor, Finite Fault Calculator, and an Array Processor. Additional magnitudes include the wave magnitude which serves to calculate specific magnitudes (the mantle magnitude 'Mm', an "energy" magnitude 'Me', another version of the surface wave magnitude 'Ms', and a discriminating ration known as "theta". Finally, core SeisComP3 modules (scevent, scautopick, scautoloc) were updated to find nearby cities, pick polarity and first motion, and to allow disassociation of manually rejected picks.

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ESC2018-S28-49

RELATIONSHIPS BETWEEN MICROSEISM, SEA ICE CONCENTRATION AND WAVE ACTIVITY IN THE ROSS SEA AREA (ANTARCTICA)

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The most continuous and ubiquitous seismic signal on Earth is the microseism, mainly composed of surface waves and closely related to ocean wave energy coupling with the Earth's motion. The lack of anthropogenic seismic noise, together with the presence of strong storms in the Southern Ocean, make the Antarctic continent an ideal natural laboratory for microseismic studies. In this work, we quantitatively investigate the relationship between microseisms recorded on the coasts of the Ross Sea, sea ice concentration in the Ross Sea and significant wave height in the southern hemisphere. In particular, we show how, according to the different seismic station and frequency band, the areas characterised by the strongest anti-correlation between microseism amplitude and sea ice concentration are distinct. In addition, by using deep neural networks we show that it is possible to infer the sea ice distribution in the Ross Sea on the basis of the microseismic amplitudes at distinct seismic stations, calculated in different frequency bands. Finally, we note how the oceanic areas, whose wave activity mostly affects the microseisms recorded in the Ross Sea, are the Antarctic coasts close to Ross Sea and the Drake passage.

ESC2018-S28-64

THE IMAGING OF FAULT ZONES OF TUNKA BASIN (BAIKAL RIFT SYSTEM) USING AMBIENT NOISE

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We use the method of H/V ratio (Nakamura's method) for investigation of inner structure of Tunka basin (Baikal rift system). The submeridional profile in the southern side of the Tunka depression crossing the zone of the Baikal-Mondy fault is a good illustration of the HVSR method. The thickness of the sedimentary cover here increases in the north. At the same time the complexity of the section increases due to the appearance of dense inhomogeneities. It is reflected on H/V curves in the appearance of additional maxima of the H/V ratio values. The results obtained were compared with drilling data. The zone of the Baikal-Mondy fault is represented by three branches in the basement that emerge into the sedimentary cover. Sublatitudinal cross-section along the left side of the Irkut river valley in the east of Tunka basin shows large differences in the composition and the constitution of one in the eastern and western parts. West, the deepest part of the basin, is composed by mainly of soft, and at the bottom - denser sediments. Basement depth here is about 1000 meters. To the east an uplift of basement reveals along the fault of reverse or thrust type, or the existence of dense body of volcanic rocks in the lower part of the section. Still further to the east there is a gradual rise of the basement corresponding to the modern relief of the western slope Elovsky spur. Here, in the upper part of the section high density layers are allocated, which correspond to basalt flows established by drilling and geological observations. Two submeridional profiles in the western part of the basin made it possible to determine the position of individual faults in the zone of the Baikal-Mondy fault. The general structure of this zone is a graben with depth 1200 m. The graben is crossed by a longitudinal fault, along which vertical displacement of the surface of the PR basement of the depression is also noted. The interpretation of submeridional section across Tunka fault shows the vertical displacement of basement surface with amplitude at about first tens meters along the fault plane. Further to the south on 5 km the inclined step is traced. The reported study was funded by RFBR according to the research project 17-05-00826.

ESC2018-S28-82

CHANGES OF SEISMIC NOISE AFTER LARGE EARTHQUAKES IN A FEW-HOUR PERIOD RANGE

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The records from 161 identical broadband seismic stations located in the different regions of the world after large earthquakes off the Sumatra Island on December 26, 2004 with the magnitude M = 9.1, in Chile on February 27, 2010 with M = 8.8, and the Tohoku earthquake in Japan on March 11, 2011 with M = 9.0 are studied. Oscillations with a period of ~11 h are analyzed. They are observed as pulsations in the free radial oscillations of the Earth lasting for more than one week. The stations located a few hundred kilometers away from each other demonstrate identical records. As the distance between the stations becomes larger, the structure of the records becomes different. At the interstation distances of about 3800 km the records at the stations have opposite phases, and at the distances of ~7600 km the phases coincide. This is reflected in the spatial structure of the areas of positive and negative phases of the oscillations on the Earth's surface. This structure recurs at the same time instant after the three considered earthquakes, which indicates that this effect is independent of the properties of the sources. The spatial positions of the areas of positive and negative phases are also not correlated to the geological conditions in the vicinity of the stations which are located both in the subduction zone and within the platform. The structure of the pulsations and their spatial distribution differ from the variations of the Earth's tides. The oscillation period of ~11 h is by an order of magnitude larger than the longest period of the theoretically predicted and experimentally detected free spheroidal oscillations 0S2 (53.9 min). Hence, it is unlikely that the source of the 11-h oscillations is located in the solid Earth. Among the probable sources there can be excitation of internal gravity waves (IGWs) in the atmosphere and ionosphere which appear in a wide period range. The vertical displacements of air masses in the hour period range will affect the readings of the broadband seismographs responding to the changes in gravity.

ESC2018-S28-100

IMAGING MEDIUM CHANGES AT DEPTH USING 3-PROBABILISTIC BODYAND SURFACE-WAVE SENSITIVITY KERNELS

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In the context of seismic monitoring, recent studies made successful use of seismic coda waves to locate medium changes on the horizontal plane. Locating the depth of the changes, however, remains a challenge. We build 3-D sensitivity kernels as a linear combination of body- and surface-wave sensitivity (Obermann et al. 2016) and show their potential and limitation for imaging purposes at depth. We use both, numerical simulations and real-data applications.

Obermann, A., Planès, T., Hadziioannou, C., Campillo, M. Lapse-time dependent coda wave depth sensitivity to local velocity perturbations in 3-D heterogeneous elastic media, Geophysical Journal International, 207, 59-66, doi: 10.1093/gji/ggw264

ESC2018-S28-185

SHALLOW RIGIDITY DETERMINATION USING CO-LOCATED PRESSURE AND SEISMIC SENSORS FROM THE ATMOSPHERE-SOLID EARTH INTERACTIONS IN THE FREQUENCY BAND 0.01-0.05 HZ

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There are now many co-located seismic and pressure sensors in various parts of the world. At these sites, high coherence is found between pressure and seismic noise for frequencies between 0.01 Hz and 0.05 Hz. In this frequency band, atmospheric effects are clearly much stronger than oceanic effects and surface pressure changes are the dominant source of seismic noise. This interaction process can be modeled by elastic deformation of the solid earth caused by surface pressure loading. By modelling this process, we can derive the rigidity near the surface and the pressure-wave velocity on earth's surface. Pressure-wave velocity is presumably related to wind speeds. Depth extent of pressure-driven elastic deformation occurs typically within 50-100 m from the surface but can be larger as it changes with pressure-wave velocity on the earth's surface. The rigidity we derive is (1-Vs**2/Vp**2)G where G is (the true) rigidity and Vp is P-wave velocity and Vs is S-wave velocity. Therefore, it is not exactly the raw rigidity (G) but the factor (1-Vs**2/Vp**2) approaches 1 near the surface, based on studies on the density vs. seismic velocity systematics for materials at

shallow depths (e.g., Brocher 2005; Boore, 2016). In fact, this factor is about 0.95 in one of the Boore's models (2016). Also, we can convert our rigidity results to raw rigidity by using the density and seismic-velocity relations derived from studies on the systematics. Our results on rigidity can be compared against models of shallow structure (geotechnical layer) such as Vs30 and may provide a useful independent test on these models. We report our analysis on data from the Earthscope Transportable Array (TA) and the California Integrated Seismic Network (CISN). In addition to pressure and seismic sensors, some of these stations (TA) had wind data which enabled us to compare our pressure-wave speed estimates against wind speeds directly measured from wind sensors. Currently, we cannot see close correlation between them because of large scatter but we hope to find a way to clarify the relationship.

ESC2018-S28-255

SOURCES OF BACKGROUND SEISMIC NOISE IN MOUNTAIN AND URBAN ENVIRONMENTS

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Although most of the studies based on ambient noise seismic data focus on the microseismic peak, generated by the interaction of oceanic waves, it is well known that a large number of processes contribute to the Earth shaking recorded in absence of earthquake arrivals. In this contribution we compare the sources of background seismic signals in two very different environments; a permanent low-noise station located inside a tunnel in the central Pyrenees and a station installed, mainly for educational purposes, in a building basement within Barcelona, a relatively large European city. In a typical, low-noise mountainous environment, seismic recors span six orders of magnitude in frequency, from the fortnightly components of earth tides to the 10-30 Hz vibrations associated to human activities. The signal is clearly dominated by the microseismic peak, but the detected vibrations obey very different processes, from the gravitational effects of the Moon and the Sun to the infragravity waves generated by hurricanes along the Atlantic coast of North-America or the vibrations generated by water discharges in a mountain river located 400m from the recording site. Urban data are strongly affected by high frequency signals (f > 2 Hz) mainly related to road traffic and subway activity in the 1-20 Hz band, although the microseismic peak is still clearly identified and its time variations can be observed in good detail. It is interesting to note that for low frequencies (0.008-0.05 Hz; 20-125 s) the background seismic signal is related to the subway activities. At this point it is still not clear whether the observed signals are the result of the deformation following the train's passage or are due to variations of the magnetic field related to leakage currents. Urban background seismic signals often include features generated by a wide range of different cultural activities, including rock concerts, marathon runners, firework shows or football game celebrations, the so-called "footquakes". Therefore, urban seismology is not only useful for classical microzonation studies, but also provides a tool to monitor different man-made activities. Within the microseismic peak, the recorded data have an amplitude similar to that of the higher quality sites, and can hence be included in global studies. In addition, it is worth noting that the seismic data recorded in urban environment offer a good opportunity to gain visibility in the mass media and, therefore, have the opportunity to present Earth sciences to a wider audience. (Founding: MISTERIOS project, CGL2013-48601-C2-1-R)

ESC2018-S28-256

SEISMIC CHARACTERIZATION OF SNOWMELT EPISODES IN A MOUNTAIN RIVER

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Multiple studies have shown over the last decade that seismic data can provide a useful tool for monitoring river discharge in mountain environments. The permanent CANF seismic broad-band station, located within an old railway tunnel in the Central Pyrenees offers an excellent opportunity to extend this view, since it offers a long-term monitoring of the Aragón River, an example of Alpine-style mountain river. This station is located about 400 m of the river channel, but has a low background noise level that allows

to clearly identify the variations of river discharge in the seismic data. We focus here in the identification and characterization of the discharge variations associated with episodes of snowmelt. Those episodes result in a 24-hour cycle, with an increase in energy around 13:00 local time, with a maximum 6-8 h later and decreasing again until the end of the cycle. This signature can be observed in the seismic traces, but is more evident in the corresponding spectrograms, which show variations not only in the amplitude of the signal but also in its frequency content. For this particular site, the seismic signal associated to discharge variations is concentrated in the 2-8 Hz band. Based on these observations, we have developed a procedure that allows us to identify and quantify the days with active snowmelt. First we calculate the spectrograms between 2 and 8 Hz in 24 h intervals starting at 12:00 local time. The days with snowmelt activity will show a regular pattern, while those with signal from other origins will show more scattered distributions. We perform a 2D correlation of the daily spectrograms and then apply a hierarchical classification scheme similar to the approach used classically in seismic clustering. Although a manual inspection is needed to discard some outliers, this approach allows not only to identify snowmelt activity, but also to classify the active days according to the energy of the associated discharge. In cases of weak melting, significant seismic energy is only observed between the early afternoon and midnight and the spectrograms show a V-shaped pattern. When snowmelt is more efficient, the spectrogram pattern is similar, but the signal does not return to its base level during the last hours of the night, staying at higher levels thoughout the episode. The days with particularly intensive snowmelt are characterized by sustained levels of amplitude and a small decrease between 10 am and noon, although the 24h cycle can still be identified. From this inspection, we conclude that snowmelt in the Aragon River valley typically occurs in 3-4 main stages between March and June, with significant differences in the number and duration of the melting stages directly related to weather conditions. The availability of data covering 6 snow seasons (2011-2016) allows comparing their variations on a long-term scale, including examples of different hydrological years, ranging from the dry seasons of 2011 and 2012, with only a few days of snowmelting, and the 2013 season, with large accumulations of snow and snowmelt episodes reaching early July. Compared to typical hydrological gauge stations, seismic instruments have the advantage of being easier to install and maintain. In addition, the results are not exposed to changes in the river channel geometry. In this way, they can provide an efficient tool to monitor long-term variation in snowmelt stages, information that in turn will be useful for climatological studies. (Founding: MISTERIOS project, CGL2013-48601-C2-1-R)

ESC2018-S28-295

CHARACTERIZATION OF AN UNSTABLE MOUNTAIN SLOPE USING AMBIENT SEISMIC NOISE: FUNDAMENTAL TECHNIQUES AND CASE STUDY "CHILCHENSTOCK"

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Earthquake-induced rockfall and landslides are among the most devastating coseismic phenomena, as tragically demonstrated, for example, during the 2008 Mw 7.9 Wenchuan (China) earthquake, where about one quarter of all casualties are attributed to landslides. Coseismic failure of an unstable slope is the final consequence of a long and complex degradation process over many years. Weathering, seismic shocks, decompaction by glacial retreat and erosion, and human activity can all contribute to the preparatory destabilization of a slope. Therefore, known instabilities generally pose a risk for earthquake-triggered rockfall and landslides. However, conventional geotechnical techniques, such as radar interferometry, GNSS observations or the usage of crack- and extensometers rely on displacement rates at the surface. They fail in absence of observable surface displacements, for example, if the instability is kinematically blocked and residing in an unstable equilibrium. The acquisition and analysis of ambient seismic noise is a promising new method to map and characterize unstable areas of a slope. Computing spectral ratios between seismic stations on the potentially unstable area and stations located at a stable reference site allows for a quick mapping of the extend of the instability. The factor of amplification is thereby

an estimate for the degree of the degradation of the slope's inner structure. Automated clustering of site-specific wavefield characteristics, such as the spectral ratio of horizontal and vertical particle-velocity (H/V) and polarization attributes, allows for dividing the unstable slope into compartments of similar response. For highly fractured material, conventional array-based (f-k) and single station (H/V) techniques can be applied to invert for a one-dimensional shear-wave velocity profile and, thus, to obtain a structural model of the local subsurface within the instability. We demonstrate these techniques at the unstable mountain slope Chilchenstock, a well-known active instability in Switzerland, which threatens subjacent protective forests and, in case of a large rockfall event, a village with 1100 inhabitants. The seismological results are compared to engineering geological investigations and the displacement vectors of a permanent GNSS surveying system. We show that ambient seismic noise measurements can be successfully used to map the areas of strongest fracturation, even in the absence of significant surface displacement rates.

ESC2018-S28-326

DEVELOPMENT AND TESTING OF A LOW-COST MULTICHANNEL SEISMIC RECORDER WITH WIRELESS CONFIGURATION

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The monitoring of any physical variable usually requires a sensor and a recording system. In seismology, and specifically in microzonation studies, we use one or more sensors connected with one or more recorders. For example, the application of the Horizontal-to-Vertical spectral ratio (HVSR or H/V) method requires a three-component sensor while the use of array measurements is carried out through several vertical or three-component sensors recording simultaneously. Usually, in commercial equipment, the connection between these sensors and the corresponding recorders is done in a wired way. However, this wired connection might become a serious drawback when the accessibility to the desired location of the sensors is complicated and the setup has to be done in-situ. In other cases, e.g. array measurements, the deployment of several sensors, especially for large apertures, can make the connection of the sensors with the recorder extremely difficult. In this work, a low-cost multichannel seismic recorder with wireless configuration has been developed and evaluated. The developed equipment is formed by two types of modules: the Management Communication Node (MCN), controlled by a laptop; and the Acquisition Communication Nodes (ACN), which performs the communications tasks with the MCN, in addition to the data acquisition from the seismic sensors and the Global Positioning System (GPS) antenna. MCN is composed by Arduino Due board, Arduino shield Wireless SD (Secure Digital) with SD card and Xbee shield module. ACN consists of the same elements as MCN and also adds an Arduino GPS Shield, a GPS antenna, a PowerBoost shield adapter with Lithium ion rechargeable battery and a signal conditioning circuit, which includes an anti-aliasing filter and two amplifiers. The developed system is complemented by a user-friendly graphical user interface (GUI). This program leads the user step by step to perform the data collection. In the first step, the number of recording channels is selected. The second step consists in acquiring data from GPS in order to store the position and the set time for all the available stations. In the third step, the user selects the configuration parameters, which are sent to all the ACN modules. The configuration is the same for all the ACN modules, i.e. it is identical for all the recording nodes. Finally, the acquisition process has to be programmed for a specific time (starting time and duration) in order that all the ACN modules start simultaneously the data registration. The developed system has been initially evaluated with three channels. Concretely, we have used a three-component sensor and tested its suitability to the remote application of the HVSR method. The experimental measurements were carried out in several sites, where the H/V response was obtained previously using commercial equipment. The comparison between the estimated H/V curves obtained with the commercial equipment and the ones obtained by the developed low-cost system with wireless configuration shows a good

agreement. These results demonstrate the right performance of the developed system to record seismic noise data. All the necessary information to reproduce this system: electronic scheme connections, computer code and Xbee modules configuration are open source allowing any researcher to assemble their own system and use it for research or educational purposes.

ESC2018-S28-384

OBSERVATIONS OF AMBIENT NOISE INDUCED BY HURRICANE KATRINA IN THE SOUTHERN USA

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The study of ambient noise is increasingly becoming a significant topic of research in the fields of seismology and applied geophysics. Ocean waves generate noise that can be recorded by seismographs in large distances from the source. Based on the location and type of its nature, ambient noise can be classified as primary (0.05 – 0.1 Hz) and secondary (0.1 – 0.5 Hz). By processing the Rayleigh-dominated content of short period secondary microseism, i.e. above 0.2 Hz, indicators regarding the location (e.g. wave polarization) and proximity (e.g. displacement amplitude) of local noise sources can be extracted. Violent local weather phenomena, such as tropical storms, are known to generate observable ground excitations and, thus, can be exploited for correlating seismological and meteorological observations. Nevertheless, the nature of ambient noise is complex and there is a wide range of factors that affect it, such as coastal morphology, variations in wind characteristics (speed and direction) and circulation of currents. In the present study, we examine a tropical storm in the southern United States of America (USA). Hurricane Katrina was formed in the Gulf of Mexico on August 23rd 2005 and dissipated 8 days later, after making landfall in the continental USA and causing extensive damage. The passing of Katrina through the Gulf of Mexico enabled the recording of high amplitude ambient noise at stations in the southern USA. Waveform data were obtained from the international Federation of Digital Seismograph Networks (FDSN), recorded by broadband stations of the Global Seismograph Network (IU). The processing scheme that was applied is the following. Initially, daily waveforms were cut in hourly windows and the trend and mean were removed. After decimating the recordings to a sampling frequency of 2 Hz, the response of the instrument was removed. The dominant frequency of the signal was manually determined from the Power Spectral Density (PSD) computed for the vertical component of the processed signals. Along with the PSDs, waveforms were visually inspected and recordings contaminated by earthquake signals or instrument malfunctions were removed from the dataset. For the remaining data, we obtained the polarization direction of the signal by performing a grid search (Tanimoto et al., 2006) in the range N0°E – N359°E employing horizontal waveforms. Using the spectral amplitudes of the horizontal components around the defined dominant frequency, a polarization factor (I) was calculated. The azimuth value that minimizes I is the preferred polarization direction value. Despite possible scatter in the results due to remaining contamination from other noise sources, the above procedure yielded a correlation of the polarization direction with the location of the storm in the respective time window. The possibility of combining ground motion amplitude data and PSD curves with the proximity of the cyclone to the station is explored. This approach is considered as a first step in investigating the topic of storm tracking with the use of land seismological stations from permanent networks, for cost-effective application in areas without Ocean Bottom Seismographs.

Acknowledgements: We would like to thank the staff of the Incorporated Research Institutions for Seismology (IRIS) and the United States Geological Survey (USGS) for rendering seismological data available to the scientific community, as well as the personnel of FDSN for providing open access to the waveforms and station metadata. We would also like to thank the National Oceanic and Atmospheric Administration (NOAA) for providing hurricane data.

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ESC2018-S28-472

LANDSLIDE ANALYSIS AND SEISMIC NOISE VIBRATION IN ALGERIA

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Many works on instabilities have been carried out in geophysics, mainly by electrical resistivity (e.g. McCann and Foster 1990; Hack 2000). The application of H/V ambient vibration for instability is over the last two decades. We present a study by seismic ambient vibration of the Djebahia (NE Algeria) landslide which is that of Djebahia triggered in 2012, where independent geotechnical investigations have been carried out. These investigations consist of simple H/V ambient vibration acquisitions, in order to determine the geometry of the rupture surface, the delimitation of the unstable area and test the effectiveness of this method. Acquisition campaign of ambient seismic noise on the Djebahia site, on a surface of about 0.5 hectare, consisted of more than 100 records of seismic noise with a 10 to 20 meters grid size. The H/V ambient vibration records have been made both in the stable and unstable area. This instability site is multilayer bedding. Therefore, we have selected two or more peaks on the H on V curves, interpreted respectively as the interfaces between Backfill, sandy clay and marl. The results obtained with the seismic ambient vibration made it possible to analyze the resonance frequencies of the site sought, even if the H/V treatments were carried out over a wide frequency band ranging from 0.4 to 45 Hz and particular attention was paid to the peaks of the frequency domain between 0.5 and 25 Hz, in order to try to make the concordance with the all rupture surfaces. The different HVSR curves obtained have been interpreted according to their shapes and their frequencies. Analysis of the H/V curves between 0.6 and 40 Hz shows the soil frequencies, varying from 18 to 40 Hz for the high frequencies and we show 25 Hz. Considering an S waves velocity of the order of 140 to 160 m/s determined in redesigned backfills such as those of Algiers (JICA 2006), and using equation from Haskell (1960), we estimated the thickness H of this layer which is on the order of 1,5 to 2,5 meters which corresponds to part of the backfill. This indicates the existence of a velocity contrast within backfills, which, as we have seen above, have a total thickness ranging from 6 to 9.7 m. In other places of the slide, we have determined frequencies around 8 Hz, Average thickness H of this formation of backfill of the order of 5 m. These thickness values are close to the thicknesses determined in the boreholes for the backfill layer. At some points, HVSR treatments yielded curves with frequency peaks centered on 3 Hz. In view of what preceded on the layer of marly clay under the backfills, and with this value of 3 Hz, lower than the frequency of 8 Hz previously obtained corresponding to the backfill, the 3 Hz should have fallen into this layer Of marly clay. Considering a velocity as estimated for the saturated clays by Mari et al. (1998) from 200 to 800 m/s, knowing that the clays of the site affected by the landslide are very reworked, therefore they can only be attributed to them Vs close to the value of 200 m/s. With Equation 1, using the average velocity estimate as given by Madera (1970) and with h estimated at 6m for each. A Vs of about 200 m/s is obtained, giving an estimate of the mean thickness H of this formation giving this resonance frequency of 3 Hz of the order of seventeen meters (about 16 m). The 1 Hz peaks probably correspond to deep levels of compact claystone. The results obtained by the spectral ratios HVSR ambient vibration method tell us about depth of the various interfaces in the case of landslide affecting homogeneous terrain. This method allows to determine the thickness of the geological formations and to highlight the lateral and vertical facies changes.

ESC2018-S28-509

SECONDARY MICROSEISM POLARIZATION IN MACARONESIA (NORTH ATLANTIC)

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It is known for more than 50 years, that the strongest seismic signals recorded in the absence of earthquakes are generated in the oceans, but it is only recently that it has been accurately

modeled. When ocean waves coming from opposite directions meet, they generate pressure fluctuations that propagate in the ocean and are converted at ocean bottom into various seismic waves, which then travel within the Earth. These seismic waves are called secondary microseisms, they are recorded everywhere on Earth and can be used to monitor the ocean activity. The strongest microseisms are related to strong oceanic storms. To improve our knowledge of the ocean wave activity in the North Atlantic Ocean, stations in the islands of Macaronesia are of primary importance. Till now, the secondary microseisms recorded in Macaronesia islands, located in the western Atlantic Ocean, have never been studied and their analysis will provide a better knowledge of the wave activity in that area. This study benefits from a vast seismic dataset of high-quality broadband seismic data in the Portuguese, Spanish and Cape Verde territories. We present here the preliminary results obtained using a small subset of stations, located in the archipelagos of Madeira and Cape Verde. To analyze the three-component data records and characterize the secondary microseismic noise, we used the time-frequency polarization method (Schimmel et al., 2011), in the frequency band 0.10 - 0.20 Hz. This technique allows us to detect signals elliptically polarized in the vertical plane which is the characteristic of Rayleigh waves. We analyze the degree of polarization (DOP) and the back-azimuth (BAZ), as a function of time and frequency. We then compare the BAZ with the theoretically determined sources obtained through the numerical ocean wave model (IFREMER model, Ardhuin et al., 2011). Finally, we investigate the effect the islands geometry and the associated bathymetry to understand the variability of our observation. This work was partially supported by COST action TIDES (ES1401) through the STSM-39414.

ESC2018-S28-537

IMPACT OF WIND TURBINES ON SEISMIC NOISE

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In recent years the number of newly installed wind turbines and wind farms to produce electric energy has dramatically increased. Unfortunately, this can have a counterproductive effect on the data quality of permanent seismological stations, as the ambient noise level at frequencies between 1 and 20 Hz is increased by the operation of wind turbines up to distances of at least 10 km. We aim at defining an easy-to-use procedure to quantitatively estimate the noise level increase, which could be used by licensing authorities to evaluate the adverse effect of wind turbines on existing seismic stations for monitoring local, regional or global seismicity. To define this effect, three factors have to be evaluated: 1) The vibration emissions caused by the wind turbine operation in the seismologically relevant frequency band between 1 and 20 Hz. The emission characteristics (amplitude, frequency) clearly depend on the type and size and foundation of the wind turbine, as well as on the wind speed and blade rotation rate. 2) The seismic wave propagation features in the subsurface, depending on soil geology, topography and attenuation; 3) The distance-dependent increase of the naturally existing ambient noise level in frequencies between 1 and 20 Hz, and the definition of an acceptable threshold. In order to investigate and quantify these effects separately from each other we recorded continuous seismic noise on circular and linear arrays around single wind turbines of different type, on different subsurface conditions, and under different wind speed conditions. The seismic noise produced by the wind turbine operation appears at certain frequency bands with a clear linear relation between their spectral amplitudes and the wind velocity or rotation velocity of the turbines. Distance-dependent attenuation laws for different subsurface conditions have been found from wave propagation modelling and can be calibrated with measurements like those presented here. The final aim is to provide a simple classification scheme that can be used by authorities to define protection zones from new wind turbines for existent seismological stations.

ESC2018-S28-652

CONFIRMATION OF THE THéNIA FAULT ZONE BY HVSR AMBIENT SEISMIC NOISE (ALGERIA)

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The Thénia fault is the most important strike slip tectonic structure in the region of Algiers and Boumerdes. It extends from the Bay of Algiers to Oued Isser for a total length of about 35 km. The western segment of the Thénia fault penetrates the continent up to Cap Matifou in a direction generally N110°. Its trace coincides with a 7 km long line, drawn by an escarpment culminating at 50 m altitude. This scarp, formed by Plio-Quaternary deposits, would be the signature of a recent tectonic activity in agreement with a regional compression NNW-SSE (Boudiaf et al., 1998). Recent work (Moulouel et al., 2017) has made it possible to constrain several aspects relating to this fault zone including the thickness, structure and quaternary characteristics as well as the active aspect. For experimentation of HVSR ambient seismic noise on the Thénia fault, a site was chosen in the locality of Heuraoua located on the west bank of the lake of Réghaia, where we realized, perpendicular to the trace of the fault scarp, a profile of HVSR ambient seismic noise recording and electrical resistivity tomography (ERT), to constrain both results. The ERT profile revealed a relatively subvertical fault, delimiting the low-resistivity marl formation in the north and the resistant sandy formation in the south. The results analysis of the HVSR, on the profile of Heuraoua, show variations in the shape of the HVSR curves. We have sorted according to the typology of the HVSR curves obtained. This sorting allowed us to have three families of distinct curves and allowed to locate a fault zone. However, if we rely on HVSR curves, the fault zone is wider than that evidenced by the ERT profile. The results obtained with HVSR ambient seismic noise method, for the case of Thénia fault in its western part, show that the changes in the shape and peak frequency of HVSR curves are also sign of localization of the fault zone that coincide well with the ERT cross-section.

ESC2018-S28-674

AMBIENT NOISE ANALYSIS IN A DEEP BASIN UNDER DIFFERENT SHALLOW STRUCTURES

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Campo de Dalías basin (SE Spain) has been the location of various field surveys conducted to characterize its deep and shallow Vs structure. The main urban areas in this basin, Roquetas de Mar and El Ejido, were densely sampled and they showed very different near-surface conditions despite being relatively nearby towns. The basin basement has a folded geometry with a general trend of sediment thicknesses to dip from NW to SE. The maximum sediment thicknesses are found in El Ejido synform and in the SE area, whereas the minimum are reported close to the hills of Sierra de Gador mountain range and along Guardias Viejas antiform. Both towns are over medium-hard sedimentary rocks whose thicknesses vary roughly between 100 and 600 m. Microzonation in terms of predominant frequencies for both towns has been done through HVSR technique from a total of 42 single-station ambient noise records in Roquetas de Mar and 94 in El Ejido. Results obtained from this characterization show fundamental low-frequency peaks, between 0.3 and 2 Hz, in both areas. In addition, a set of secondary high-amplitude peaks above 2 Hz are also obtained in Roquetas de Mar. The landform has been investigated by active and passive seismic methods as well as by techniques of geological and geotechnical analysis. Multichannel Analysis of Surface waves (MASW) and Spatial Autocorrelation method (SPAC) were used to determine phase velocity dispersion curves in the frequency range from 0.8 to 28 Hz. Resulting VS30 values are found to range between 300 and 650 m/s for Roquetas de Mar. The softer soils are located within and surrounding a salt marshes area in the northern zone of this town and they are behind the set of secondary high-amplitude HVSR peaks obtained there. On the contrary, all VS30 values obtained in El Ejido are above 500 m/s, where calcarenites of the Upper Pliocene outcropping in some areas of this town are considered as the geotechnical basement. Finally, the elastic properties of the subsoil for both towns were retrieved taking advantage of a recent theoretical approach based on the assumption of diffuse character for the seismic noise wavefield (DFA). Inversion of HVSR curves under this DFA was done for some points in these two urban areas, taking into account a priori information and calibration by records atop boreholes. The non-uniqueness of the models obtained by HVSR inversion was reduced through joint inversion of HVSR and dispersion curves.

Pentagonal and triangular ambient noise arrays with radii up to 425 m were deployed at both towns in order to extend the dispersion curves towards low frequencies as much as possible. These large-aperture configurations enabled us to partially overlap the frequency range of the fundamental peak. Despite the greater complexity, better fittings were achieved for the double-peaked HVSRs found in Roquetas de Mar in comparison with single-peaked spectral ratios obtained on stiff soils in El Ejido.

ESC2018-S28-688

NUMERICAL SIMULATION OF SEISMIC AMBIENT NOISE PROPAGATING 2D AND 3D STRUCTURES USING 3D FINITE-DIFFERENCE METHOD

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Demand on the development of non-invasive measurement methods for shallow S-wave velocity structure is increasing. Active and passive surface wave method will play important role in such measurements. Passive surface wave method or microtremor array measurements particularly receive large attention since the method can penetrate several hundreds to several kilometers easily. Applicability of microtremor array measurements to complex velocity structures with horizontal velocity changes is the one of the issues to be figured out to apply the method to site investigations. We performed numerical simulations of ambient noise tomography with 2D and 3D structures using the 3D finite-difference method to evaluate the applicability of the method to complex velocity structures. One of the simulations is a simple two-layer model with a step. S-wave velocities of two layers are 200 and 400 m/s respectively. Depth to the boundary ranges 20 to 40 m. Another model is more complicated three-layer model with low velocity zones. The model consists of three layers with S-wave velocity of 400, 600 and 800 m/s respectively. There are two low velocity zones with S-wave velocity of 200 m/s at the depth of 3 m and 6 m. In both simulations, receivers are deployed in a 100 x 100 m square array with 4 m spacing. The number of receivers is 676. The dimensions of the model are 550 x 550 x 150 m. Sources were randomly distributed outside of the receiver array to simulate ambient noise field. A 3D viscoelastic finite-difference method with 4th order velocity-stress staggered grid scheme was used to calculate seismic wave field. Cell size is 1 m, time step is 0.25 ms and data length is 65 s. Ten 65 s records were calculated with different source distribution. Ambient noise data were processed by CMP-SPAC method. CMP interval (bin size) was 10 m and the number of bins was 100. A dispersion curve was calculated for each bin. An 1D inversion was applied to each dispersion curve with horizontal constraint. The 1D velocity profiles were interpolated to a 3D S-wave velocity model. The resultant 3D S-wave velocity models obtained from the simulations were generally consistent with the true model. The results of simulations demonstrated that the applicability of microtremor array measurements to complex velocity structures with horizontal velocity changes.

ESC2018-S28-711

INSIGHTS IN THE INTERNAL STRUCTURE OF THE CEBORUCO VOLCANO (MEXICO) FROM AMBIENT SEISMIC NOISE TOMOGRAPHY

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Although it is one of the only historically active volcanoes at the western end of the Mexican volcanic belt, the internal structure of Ceboruco volcano remains poorly constrained. This issue motivated this first seismic tomography of the upper 15 km of the crust to characterize the magma chamber and the hydrothermal system of the volcano. Seismic interferometry applied to ambient seismic noise is increasingly used to retrieve the Green's function between pairs of stations. This technique allows producing high-resolution images of the upper crust with the advantage of using continuously available, non-destructive data. We use the cross-correlations of the ambient seismic wavefield recorded by a dense network of 21 temporary short-period stations deployed to image shallow crustal structure of Ceboruco volcano. We present the preliminary tomography based on this analysis.

ESC2018-S28-791

DECTECTING CHANGES OF SEISMIC VELOCITIES DURING THE CENTRAL ITALY SEISMIC SEQUENCE OF 2016-2017 WITH AMBIENT NOISE MONITORING.

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We retrieve the seismic velocity variations within the Earth's crust in the region of Central Italy which was struck by a series of moderate to large earthquakes during the sequence of 2016-2017, by analyzing the cross-correlations of the vertical components of more than one year (January 2016 - March 2017) of continuous seismic recordings from a network of 28 stations. The technique we apply - based on the reconstruction of Green functions from these repeated cross-correlations as virtual seismograms - has been proved in the last decade to be an appropriate tool for monitoring the relative seismic velocity changes associated to several geophysical processes, like volcanic eruptions or large earthquakes. We observe a decrease of seismic velocities soon after the three largest mainshocks of the sequence (as reported in many similar cases), followed by a slow recovery of velocity towards pre-earthquake conditions. The absolute value of the velocity drop is not proportional to the magnitude of the corresponding seismic event, while it largely depends on the volume of crust sampled by the stations considered in the computations. In addition, we find that the velocity variations are strongest at relatively high frequencies (0.5–0.9 Hz) suggesting that they are mostly related to the damage in the shallow layers of the crust. Finally, we determine the spatial extension of the area interested by the relative velocity decrease, through maps of the temporal evolution of the velocity drop, in order to investigate its potential causes and how it is modified by the combined effect of subsequent events.

ESC2018-S28-800

DIVERSITY OF SEISMIC VELOCITY CHANGE PATTERNS IN THE SAN JACINTO FAULT ZONE ENVIRONMENT ASSOCIATED WITH REGIONAL AND LOCAL EARTHQUAKES

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We use ambient seismic noise monitoring techniques to study the response of crustal and fault zone materials in the San Jacinto fault zone environment, southern California, to earthquakes at regional and local distances. Using seismic records from 20 three-component stations of a regional seismic network around the Anza Seismic Gap we decipher the relative velocity change (dv/v) signatures of aseismic slip episodes in a broad region around the fault. We focus on slip episodes that follow the 4 April 2010 M7.2 El Mayor-Cucapah (EMC) earthquake that occurred some 100 km away on the Laguna Salada fault system in Baja California, Mexico; and the 7 July 2010 M5.4 Collins Valley event that occurred on the San Jacinto fault system within the network. In addition, we discuss the dv/v signature of the 10 June 2016 M5.2 Borrego Springs event using data from two short, dense three-component line arrays that are installed in the damaged fault zone material across the Clarke fault branch that also hosted the earthquake. The spatial, temporal, frequency, and lapse time dependence of the obtained dv/v time series demonstrate a remarkable variability in the response types following these events. The dv/v signature of the deep aseismic slip following the distant EMC event lasts for tens of days and suggests a spatially variable upward migration of the deformation pattern. The signal following the local Collins Valley event is characterized by shorter duration and smaller velocity reductions, although the governing deep aseismic transient has the same reported magnitude as the transient following the EMC event. In contrast, the response of the fault zone material following the Borrego Springs earthquake shows the 'instantaneous-drop-and-slow-recovery' pattern that is commonly observed in many earthquake source regions, suggesting the observed velocity reduction results from the ground shaking. In addition to these transient signatures the obtained dv/v time series show significant cyclic loadings with variable periodicity that are governed by seasonal or tidal effects. The fault zone environment is thus subject to constant and intermittent loading and unloading effects that are governed by various internal and external

mechanisms. The emerging picture is that the different competing mechanisms result in complex spatio-temporal deformation episodes that are characterized by a range of dv/v sequences, amplitudes, and durations. The diversity of the signatures highlights the capability of passive seismic monitoring methods to yield important observations of variable material properties in active fault environments that are complementary to geodesy or seismicity studies. The obtained results contribute to a better understanding of fault zone dynamics, earthquake interactions, nucleation, triggering mechanisms, and deformation modes, and open up new research opportunities for improved seismic hazard assessment.

ESC2018-S28-826

INVESTIGATION ON THE NATURE OF A RECURRENT ARTEFACTUAL MICROTREMOR H/V PEAK BETWEEN 1.4 AND 1.7 HZ IN ITALY

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Ambient noise techniques are largely appreciated among scientists and professionals, as they allow the evaluation of shear wave velocity (Vs) profiles and amplification frequencies of subsoils. These values are required by the building design and urban planning codes of several countries worldwide. Among passive techniques, the single station approach (also known as H/V or HVSR) is widely applied for assessing the subsoil resonance frequency. This information can be used both in stratigraphic sense and to realise seismic microzonation maps. Acquiring ambient noise and getting H/V curves is an easy task both in the field and in the office. However, as it always happens, caution must be practised. Incorrect calibration, wrong placement of the instrument, incorrect data processing and, above all, the incapability to distinguish H/V peaks of stratigraphic origin from artefacts or peaks induced by nearby structures can totally mislead the final interpretation. Since the early application of the H/V technique in Italy (approx. in 2000-2002) a clearly artefactual H/V peak (or trough) at 1.4-1.7 Hz was observed at some sites along the Adriatic coast. This feature seemed to be independent from the instrument used to record microtremors and its amplitude appeared to vary with time (being usually higher at daytime compared to night-time, with times where it totally disappeared). Initially, this feature was attributed to an industrial origin, then to devices installed within military airports. Later it was noticed that it occurred more commonly nearby streets and parking spaces (the 1.7 Hz peak in the H/V curves acquired during the surveys for the seismic microzonation of the town of Spoleto in central Italy in 2006 was reported in 58 out of 85 total measures). An electromagnetic origin was also proposed. In the following years, in Italy, the artefact was reported by a number of professionals working with different instruments, mainly - but not only - along the central Adriatic coast and the eastern sector of the Lombardia region. We have observed the same artefactual peak (or trough) in diverse urban contexts in the Friuli Venezia Giulia region (NE Italy). This feature appears not only when using mobile seismic stations, but also in recordings of some permanent stations of the OGS (Istituto nazionale di oceanografia e di geofisica sperimentale) network. Since distinguishing natural from anthropic peaks is mandatory for the interpretation of any H/V curve, establishing the origin of this artefactual 1.4-1.7 Hz peak (or trough) is interesting for anyone working in Italy, particularly in the present years when seismic microzonation studies are ongoing all over the territory. In this work we aim at assessing the nature of this anthropic peak. The simplest way to achieve this goal is to study the directivity of the signal (which can be bidirectional for each site where it is noticed) following the triangulation principles. Since we already know a number of sites where we expect it to appear, we aim at placing additional stations in a network configuration that can help us to identify its origin in a statistically reliable way.

ESC2018-S28-936

PRELIMINARY RESULTS OF SEISMIC AMBIENT NOISE MEASUREMENTS AT THE NATURAL ROCK ARCH OF WIED IL-MIELAH (MALTA)

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Rock arches are natural structures that represent important tourist attractions worldwide. The Maltese Archipelago (Central Mediterranean Sea) hosts a significant number of natural rock arches, distributed all along the coastlines of its three islands. The arch of Wied il-Mielah, located on the island of Gozo, became probably the most important natural rock arch of the Maltese Archipelago after the collapse of the most famous Azure Window arch, which occurred on March 8th 2017 during a severe storm event. The Azure Window collapse motivated the need to characterise this type of natural structures and evaluate the design of consolidation interventions to preserve them as long as possible, as well as the installation of monitoring networks devoted to early warning to ensure the safety of visitors of the site. The Wied il-Mielah arch is located at the end of the Wied il-Mielah Valley, on the Northwestern coast of Gozo. Similarity to the former rock arch of Azure Window, it is composed of sub-horizontal strata belonging to the several members of the Lower Coralline Limestone (LCL) formation, a hard and compact grey limestone of Oligocene age (Chattian). The limestone forming the arch is intensely jointed, testifying the natural proneness to gravity-induce instability of this natural structure. During the spring of 2017, an intensive field campaign was carried out at the Wied il-Mielah rock arch. First, the joint system was characterised in detail by engineering geological surveys, that allowed to obtain the spatial distribution of the joints and their mechanical properties. In addition, several samples were collected to obtain the physical properties of the rock mass. Seismic ambient noise was recorded in 20 single-station measurements distributed on the top of the arch by considering the different elements (i.e. pillar, beam and abutment) and the joint distribution to obtain a preliminary seismic response of the structure. In addition, 4 stations were distributed outside the rock arch and 1 station was located in the inland zone as possible reference. Each recording was processed through the Horizontal-to-Vertical Spectra Ratio (HVSR) approach (Nakamura, 1989) as well as by the WAVEPOL package (Burjánek et al., 2012) for analysing polarization and ellipticity of the particle motion. By considering the HVSR analysis, the related curves show a first resonance peak at the frequency of about 5 Hz both on the pillar and on the abutment. The measurements carried out on the beam do not evidence significant resonance peaks. The first HVSR peak results at about 6 Hz for two stations located in the Eastern part of the arch between the pillar and the beam, in a zone where large joints isolate several rock blocks. On the other hand, all the stations located on the pillar and on the beam are characterised by a concave shape (i.e. HVSR lower than 1) at about 11 Hz. Finally, the HVSR curve obtained by the measurement carried out at the inland station shows neither resonance peaks nor concave shapes. The polarization analysis allowed to define additional features about the seismic response of the Wied il-Mielah rock arch. The obtained results show that all the stations located on the pillar and on the abutment are characterised by both a strong directivity effect and a polarization of the particle motion (with azimuthal value of 175°) at about 5 Hz. This specific feature is observable also in the two stations located in the Eastern part of the arch whose HVSR analysis shows a main resonance frequency at 6 Hz; in the polarization analysis, such a frequency shows slight effects of directivity and polarization of the particle motion at about 75°. Finally, the measurement carried out at the inland station does not show effects of directivity or polarization of the particle motion. In the light of the obtained results, some preliminary features of the seismic response related to structure of the Wied il-Mielah rock arch were obtained by seismic ambient noise measurements. The entire portion of the arch composed by the pillar and the beam is characterised by a frequency resonance of about 5 Hz that outputs effects of ellipticity and polarization of the particle motion in a direction almost parallel to the length of the arch. These features allow to deduce that this frequency is associated with the first eigenmode frequency of the structure; such an information could be useful to characterise the vibrational behaviour of the natural rock arch. The definition of the eigenmode frequencies of a structure can be the basis for designing consolidation interventions to ensure the preservation of such a type of natural structures. Finally, a 3D model of this natural structure was built employing the Finite Element method to reproduce the first experimental modal frequency of the structure. The numerical results quite successfully reproduced the experimental ones collected by the geophysical surveys.

ESC2018-S28-980

SEISMIC IMAGING OF CENTRAL ANATOLIA, TURKEY, USING AMBIENT NOISE CROSS-CORRELATIONS

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We analyze ambient seismic noise field to investigate crustal structure and seismic anisotropy in Central Anatolia, Turkey. This technique is widely used to obtain shear wave structure but rarely for seismic anisotropy. Moreover, in recent years it is shown that P-wave Green functions can be successfully estimated in order to compute P-wave velocity model in lack of sufficient earthquake data. We use three years of broadband data from national networks and previous seismic experiments. We pursue ambient noise pre-processing steps as stated in Bensen et al., 2007; removing instrument response, time domain normalization, whitening and stacking the seismic noise cross-correlations of all possible station pairs. Firstly, vertical-component cross-correlations are computed in 0.08-4 Hz frequency band in order to estimate P-wave Green functions. As a second step, Rayleigh wave dispersion curves obtained from surface wave Green functions using automated frequency-time analysis (FTAN), are inverted for azimuthal anisotropy parameters. Results will be presented accordingly to elucidate the complex tectonics of the region of interest in detail.

ESC2018-S28-981

EXTRACTING SEISMIC NOISE TIME SERIES FROM PAPER SEISMOGRAMS

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We report on the digitization of seismic noise extracted from old paper seismograms from the 1910-1913 period and their interpretation. The original paper records are scanned using a 2-roll scanner, then vectorised and split in minute chunks, as on the original data. The amplitude is calibrated based on the original metadata mentioned on the paper sheets. The digitized time series are finally stored in MiniSEED format and processed using ObsPy to extract Probabilistic Power Spectral Densities (PPSD). The PPSD are then compared with modelled seismic noise levels using WaveWatch III Hindcast data.

ESC2018-S28-1045

HOW MUCH FREEDOM CAN RESEARCHERS EXERCISE WHEN WORKING ON AMBIENT NOISE STUDIES

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The Free Software Foundation (FSF) is an international organisation with a worldwide mission to promote computer user freedom. We defend the rights of all software users including those researchers working with ambient noise signals. We campaign for these freedoms because everyone deserves them. Consequently, I clarify certain points about what makes specific freedoms adequate or not. I first invertigate basic requirements such as the freedom to run programs as you wish, the freedom to study the source code and make changes, and the freedom to redistribute if you wish. I then delve on the ideas of copyleft, rules about packaging and distribution details, export regulations, legal considerations, the use of the right words when talking about technology and software, and how to interpret the current state of affairs.

36thGA
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2018

SESSION 29

ESC2018-S29-103

PECULIAR CHARACTERS OF NEAR AND FAR FIELD MEASURED PARAMETERS FROM RECENT ITALIAN STRONG MOTION EVENTS

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Italy shows a medium-high seismic hazard level characterized by peculiar tectonic mechanism: the normal faulting mostly observed alongside the central-southern axial zone of the Apennine chain and the compressive faulting prevalent in the North part of Italy. Focusing on the wave shapes of the recorded seismic events through the Italian peninsula different characters can be evidenced comparing near and far field records. In this study, a number of strong motion events from recent Italian strong earthquakes have been analyzed due to their disastrous effects in terms of several hundred of casualties and damages to dwellings and infrastructures with millions of euros lost. They are: Umbria-Marche seismic sequence (26 September 1997 (00:33:11 UTC, Mw 5.7; 26 September 1997 (09:40:24 UTC, Mw 6.0); 14 October 1997,(15:23:09 UTC, Mw 5.6), 6 April 2009 mainshock L'Aquila Earthquake (01:32:40 UTC, Mw 6.1), 21 June 2013 Fivizzano Earthquake (10:33:56 UTC, Mw 5.1); the central Italy seismic sequence 2016-2017 (24 August 2016 (01:36:32 UTC, Mw 6.0); 26 October 2016 (19:18:05 UTC, Mw 5.9), 30 October 2016 (06:40:17 UTC, Mw 6.5) e 18 January 2017 (09:25:42, Mw 5.1; 10:14:09, Mw 5.5; 10:25:26 Mw 5.4; 13:33:37 Mw 5.0), 31 October 2002 San Giuliano di Puglia Earthquake (10:33:00 UTC, Mw 5.7), 01 November 2002 San Giuliano di Puglia Earthquake (15:09:02 UTC Mw 5.7) and 29 May 2012 Emilia Earthquake (07:00:02 UTC, Mw 6.0). In the aftermath of these events, differential site effects have been observed and surveyed in urban and peri-urban areas (GEER Reconnaissance 2017, 2018; EMERGEO GL 2002, 2009, 2012, 2016) The main objective of this comprehensive study is to calculate some strong motion parameters that represent the recorded signals in time and frequency domain measured from seismic stations located both near (within 30km) and far field (up to 100km). The parameters taken into account are the peak ground acceleration PGA, the peak ground velocity PGV, the peak ground displacement PGD, the Arias intensity IA, the spectral acceleration SA at 0.1s, 0.3s and 1s, the Housner Intensity IH and the Trifunac duration Df. Results of the analyses confirm that the general trend of PGA, PGV, PGD, IA and IH is a reduction with the distance from the epicenter but such a trend raises beyond 30km; within this epicentral distance a trend is not evident and high scattered values can be recognized of the aforementioned parameters. Furthermore, within 30km from the source, the PGA values recorded along the three directions show similar values and sometimes the vertical PGA component is even higher than the horizontal ones. Thus, near field seismic signals show horizontal and vertical contributions of comparable magnitude and scattered according to the site response. Instead, far field records show a common 2/3 ratio between vertical and horizontal acceleration components and a more predictable soil response according to regional specific Ground Motion Prediction Equation (GMPE) feasible for different strong motion parameters. Conversely, the Trifunac duration increases as the epicentral distance increases according to the signal enrichment in surface waves getting far away from the epicenter. Moreover, the seismic soil categories according to the Eurocode 8 classification has been investigated in terms of the influence on the amplitude of the abovementioned strong motion parameters. As expected, the results confirm that type soil A shows lower amplification than soil type D and E.

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ESC2018-S29-147

RELATIONSHIP BETWEEN THE SHEAR VELOCITIES FROM MICROTREMOR ARRAY OBSERVATIONS AND SEISMIC CONE PENETRATION UNIT TEST RESULTS

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A database of shear-wave velocity (Vs) measurements using microtremor arrays technique and seismic cone penetration test unit measured on high-quality samples for rock and soft soil in Padang sites has been established. The purpose was to evaluate the different methods of measuring Vs, to present guidelines and correlations to assist in estimating Vs profiles in these clays in the absence of site-specific data, and to outline relationships that can be used to give first-order estimates of soil properties. It was found that consistent measurements of Vs can be obtained from microtremor array of technique and that for practical engineering purposes the Vs values obtained from the different methods are similar. The comparison shear velocity for each soil type between microtremor array observation results and soil penetration test results shows a good agreement from 0-4m of depth with 5% average higher from Vs of microtermor value for rock soil type (layer 1) and 0-25m of depth is good agreement with 1% average higher from microtremor value for soft soil type. Based on these studies numerical analysis from microtremor observation has high accurate to determine soil characteristic.

ESC2018-S29-149

THE INFLUENCE OF GEO-LITHO-SEISMIC SECTION RECONSTRUCTION IN PREDICTING URBAN RESPONSE SITE EFFECTS INDUCED BY STRONG MOTION EVENTS: THE CASE STUDY OF FAETE HAMLET (ITALY)

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The study focuses on the role of the geo-seismo-litho-technical model of the subsoil at urban sites reconstructed for carrying out 2D numerical simulations of local seismic response RSL for microzoning maps at level III. The study site is located in Faete hamlet, set in Arquata del Tronto district, struck by the 2016 Central Italy seismic sequence. To this end, three different models have been reconstructed through the ambient noise measures interpreted by the Nakamura HVSR technique performed during the activities for the seismic microzonation of level 1 and later indirect and direct geophysical surveys . The first model was built on the basis of a geological survey and a few HVSR and MASW investigations collected within a larger area including neighbouring locations to Faete hamlet with similar geological conditions. Thus, the first model has been characterized through averaged physical and seismic properties. The reconstruction of the other models is based on geophysical tests carried out at the Faete urban area such as MASW, ERT, down hole, seismic refraction and passive seismic tests (HVSR). Especially, the second model has been carried out taking into account the seismic information reported in the seismic microzonation map of level 1 , together with the results drawn from the interpretation of the geophysical surveys in terms of shear wave velocity Vs. This model considers a low-velocity colluvial deposit (Vs =150 m/s), less than 5 m thick overlaying slope deposits with a 250m/s velocity. Underneath there is the sandstone-dominated bedrock (Laga Formation) with a Vs equal to 700m/s . In the third model, instead, the colluvial layer has been neglected to take into account the common excavation for building foundation setting thus only the 250m/s surficial slope deposit has been considered. The results of the numerical seismic response analyses at the surface have been shown in terms of the elastic response spectra, the amplification functions and spectral acceleration amplification factors FA in the following period ranges: 0.1 s ÷ 0.5 s, 0.5 s ÷ 1.0 and 0.1 s ÷ 2.5 s. The results obtained for the first model show almost uniform amplifications concentrated in the range of periods 0.1 s and 0.5 s (FA varies between 1.5 and 3.15). The second and third models show different amplification scenarios, with amplified range of periods higher than 0.3 s ÷ 0.4 s in the northern part of Faete hamlet (FA varies between 2.5 and 5.0 for the model 2 and 2.0 - 4.0 for the model 3) and T

ESC2018-S29-169

THE CENTRAL ITALY 2016-2017 SEISMIC SEQUENCE - SITE RESPONSE ANALYSIS BASED ON SEISMOLOGICAL DATA IN THE ARQUATA DEL TRONTO-MONTEGALLO MUNICIPALITIES

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In this study we evaluate the local seismic response for thirteen sites located in the municipalities of Arquata del Tronto and Montegallo, two areas that suffered heavy damage during the Mw 6.0 and Mw 5.4 earthquakes, which struck Central Italy on August 24th, 2016. The study has been performed within the framework of OGS intervention set up during the seismic sequence that followed the mainshock of August 24th, 2016 and was coordinated by "CMS - Centro di Microzonazione Sismica e sue applicazioni" on request of "DPC - Department of Civil Protection" with the final goal of performing a Level 3 seismic microzonation of the most damaged municipalities. The equipment of the mobile stations consisted of a 1 Hz three-component velocimetric sensor (Lennartz 3Dlite) possibly buried in the soil, a datalogger set for continuous data acquisition with a sample rate of 100 Hz, a GPS antenna and a battery connected to photovoltaic panels when power supply was not available. Five stations were also equipped with a strong-motion sensor. Particular care was devoted to the selection of the reference site, as it is crucial for spectral analyses. In the considered area the bedrock is represented by the arenaceous lithofacies of pre-evaporitic member of Umbria-Marche-Romagna-stratigraphic-succession amed "Laga Formation" (Messinian p.p.), despite large carbonate blocks of paleo-landslides diffusely outcrop. Among the stations deployed on geological bedrock, a site located in Uscerno hamlet was identified as the reference one in virtue of its flat Horizontal-to-Vertical Spectral Ratio of ambient noise recordings. The other sites are located on Quaternary sediments of diverse origin (alluvial, colluvial deposits, landslides, anthropic reports) laid on the different members of Laga Formation. From a morphological point of view, three sites are located on the top of topographic irregularities (reliefs, ridges); four sites are set along narrow valleys while the remaining ones are on the flank of hills. The input dataset is made by ground motion recordings of 348 events occurred during the seismic sequence in a period of about five months (October 2016-February 2017). The estimation of the seismic response is performed by the Generalized Inversion Technique (GIT), using GITANES (GIT ANalysis of Earthquake Spectra), a Matlab package that has recently been developed at OGS. The interpretation is further improved through the information provided by a non-reference-site method (i.e., the so-called Receiver-Function Technique, EHV) and by the Horizontal-to-Vertical Spectral Ratios (NHV) of ambient noise recordings. We also provide an independent estimate of the local amplification by comparing the Peak Ground Velocity and the Spectral Amplitudes observed at each site to the values estimated by well-established Ground Motion Prediction Equations for a rock-class site. Results obtained by the adopted methodologies are all highly consistent each other, and emphasize the different seismic behavior of several sites at a local scale. Thus, sites located on Quaternary deposits overlying the bedrock, such as Castro, Pretare, Spelonga, Pescara del Tronto, and Capodacqua feature some relevant amplifications in a medium (2-10 Hz) frequency range; two sites at Spelonga show amplifications also at low frequencies; three sites located on stiff formations (Uscerno, Balzo and Colle d'Arquata, respectively) feature either nearly neutral response or low amplification level. Some differences between reference site (GIT) and single-station methods (EHV and NHV) can be ascribed to the amplification level of the vertical component. A probable topographic effect was identified at the rock site of Rocca di Arquata.

ESC2018-S29-192

ANALYTICAL EXPRESSIONS OF THE FUNDAMENTAL PEAK FREQUENCY AND THE AMPLI CATION FACTOR OF S-WAVE TRANSFER FUNCTION IN A VISCOELASTIC LAYERED MODEL

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It is well-known that the resonance frequency and amplifi cation factor of soft-soil could be explained in terms of S-wave transfer function. This paper concerns the propagation of vertical incident SII

wave from the viscoelastic bed rock overlaid by a stack of viscoelastic soft layers that are assumed isotropic and homogeneous. First, the exact formula of the SII wave transfer function is obtained using the transfer matrix method. Then approximate expressions of the fundamental peak frequency of the SII wave transfer function and the corresponding amplifi cation factor are derived. The fundamental peak frequency expression has a similar form of the quarter wave length law for the model of one layer only but with two additional factors. The first factor shows the coupling effect between the soft layers and the bed rock through the impedance contrast. The second factor shows the effect of the viscosity of the layers and bed rock. The expression of the amplifi cation is also expressed in a similar way. Some numerical calculations are carried out to compare results from both synthetic data and the newly obtained expressions. The prediction from the expressions underestimates the synthetic data however it reflects very well the change of peak frequency and amplifi cation factor due to the viscosity.

ESC2018-S29-235

SETTING UP A TEMPORARY SEISMIC NETWORK TO INVESTIGATE SEISMIC SITE RESPONSE IN THE VALAIS AREA

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The majority of recorded earthquakes in Switzerland occur in the alpine area and the Canton Valais is one of the most active zones. The Rhone valley is part of the canton with sediment deposits reaching thickness of about 800 m. These characteristics make this valley susceptible of 2D/3D effects, with important site amplification effects. For this reason, in the framework of the project Risk Model for Switzerland, the Swiss Seismological Service is planning to complement the existing permanent seismic network with 12 additional temporary long-period seismometers. The temporary network will be deployed for several months, focusing in particular on the central and upper Rhone Valley, where the influence of 2D/3D effects on the local amplification behaviour is expected to be particularly significant and where important infrastructure is located. The criteria we used for the selection of the new seismic station locations are: i) Swiss building-code soil class, ii) bedrock depth (preferred sites with deep bedrock/sediment interface), iii) homogeneous distribution of stations inside the valley, iv) variety of geological cover, v) closeness with infrastructures/populated areas and vi) position along valley width. The recorded ambient vibrations and earthquakes will be used to get information on valley eigenfrequencies (1D/2D), on seismic wavefield polarization, edge generated surface waves and empirical amplification functions. The integrated interpretation of both geophysical and seismological data will help to complement a 3D geological model, useful to develop an amplification model for the investigated area

ESC2018-S29-275

SITE-SPECIFIC SEISMIC ANALYSES INCLUDING THE EFFECT OF ENGINEERING BEDROCK STRATUM DEPTH

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The importance of the effect of soft soil layers above engineering bedrock in modifying the strong ground motion in term of amplification and frequency content has been long recognized. Most of seismic codes define response spectra for several types of soil classes to account for these effects. For vital constructions (electrical power plant for example), the Algerian seismic code (RPA99/2003) recommend a site-specific seismic analysis. This paper presents the site-specific seismic analysis of the site selected for receiving an important project (Olympic Stadium). The site is located in Algiers (Algeria), characterized by a moderate to high seismicity with some significant historical earthquakes (January 3rd 1365, February 3rd 1716). A seismic hazard study of the region, carried out beforehand, provides the horizontal peak ground acceleration (PGA) at bedrock for a 475 year return period. The engineering geological structure of the site is assessed, based on geotechnical and geophysical investigations including laboratory tests. More

than nine 40m deep boreholes were drilled. Fourteen pressuremeter drills were conducted and three profiles of penetration resistance were obtained from Cone Penetration Tests. The down hole procedure is adopted to conduct P-S logging in only four boreholes. In parallel, an ambient noise records campaign was performed H/V to evaluate the fundamental frequency peak. The geotechnical site model, constructed using all the data, indicates a variation in the engineering seismic bedrock depth, namely the fresh blue marl layer. The analysis of the depth effect on response spectrum has shown that the structure to be built on this site will be subjected to a spatial variability in the seismic excitation. From the studies made, it is clear that considering only the seismic code suggestions may not ensure accurate and safe seismic excitation.

ESC2018-S29-276

SEISMIC RESPONSE ANALYSIS OF ALTERED ROCKY STEEP SLOPE

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Concentration of damage of buildings near the edge of hard or dense cliff has been observed during a number of earthquakes. Numerical analysis of topographic effects of rocky acute slopes knowingly neglect the stratigraphic effect. The presence of altered layer on surface (heavily alteration of rock by water flow and erosion) can modify the ground response in the sense of higher amplification, more variability and inducing a considerable vertical acceleration component. In this paper, the coupled stratigraphy-topography amplification is investigated through a parametric analysis including the thickness of altered layer, its stiffness and impedance contrasts. The effect of soil non-linear behavior is examined through equivalent-linear analysis. The obtained results show that the presence of altered portions of the rock amplify the seismic response, in addition to the slope geometry irregularities especially near the edge. It contributes to the apparition of systematic amplification of higher modes and aggravates the amplitude of induced vertical acceleration.

ESC2018-S29-279

THE SEISMIC MICROZONATION MAPPING PROJECT FOR METRO VANCOUVER, BRITISH COLUMBIA, CANADA

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A five-year project to accomplish seismic microzonation mapping for Greater Vancouver is currently underway, including shaking, liquefaction and slope stability hazards. The project is supported by Emergency Management British Columbia and the Institute for Catastrophic Loss Reduction. The project will also generate professional practice guidelines for development, use and interpretation of seismic microzonation maps in British Columbia through a peer review process in consultation with Engineers and Geoscientists of British Columbia (EGBC) and the Earthquake Engineering Research Institute British Columbia Regional Chapter (EERI-BC). Southwestern British Columbia (BC), including Greater Vancouver, has the highest seismic risk in Canada due to the complex tectonic settings and high population of the region. Inclusion of local site effects is critical for accurate ground motion prediction and seismic hazard assessment. For example, Quaternary deposits vary from softer thick Fraser River delta sediments in the south to stiffer glaciated till deposits in the north (1D site effects), which are located within a Late-Cretaceous sedimentary basin (3D basin effects) that is bounded to the north by the plutonic Coast Mountains (topographic effects). The first key task of the project has involved assembling a 3D geodatabase of previously collected geological, geophysical and geotechnical datasets. In summer 2018, a field campaign of microtremor measurements for subsurface site characterization (e.g., Vs30, site period, depth to bedrock) will be conducted and added to the 3D geodatabase. In addition, all available strong-motion recordings from 7 moderate earthquakes of magnitude (M) > 4.3 between 1976 and 2015 are utilized to provide a comprehensive assessment of observed site amplification in Greater Vancouver. A comparison between earthquake site amplification and microtremor horizontal-to-vertical spectral ratio will test the validity of the latter as a proxy of site amplification for application in seismic microzonation mapping

in Greater Vancouver. The 2015 M 4.7 earthquake is the first earthquake recorded at depth within three borehole arrays in Greater Vancouver. We are using 1D numerical modelling to assess whether the relatively known soil column in each borehole causes the observed amplification at two upper instrumented depths, using the base recording as input motion. Preliminary liquefaction and landslide susceptibility mapping is accomplished using available remote-sensing datasets, including surficial geology, slope angle, vegetation and stream indices. Updates on the state of mapping accomplished as well as the underlying datasets and how they were collected or analyzed will be presented.

ESC2018-S29-341

A STUDY OF THE VARIATION IN SEISMIC RESPONSE OF A LOADBEARING MASONRY BUILDING TYPOLOGY OVER ROCK OR CLAY SUBSOILS THROUGH NUMERICAL MODELLING

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The absence of earthquakes in Malta causing significant structural damages in the last century led to an unjustified complacency in the construction methods used for loadbearing masonry structures (Galea, 2007). The Maltese Islands are associated with a low-to-moderate seismicity and a design peak ground acceleration of 0.10g. This study focuses upon the seismic vulnerability of the contemporary loadbearing unreinforced masonry (URM) building typology, consisting of apartment blocks in row developments, typically including four to five residential levels overlying an open plan basement. The URM building typology under study includes a number of typical construction characteristics. In addition to the soft storey at the lowermost level, this typology could also include setbacks, voids in slabs, pounding problems and large openings, all of which impair the seismic resistance of such buildings. The geology of the Maltese Islands varies from lower coralline limestone or globigerina limestone in most of the Eastern part of Malta to the presence of upper coralline limestone outcrops over blue clay in the Western part of Malta and most of Gozo. To date, there is no regulated restriction on the overall safe building heights nor on the structural characteristics of buildings erected in the Maltese Islands, with the only restrictions being stipulated in the local planning building height regulations, irrespective of the site geology. While studies carried out at the University of Malta on the URM building typology under investigation showed that the investigated structures resist collapse at a lower overall number of storeys if erected on clay when compared to a rock subsoil (Borg, 2017), published literature also suggests that the presence of flexible subsoils can considerably impair the seismic resistance of buildings due to a number of factors, including the higher displacements resulting in structures with a lower number of floors, and the amplification of seismic accelerations leading to increased structural damage. This study investigates the variation in response of the URM building typology in a seismic event for six different ground formations and ground modelling scenarios through the non-linear time-history analysis (using the software package Extreme Loading for Structures) of a loadbearing masonry building, where the typical plan layout is repeated on every floor. For every ground formation case studied, the numerical model was analysed starting with a height of six floors and re-analysed following the reduction of one floor at a time, until collapse was resisted. The ground formation scenarios investigated included: i. A single 30 m thick upper coralline limestone layer (modelled as a three-dimensional block); ii. Upper coralline limestone specified as the material of the ground at the numerical model's Minimum Z-position; iii. A 30 m thick upper coralline limestone layer overlying a 30 m thick clay layer (both layers modelled as three-dimensional blocks); iv. A 1.5 m thick upper coralline limestone layer overlying a 60 m thick clay layer (both layers modelled as three-dimensional blocks); v. A single 60 m thick clay layer (modelled as a three-dimensional block); vi. Clay specified as the ground material at the model's Minimum Z position. A simulated ground motion record for the Maltese Islands (similar to the last major earthquake, which hit the Maltese Islands, on the 11th January 1693) for a magnitude 7.6 earthquake with a hypocentral distance of 170.3km to the North-East of Malta (obtained from the database of the Seismic Monitoring and Research Unit of the University of Malta) was applied in the transverse X-direction in all analysed numerical models, and corresponded to

a design peak ground acceleration of 0.10g. The main response parameters investigated included the: 1) Comparison of the overall building height at which collapse was resisted; 2) Comparison of the natural frequency under static and dynamic loads in the two main orthogonal directions of the numerical models and for two main subsoil cases considered; 3) Comparison of the predominant frequencies in the acceleration spectrum of the ground layers to the predominant frequencies of the simulated ground motion record; 4) Variation of a wide range of structural response parameters. The study of the variation in the response parameters extracted from the analysed numerical models suggests that the resistance of the contemporary loadbearing URM building typology in Malta is severely impaired with increased overall building height and when erected over a clay subsoil as opposed to a predominantly rock subsoil. These results, therefore, suggest that maximum height limitations for URM building typologies and the consideration of seismic actions in the design of new URM buildings or in the alteration of existing URM buildings in the Maltese Islands should be regulated, particularly taking into consideration the different geological scenarios present and the seismicity of the region.

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ESC2018-S29-380

SEISMIC MICROZONATION OF THE CITY OF ELCHE (SOUTHEAST SPAIN). APPLICATION TO GROUND MOTION EARTHQUAKE SCENARIOS

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Elche town is located in the Alicante province (southeast of Spain). This part of Spain is one of the most hazardous zones from the viewpoint of the seismic hazard. The current Spanish seismic normative assigns a PGA value of 0.20g (return period of 475 years) to this city being the maximum 0.23g in the city of Jacarilla (Alicante). In this work, we have first carried out a complete study of the soil characteristics of the urban area of the Elche town, based on geotechnical data and seismic measurements. Borehole information, as well as geological data were collected from different sources. The geology in Elche is quite homogeneous. It corresponds to Quaternary deposits composed mainly of conglomerates and clays, followed by silt and marl, being able to form a deposit of great power, according to the boreholes carried out in the study area and in zones close to it. The basement is formed by limestones and dolomites found around 1000 meters deep. After that, a microzonation campaign was carried out around the city of Elche using a 500x500m grid. Thus, 90 measurement points were selected. For these measurements, Mark L-4C-3D 1 Hz sensors connected to Reftek and Geophonino digitizers were used. Most of the obtained resonant periods corresponds to approximately 3 seconds, which is not close to the fundamental period of the buildings in the city. However, in the east part of the city, we have found additional amplification peaks at periods of 0.05 to 0.15 seconds and 0.20 to 0.30 seconds, which can be closer to the fundamental periods of buildings from 1 to 3 stories and 4 to 6 stories, respectively. These building heights are also common in this part of the city. Array measurements were also taken at different sites of the city. Circular arrays composed of five VSE-15D sensors surrounding a sixth similar device were deployed in two points of the city and one more triangular geometry in one of them. SPAC analysis was used to obtain the corresponding dispersion curves at these sites. Combining all the obtained information (borehole data, estimated H/V and dispersion curves), the local S-wave velocity structure has been estimated through an inversion based on the diffuse field assumption. Therefore, a 1-D Vs model of the city and a Vs30 map of the city have been computed. Additionally, the PSHA at the city has been updated using the CRISIS software and after a disaggregation, two main seismic scenarios have been selected. The first one, corresponding to a 100 yr return period,

is assigned to a Mw 4.5-4.9 located 10 km from the city. The second one, corresponding to a 450 yr return period, is assigned to a Mw 5.5 to 6.0 located around 20 to 30 km from the city. These two possible scenarios can be simulated using a rupture in the Crevillente fault and the other in the Bajo-Segura / Torrevieja fault, respectively. Thus, the shake maps can be computed using the information obtained in the previous microzonation study by means of computing synthetic seismograms at the surface, using attenuation relationships with site effects coefficients and applying amplification factors for soil types as specified by EUROCODE 8. After a comparison of the results, we point out the importance of considering the site amplification in the shake maps of earthquake scenarios and the sensibility of the results to the chosen method used to consider the soil amplification. Keywords: Seismic microzonation, H/V method, fundamental period, resonance frequencies, shake maps.

ESC2018-S29-436

SEISMIC SITE RESPONSE IN AREAS CHARACTERIZED BY THE PRESENCE OF BURIED LOW-VELOCITY LAYER: THE EXAMPLE OF FLORIDIA, ITALY

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The Hyblean foreland represents one of the most important structural element of South Eastern Sicily. Its eastern part is characterized by deep valleys where calcarenites sediments outcrop. The Floridia area is located on the namesake graben, a few kilometers west of Siracusa. The local lithotype sequence is formed by Oligocene–Miocene whitish calcarenites overlaid by clays that are, either overlaid or etheropic with calcarenitic and sandy levels. These, together with terraced alluvial deposits, represent the shallower lithotypes characterizing the surficial geology of the study area. Such a litho-stratigraphic sequence imply the existence of significant shear wave velocity inversions. The present work aims at studying the dynamic properties of main outcropping lithotypes and to investigate the role of local geology on the site response. Ambient noise recordings (about 45) were performed using a Tromino, locating the measurement sites at the hubs of a network having inter-space of about 500 m. The recorded data were processed through standard and horizontal-to-vertical spectral ratios (HVSR). Besides free field recordings, ambient vibrations were recorded inside several buildings, having either masonry bearing walls and/or reinforced concrete structure, to evaluate dynamic properties of the edifices.. Further investigations were performed, using multichannel analysis of surface waves (MASW) and f-k 2D methods, in order to get subsoil velocity profiles and to characterize Vs values for site classification of the main outcropping lithotypes. The combined use of different prospecting approaches allowed us to go through the limitations of each methodology comparing and checking the obtained results. Processing of all recorded data was achieved through the Geopsy software. In particular, maps of both dominant frequencies and amplitudes experimentally obtained, were drawn. The results set into evidence the occurrence, in the spectral ratios, of significant amplification of the vertical component, that appear related to velocity inversions existing in the lithotype sequence. All the investigated sites exhibit clear and consistent peaks in the frequency range of 1 Hz to 3 Hz. This is tentatively attributed to the presence of a sharp velocity contrast between calcarenites with interbedded sandy levels and the overlaying clays and terraced alluvial deposits. Vs30 results point out the presence of class B terrains, having shear waves velocities of about 400-500 m/s, represented by the outcropping calcarenites, and class C terrains, with shear wave velocities of about 200-400 m/s that can be ascribed to the clayey deposits whereas the seismic bedrock (not outcropping in the study area) shows Vs values greater than 800 m/s. The site effects induced by the clayey and soft layers have implications for the assessment of seismic risk.

ESC2018-S29-443

SEISMIC MICROZONATION BASED ON LARGE DATABASE OF BOREHOLE DATA: APPLICATION TO LISBON

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The 1st November 1755 earthquake (M8.5) is considered by many authors has the larger earthquake occurred in Europe in historical times. Its source is located at S-SW offshore Portugal, it strongly affected the whole country, large regions of Morocco and Spain, and its effects were observed in many European countries. In particular, the town of Lisbon was severely struck, and many monuments collapsed and a large part of the population (estimated around 10%) lost their lives. Due to its historical seismicity and to its economic and social importance, the town of Lisbon is considered to have moderate to high seismic risk. It is well known that the influence of the local site conditions can strongly affect the ground motion produced by an earthquake, modifying its amplitude, duration and frequency content, which may induce damage larger than expected to buildings and infrastructures. Aware of this situation the Municipality of Lisbon supported the development of a project to characterize the soil in more detail aiming to elaborate soil classification according to EC8. Taking profit of the NSPT database of the Municipality of Lisbon, composed by 8792 boreholes, an expedited methodology was proposed to perform the site classification. The results will be compared and validated with non-invasive field experiments (surface waves seismic profiles and HVSR performed with ambient vibrations), as well as with the geology and data collected from independent geophysical reports included also in the database. The objective of this work is to contribute for long-term urban planning through the evaluation of the seismic vulnerability of the building stock as well as of the built heritage. This communication is supported by FCT-project UID/GEO/50019/2013 - IDL.

ESC2018-S29-478

NON-LINEAR ANALYSIS METHOD OF GROUND RESPONSE USING EQUIVALENT SINGLE-DEGREE-OF-FREEDOM METHOD

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When evaluating the design earthquake motion for structures, it is important to consider the ground behavior of the site. The most commonly used method for analyzing the response of ground is non-linear analysis using the one-dimensional soil layers (Konder 1963) or equivalent linearization analysis (Schnabel et al. 1972). To apply these method, however, it is necessary to obtain the detail information such as shear wave velocity Vs, the unit weight γ, non-linear characteristics (the G-γ relationship, the h-γ relationship, the adhesion c, and the internal friction angle φ), and other parameters. However, it is difficult to gather the adequate data for modeling of the ground and it takes so much calculation cost. We proposes the simple method to evaluate surface ground motions using the limited ground information, such as the natural period of the ground. In this research, the "Equivalent Single Degree of Freedom method" is proposed and is based on the results of static push-over analyses of many grounds with various properties. The ground motions evaluated from multi-layered model and the proposed method using dynamic analysis are compared. It was then confirmed that these results are almost consistent, and the proposed method is applicable to the evaluation of the surface motion. Even if only a few data with regard to soil properties property is available, the proposed method enables to estimate the ground motions in low calculation cost.

ESC2018-S29-516

EVALUATING LONG-PERIOD GROUND MOTIONS OF THE DEEP SEDIMENTARY LAYERS OF METROPOLITAN CEBU

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Metropolitan Cebu has one of the highest rates of the population increase in the Philippines, having 4.1% growth rate in 15 years. To accommodate such numbers, medium- to high-rise structures are built to maximize land use. However, Cebu frequently experiences low- to moderate-sized earthquakes due to the active faults surrounding

the area. The magnitude 7.2 Bohol Earthquake in 2013 serves as an example wherein buildings across the metropolis have been affected by the event although its epicenter in Bohol is approximately 70 km away from Cebu. It is therefore necessary to have seismic microzonation of the area to assess local site effects for seismic hazard estimation. Recently, the Philippine Institute of Volcanology and Seismology (PHIVOLCS) has conducted a geophysical survey in Metropolitan Cebu to map deep s¬hear-wave velocity structures in Metro Cebu. Array measurements of vertical microtremors were used to determine S-wave velocity structures in coastal lowland areas of Metro Cebu for the evaluation of the characteristics of long period ground motions. Phase velocities of Rayleigh waves were estimated from F-K and SPAC analyses of array data. Then, a genetic algorithm (GA) inversion method was applied to these compiled velocities to generate S-wave velocity structures of deep sediments. Furthermore, analysis was then applied to transform these shear wave velocity models to site amplifications and dominant ground periods. Based on resulting spatial distribution of predominant periods, six out of thirteen cities and/or municipalities of this metropolis are susceptible to long-period ground motion, bearing an average of 3.00s to 5.00s dominant long-period. The generated long-period microzonation map based from the outputs will be of great importance in earthquake microzonation in Metro Cebu and can be used by local administrators in city development and land use planning.

ESC2018-S29-536

LOCAL SEISMIC HAZARD EVALUATION IN NORTHERN-EASTERN SICILY (ITALY) THROUGH INTEGRATION OF GEOLOGICAL AND GEOPHYSICAL DATA

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The village of Rometta, northern-eastern Sicily (Southern Italy), experienced severe damage during the most energetic earthquakes that occurred in eastern Sicily and southern Calabria in the last centuries (e.g. 11 January 1693, Mw=7.4; 5 February 1783, Mw=7.1; 28 December 1908, Mw=7.1). Geological maps indicate that Rometta primarily lies on a stiff plate of Upper Pliocene – Lower Pleistocene calcarenites and only to minor extent on Middle Pleistocene overlying clays. Rometta is an interesting case study for site response investigation because of the apparent mismatch between the currently available geological knowledge and the level of damage caused by historical seismic events. The local seismic response has been investigated through a grid of 64 single-station measurements of ambient seismic noise by the Horizontal to Vertical Noise Spectral Ratio technique. Moreover, phase velocity dispersion curves from seismic array through the Extended Spatial Auto-Correlation method were analyzed. The H/V curves obtained show a ubiquitous frequency peak in the frequency range 0.5 - 0.9 Hz due to the deep interface between the metamorphic substrate and sedimentary sequence, and a secondary peak in the 2.5–15 Hz interval in most of the measurement points. Joint inversion of dispersion and H/V curves was also performed in order to obtain the velocity profile. These results suggest a wider extension of the outcropping clays with respect to previously available knowledge, that could be responsible for the past earthquake damage distribution observed. This can have some important implications for microzonation analysis and seismic risk assessment because the most accurate geological knowledge of the area enables a better seismic soil classification.

ESC2018-S29-563

SEISMIC RESPONSE OF THE QUITO BASIN (ECUADOR)

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The city of Quito (Ecuador) is located in an Andean valley at 2800 meters above sea level surrounded

by active volcanoes. This city of about 3 million inhabitants is prone to major earthquakes, among other natural hazards. Seismic hazard and risk assessment is therefore of paramount importance in this highly populated region. This work is part of a project that aims to understand, characterize and simulate ground motions in the Quito basin, taking into account the resonance effects of the basin (due to the complex basin geometry and the volcanic/alluvial filling), as well as those due to the strong surrounding topography. Later, this will conduct to define at least three different earthquake scenarios : one caused by an inverse fault just below the city, another one from a nearby crustal fault, and a large earthquake from the Pacific subduction zone. A seismic network of 20 velocimetric stations (Lennartz 3C 5s) has been deployed since july 2017 to record ambient seismic noise and earthquake data during one year. This database will be used to 1) characterize differential seismic amplifications already observed from previous studies: low frequency amplifications (around 0.3 Hz) in the southern part of the basin, 2) identify preferential wave propagation paths by means of empirical Green functions from ambient noise crosscorrelations, and 3) use seismic interferometry techniques to define, if possible, the bedrock depth all along the basin. These points provide an overall view of the seismic response of the Quito basin that will help to construct realistic scenarios for seismic hazard assessment.

ESC2018-S29-582

LOCAL SEISMIC RESPONSE IN ARQUATA DEL TRONTO AND BORGO HAMLETS (CENTRAL ITALY)

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This work presents the results of numerical analyses for the evaluation of the seismic response of Arquata del Tronto and Borgo hamlets (Ascoli Piceno, Italy). The villages, located about 9 km northeast of the M 6.1 Central Italy August 24th 2016 epicenter, reported after the event an irregular damage distribution, although less than 500 meters away. In particular, damage mainly concentrated in Arquata del Tronto (VIII-IX MCS), whereas Borgo suffered damage to a less extent (VII MCS) (Galli et al., 2016), highlighting significant occurrence of ground motion amplification phenomena. Arquata del Tronto is a small village, developed on a WNW-ESE elongated ridge, elevated about 100 m higher than the underlying alluvial valley, where Borgo is built on. The geological bedrock of the study area is represented by the Miocene "pre-evaporitic member" of the Laga Formation, consisting of four lithofacies associations distinguished according to their sandstone /pelite ratio: pelitic-arenaceous (LAG4e), arenaceous-pelitic II (LAG4b) arenaceous- pelitic I (LAG4d) and arenaceous (LAG4c). Arquata del Tronto is erected on a ridge made of the alternation of LAG4c, d and b lithofacies partially fractured and with high angle dipping strata. The hamlet of Borgo is located about 200 m north of the Arquata del Tronto ridge, where the geological bedrock is covered by fluvial gravels and sands and/or eluvial/colluvial gravelly deposits, whose thickness is laterally variable in the range of 10-30 m. Between the end of November and the beginning of December 2016, in the immediate aftermath of the 2016 main events (24 August and 30 October), we investigated the study area and a tentative damage zonation was made following the scheme provided by the Department of Civil Protection (DPC) in Italy for post-earthquake reconnaissance. During our surveys, an increasing level of damage was observed moving from Borgo towards Arquata del Tronto ridge. In detail, minor damage observed in Borgo, mainly consisted in cracking of non-structural elements. Instead, Arquata del Tronto was highly damaged with several unreinforced masonry structures partially or fully collapsed. Extensive geological, geophysical and geotechnical surveys were performed in the study area as part of the activities coordinates by the Center for Seismic Microzonation and its applications (CentroMS) with the aim of performing the Level 3 seismic microzonation in the municipalities mostly struck by the 2016 Central Italy seismic events. In this framework, thirteen temporary stations (1 Hz Lennartz 3D sensors) were deployed by the National Institute of Oceanography and Applied Geophysics (OGS) in the Arquata del Tronto and Montegallo municipality. In particular, in this work we used data recorded by stations located on Arquata del Tronto ridge, Borgo alluvial valley and Uscerno hamlet. All stations were deployed on geological bedrock, but only the Uscerno one was identified

as a true reference station being characterized by and almost flat H/V curve. The results of geophysical investigations performed in the area (HVSR, MASW, ERT, DH) has been used in order to constrain geometries and retrieve reliable Vs profiles. These information have then been used to implement the geological - geotechnical model for numerical analyses aimed at deriving the motion at the ground level in the study area. We used ground motion data recorded by Uscerno station as input motion and accelerometric data recorded by the OGS temporary stations at the ridge crest of Arquata and at the alluvial valley where Borgo is built on, to calibrate the numerical model by comparing numerical results and seismic data recorded. The numerical analyses were performed both in one-dimensional (1D) and two-dimensional (2D) settings, adopting the equivalent linear STRATA and QUAD4M software respectively. Studying local seismic response in such geological complex sites is a crucial challenge as many factors can contribute to modify the expected ground motion. Indeed, effects related to local surface and buried morphology are coupled with those associated to stratigraphic and tectonic setting (i.e. weathering and jointing conditions of rock mass), making the reconstruction of a reliable and thorough geological/geotechnical subsoil model to be used in numerical simulation, more difficult This work mainly aims to assess the role played by site settings in the seismic response of the case study, in particular: i) distinguishing the contribution of the topographic effect from others; ii) understanding the influence of the different mechanical properties, depending on the greater or lesser presence of the politic component; and iii) assessing the role played by the rock mass jointing/weathering conditions, that might give rise to Arquata del Tronto larger amplification compared to Borgo.

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ESC2018-S29-585

ASSESSING DIRECTIONAL AMPLIFICATION OF SEISMIC NOISE IN FAULTED ROCK MASSES FOR SITE RESPONSE INVESTIGATION IN COMPLEX GEOLOGICAL SETTINGS

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Studying seismic response in fault zone is a challenge issue to understand wave propagation in complex media. This has crucial implication for assessing seismic hazard for urban settlements located in proximity of regional fault-zone structures, especially for Mediterranean countries where much of urban centers are edified on tectonic areas Although an increasing number of case-histories documents the fault-zone related site effects and damage patterns after seismic events (Cultrera et al., 2003; Calderoni et al., 2010; Pagliaroli et al. 2015; Di Naccio et al. 2017 and references therein), the relationships between wave modifications and the internal fault architecture (including the discontinuities orientation) has not considered adequately so far. In such complex geological settings, a clear identification of the main causes of amplification is not simple, principally due of the subsoil structural complexity that can alter the expected ground motion. Recent papers have demonstrated that large systematic amplifications cannot be exhaustively explained by topographic effects, but they can be affected by the contribution of site effects related to fault zones.
In particular, it is well documented that the presence of pervasively fractured rocks may lead an amplification of seismic motion and a directional site resonance in the region surrounding a fault zone, as a consequence of the high crack density leading to a stiffness anisotropy of the rock mass. In this view, our work concerns site effects investigation on a pervasively faulted limestone sequence cropping out in central Apennines (Italy). The study area is part of a structural ridge composed of Mesozoic limestones that experienced polyphasical tectonic activity during the Apennines building in the Neogene. Our multidisciplinary approach includes geological-structural and geophysical techniques performed across a c. 50 m-thick fault zone. The geological-structural analysis was devoted to

individuate and describe the mechanical discontinuities, in terms of their spatial distribution, of the different structural domains characterizing the fault architecture (a fault core, two damage zones and a surrounding protolith). We performed some in-situ tests using a Schmidt hammer with the aim to evaluate the variation of rock geomechanical parameters within the different structural domains. Then, we evaluated the fracture intensity in each structural domain by using the circle-inventory method. The geophysical survey consisted of 22 noise measurements carried out along two ~80 m-long transects crossing the fault zone, spreading the measurement stations within the different fault domains. Seismic noise measurements were then computed using Horizontal-to-Vertical spectral ratios (HVSR) technique and results were used for documenting wave modification along and across the fault-zone (core zone and damage zones) and in the surrounding protolith. Results highlights the variability of directional amplification of seismic noise within the different fault domains. In particular, the proposed geological-geomechanical-geophysical dataset suggests a conceptual model of 3D-compartmentalised fault zone whose fault core and damage zones display distinctive seismic noise behaviour in terms of amplification and polarisation. Our results are consistent with those of recent studies that outlined a structural control on seismic response by the attitude of fault-related structures (Pischiutta et al. 2012; 2013; 2017). Eventually, our results have implication in terms of seismic response of fault zones and mitigation of seismic hazard in areas associated to tectonic activity.

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ESC2018-S29-597

EXTENSIVE MICROZONING STUDIES: THE ITALIAN EXPERIENCE AFTER THE 2016-2017 SEISMIC SEQUENCE IN CENTRAL ITALY

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In the last years, the Italian scientific and technical communities are developing an integrated feasible approach (The Italian Guidelines for Seismic Microzoning - IGSM) to local seismic hazard assessment based on the strict cooperation with local authorities and trained practitioners also operating locally. New field procedures and experimental tools have been developed and (more importantly) disseminated. This outcome has been the result of a permanent and close cooperation between academic and non-academic technical bodies, allowing the fruitful match between scientific knowledge and real application: both research and practice took advantage of this major methodological effort. By involving several Research and Academic

Institutions, the Italian Centre for Seismic Microzoning and Application (ICSMA) has been established to support local Authorities and practitioners performing and implementing seismic microzoning studies by following the IGSM. A key element of the adopted microzoning approach is its gradualism: three levels of microzoning have been defined, each characterized by growing complexity and commitment (and financial efforts). Specific outcomes are expected from each level. This organization allows graduating field activities with respect to available resources, specific goals and possible presence of local criticalities. After the destructive seismic sequence that affected Central Italy (2016-2017), the Italian Government planned a large reconstruction plan and charged the ICSMA to coordinate highest level microzoning activities supporting retrofitting and restoring activities in the damaged areas. 138 Municipalities were involved and this implied a huge amount of formative activities, field surveys and geophysical measurements whose outcomes had to be collected and standardized. The whole work was successfully concluded in few months (less than one year). The presentation will outline major aspects of this big effort by underlying the most important implications (technological, pedagogical, and political) that revealed to be feasible despite a number of important criticalities that, however, were not able to hamper the project.

ESC2018-S29-639

THE HVSR INTERPRETATION TECHNIQUE OF AMBIENT NOISE TO SEISMIC CHARACTERIZATION OF SOILS IN HETEROGENEOUS GEOLOGICAL CONTEXTS

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This study focuses on the analysis and the critical evaluation of the HVSR Nakamura method (Nakamura 1989) that is applied over different geological setting of urban centers when microzoning studies are performed. 372 In field measurements of ambient noise of 30 minutes length each have been acquired. 15 Sites have been involved into the study located within Pescara urban area (the New Court building site and the tourist harbor site) and in the outskirts of Chieti Scalo city center, within the University Campus area. Measures have been repeated on averaged over four days, eight measures a day (in the morning and in the afternoon) using two typical double geophone configuration, that are linear and crossed. The ambient noise acquisition campaign is aimed at validating the HVSR technique for seeking the fundamental frequencies of urban and suburban sites. The first areas are commonly rich in anthropic noise meaning that the noise is made up of mainly Rayleigh waves with a strong directivity. The suburban areas show a noise riches in SH waves, instead. From the results of the present study, the quality of the fundamental frequency f0 estimated by means of the HVSR technique has been confirmed only where the subsoil conditions (plane and parallel setting of the buried soil geometries of the bedrock interface) postulated for the validity of the Nakamura method are satisfied. Conversely, in hilly geo-morphological conditions where complex buried geometries are met, the Nakamura method is not predictive and different fundamental frequencies that are almost wrong are shown. The measured f0 has been compared with the theoretical value calculated by the Haskell (Haskell 1960) equation: $f_0=V_S/4H$ (1) This latter evidence is confirmed from several measurement repetitions during the day and over four consequent days. Furthermore, the role of Rayleigh waves in urban noise spectral components have been investigated according to HVSR Nakamura method enhancements (Nakamura 2000, 2008). As he stated, where directional Rayleigh waves are predominant (meaning that the vertical spectral component of the noise is higher than the horizontal ones) on the shear waves the fundamental f0 of the site can be recognized as half on the vertical Rayleigh peak frequency. This is definitively confirmed in the urban sites at Pescara city center. Finally, from this throughout in field survey of seismic noise it can be stated that HVSR works very well in ideal geo-morphological setting conditions although the wind, the urban noise (traffic and building oscillations) cannot be avoided. On the other hand, in quiet sites where the geo-morphological conditions are not compliant with the hypotheses of Nakamura's method, the f0 estimations are different to the calculated values by Eq. (1). Thus,

on this seismic passive technique the geological setting of the site plays a paramount role on its capacity .

ESC2018-S29-641

LOCAL SEISMIC HAZARD ASSESSMENT IN EXPLOSIVE VOLCANIC SETTINGS BY 1D AND 2D NUMERICAL ANALYSES

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In this study, we face the problem of local seismic response in explosive volcanic setting by using an integrated geological-geophysical-geotechnical approach in the test area of Stracciacappa maar (Sabatini Volcanic District, central Italy). Our aim is to understand if the horizontal and vertical chaotic heterogeneity typical of the volcanic deposits influence site response. The Stracciacappa maar is an active eruptive centre characterised by a crater of about 1 km in diameter and a crater floor of about 30-40 m below the rim (De Rita et al. 1983; Sottili et al. 2012). The ring is mainly composed by the pyroclastic succession belonging to the last phreatomagmatic activity. This pyroclastic succession generally bends outward the rim with low angle dip (10-20°). It consists of at least 25 metres thick alternation of decimetre- to centimetre-thick layers of fine-medium ash and small lapilli. The crater depression is filled by epiclastic debris deposits and by recent and present-day lacustrine muds. The epiclastic debris deposits, of alluvial and delta origin, consist of alternation of cm-thick reworked fine-grained and coarse-grained volcaniclastic material, dipping with low-angle (1s) motions, compared to tectonic events of equivalent magnitude (Jousset and Douglas 2007); the unscaled recording at Bronte Station (BNT in ITACA database, http://itaca.mi.ingv.it) of the ML=4.4 October 27, 2002 event was employed; 2) a high magnitude far-field “tectonic” event (tectonic scenario), whose reference spectrum was built with Ground Motion Prediction Equations (Ambraseys et al., 2005) assuming M=6.5 and distance of 70 km. These conditions are compatible with seismogenic sources located in central Apennines of Italy. Three unscaled recordings of events characterised by magnitude and distance in the range of 6-7 and 60-90 km, respectively, were extracted from ITACA database (http://itaca.mi.ingv.it), matching on average the reference spectrum Two subsoil models have been considered: a detailed model (based on distribution of the lithotypes unravelled by the geological survey) and a simplified one (obtained by grouping interfingering lithotypes resting below the lacustrine silty clays). The result show that the two models have similar response in all range of the interesting period (0.1-1.0s); the damping properties of soft clays and sands deposits in the upper meters reduce the difference in the seismic response at the surface of both models. The results suggest the possibility to simplify the heterogeneous distribution of deposits in this volcanic context for assessment of seismic response purposes. Finally, we carried out both linear and equivalent linear analyses in one-dimensional and bi-dimensional conditions, in order to investigate the bidimensional effects and the role of nonlinearity on the seismic response,. In linear case the behaviour of soils was assumed linear visco-elastic with small strain damping ratio values D0; amplification factors higher than 10 were reached at 2 Hz at soft clays surface in correspondence of the centre and western edge of the maar in bi-dimensional analysis, whereas the 2D/1D ratios were in the order of 2-3 around 2 Hz with maximum values at the maar edges. In the nonlinear analyses, the maximum amplifications dropped below 10 and the 2D effects (i.e., 2D/1D ratios) were generally lower than 2 in the whole range of frequency.

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ESC2018-S29-727

GITANES: A MATLAB PACKAGE FOR ESTIMATION OF SITE SPECTRAL AMPLIFICATION WITH THE GENERALIZED INVERSION TECHNIQUE

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The generalized inversion technique (GIT) is a well-established approach to evaluate the local spectral amplifications from seismic records acquired by a seismometric network or group of stations. The technique consists in the linearized decomposition of the Fourier spectra of the signals recorded at the instrumented sites into source propagation and site-response contributions, respectively. We have implemented a MATLAB package, called GITANES (GIT ANalysis of Earthquake Spectra), which guides through the GIT processing of a given dataset of seismic records written in SAC format, with the aim of assessing the spectral site response for a group of selected sites. The user can execute the workflow interactively from the MATLAB command window or with the aid of a graphical user interface (GUI). The latter allows the user to have a rapid visual overview of the available data and immediate insight into the results for a variation in the propagation model or changes in the selection of data-channels and events. In particular, considering that GIT can also be seen as an extension of the classical Reference Site Spectral Ratio, the user can rapidly examine different choices of the group of sites used as reference sites. GITANES also implements the Receiver Function, i.e. the spectral ratio between the horizontal and the vertical components for a set of earthquake recording, which can be considered as a proxy of the acual site response, tough with some severe limitations. GITANES also provides the amplitude spectra of the source time function of the recorded seismic events as a by-product of the analysis. In our presentation we present the overall GITANES package and demonstrate its application to the site response estimation of the stations of the OGS Seismometric Network of North-Eastern Italy.

ESC2018-S29-765

SITE EFFECTS AND DAMAGE PATTERN FOLLOWING THE 2016 CENTRAL ITALY SEISMIC SEQUENCE: THE CASE HISTORIES OF CAMPOTOSTO AND TORRICELLA SICURA MUNICIPALITIES (ABRUZZI REGION)

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The study focuses on the damages following the 2016 Central Italy seismic sequence, detected in the villages of Campotosto and Torricella Sicura which experienced MCS intensity values of V–VI and V, respectively, after the October 30, 2016 event. The damage intensity was evaluated by a detailed reconnaissance survey according to the EMS-98 macro-seismic scale (D0 = No damage; D1 = minor damage to non-structural elements; D2 = Major damage to the non-structural elements; D3 = Significant damage to load-bearing elements, but no collapse; D4 = Partial structural collapse; D5 =Full collapse). The damage pattern detected in the two villages was then related to local geological and geotechnical conditions, responsible for ground motion amplification phenomena. The municipality of Campotosto is sited along the axial zone of the Central Apennines chain, lying within an intramontane tectonic depression at the hanging wall of the Laga Mts Quaternary normal fault. In particular, the village is built along a N-S oriented ridge, where the Late Miocene siliciclastic bedrock (Laga Formation) generally crops out; this bedrock is represented by east-dipping thick layers of sandstone locally interbedded with finer-grained and thinner pelitic strata (i.e., arenaceous and arenaceous-pelitic

lithofacies of the Laga Fm. "Campotosto member"). The Torricella Sicura village is located in the Adriatic foothills and, similar to Campotosto, it is built along a gentle ridge, ca. N-S oriented, made of SE-dipping sandstones having, however, thinner strata, relatively scarce cementation and more frequent interbedding of pelitic layers (i.e., arenaceous-pelitic and pelitic-arenaceous lithofacies of the Laga Fm. "gessarenitico member"). Moreover, large areas of the Torricella present a layer higher than 10 m thick of silty-sandy and clayey Holocene colluvial deposits overlying the bedrock. Both the arenaceous and the arenaceous-pelitic lithofacies can be overlaid by a local (i.e., Campotosto) or extensive (i.e., Torricella) cover of fractured/weathered bedrock. The subsoil models for site response analyses resulting from geological, geotechnical and geophysical investigations (mainly down-hole tests and MASW tests as well as cyclic/dynamic laboratory tests) were finally calibrated by comparing numerical amplification functions, in the linear range, with horizontal-to-vertical spectral ratio derived from noise recordings. Regarding the input motion for site response analyses, the October 30 event was simulated. A ground motion prediction equation was employed to estimate the acceleration response spectrum at outcropping rock conditions (reference spectrum) for both villages, taking into account the magnitude of the event (Mw=6.5) and the distance of the villages to the fault. Seven acceleration time histories, including several October 30 recordings, compatible on average with the reference spectra were then selected for each village. Site response analyses in 1D and 2D conditions were carried out by employing a frequency domain and time-domain finite element code, respectively, both characterized by an equivalent linear approach. The results have shown that site amplification in Campotosto is mainly related to topographic amplification phenomena coupled with the effects associated to weathering and jointing conditions of the upper part of rock mass. On the contrary, impedance contrast between the soft silty-clayey covers resting on the stiffer flysch, are responsible for ground motion amplification in Torricella Sicura village. The results were expressed in the form of amplification factors FHa defined in terms of integral of elastic response spectra in pseudo-acceleration in different ranges of periods (0.1-0.5s, 0.4-0.8s and 0.7-1.1s). The 2D profiles of FHa, as well as the results of 1D simulations, were used to derive the level 3 microzonation maps in the two villages. Amplification as high as 1.9 and 2.2 were computed at Camposto and Torricella, respectively, in the 0.1-0.5s period range significant for the buildings located in the villages (essentially 2-3 storeys masonry buildings). A good qualitative agreement between the map and the damage pattern was found. Moreover, a good quantitative relation was found between damage level and spectral acceleration at the fundamental periods of the structures. In particular, at Torricella Sicura, damage levels D0, D1, D2, D3, D4 and D5 were detected for the 21.74%, 34.78%, 30.43%, 4.35%, 8.70% and 0% of all the masonry buildings of the historic centers, which experienced spectral accelerations ranging between 0.2 g and 0.3g. Also, it has been observed that for the same building type, spectral accelerations of 0.3 g led to a damage level D4, whereas no damaged buildings were subjected to spectral acceleration lower than 0.2 g. At Campotosto, where spectral acceleration between 0.2g and 0.65g occurred for masonry buildings, damage levels D0, D1, D2, D3, D4 and D5 were detected for the 20.34%, 27.97%, 21.19%, 16.10%, 5.51% and 8.90% were detected in the whole historic center. Also, it has been observed that damage levels D5 was due to spectral accelerations higher than 0.4 g while D2-D3 damage was due to spectral acceleration ranging between 0.25g and 0.3g, with the development of local mechanisms.

ESC2018-S29-782

MULTI-DISCIPLINARY STUDY FOR SEISMIC MICROZONATION OF PESCARA DEL TRONTO (AP), ITALY

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Between August 2016 and January 2017 a seismic sequence made of more than fifty-thousand events struck the Apennine in Central Italy, causing about 300 casualties and the complete destruction of many villages across the Lazio, Umbria, Marche and Abruzzo Regions. Due to the inner geo-structural complexity and the relatively shallow seismicity, this area of central Apennine is classified like a first category seismic zone in the

Italian probabilistic seismic hazard map. The seismic risk coexist with the landslide one for many municipalities located in this macro-area, due to the fact that this Apennine sector is characterized by geodetic strain rates and, therefore, not only a big amount of strain is being accommodated along the main faults responsible of quakes (D'Agostino et al., 2011) but also the conditions for both new and reactivated landslide are present. As a consequence of 2016-2017 earthquake, hundreds of landslides of various type and magnitude (rockfalls, slidings etc) have been observed and reported. The Seismic Microzonation (SM) is an effective seismic risk mitigation tool that can increase the degree of resilience of the territory and populations, in particular suggesting new areas for productive and residential settlements characterized by sustainable/acceptable risk. On the other hand, being SM focused on the analysis of Local Seismic Response (LSR), investigations are mainly conducted for the geotechnical characterization of the geological units whereas the landslide risk evaluation is often merely reduced to the analysis of existing restrictions deriving from mitigation plans made by Basin/District Authority. Pescara del Tronto, an ancient village in the municipality of Arquata del Tronto (AP) was almost completely destroyed by the 24 August 2016 Mw 6.0 earthquake and by the following events. The case study we show in this paper is an example of a SM study realized considering both geomorphological instability aspects and the geotechnical characterization for seismic risk evaluation purposes. Through an intense surveying activity (ISPRA, 2017a and 2017b) landslide phenomena along the Pescara del Tronto slope have been identified and classified into: rockfalls and toppling, superficial slidings and debris flows. The stability analysis was preliminarily aimed at verifying the absence of global slope instability phenomena along deep sliding surfaces, using a Finite Elements Modeling stability analysis. Afterwards, an evaluation of the distributed stability, based on equiareal territorial units (pixels) classification was carried out, implementing information in a GIS environment and using the following approaches to model the different types of landslides: a) The Flow-R program developed by Horton et al. (2013) to identify areas susceptible to landslides with rapid kinematics; b) the SINMAP -Stability Index MAPping- developed by Pack et al. (1999) to model sliding landslides inside superficial covers, considering the effect of instability induced by rainfall. c) A simplified volumetric approach for the debris flow phenomena according to the methodology proposed by Iverson et al. (1998), developed by Berti and Simone (2014). Using a combined matrix, the effects of each individual instability analysis were considered, resulting in a susceptibility map (four classes). This analysis showed that about 45% of the study area had been classified from high to very high susceptibility, highlighting therefore that in the reconstruction perspective the landslide risk couldn't be neglected. Geotechnical characterization of geological units was conducted too, using geophysical surveys, bore-hole investigations and down-hole geophysical tests, aiming at the numerical 2D analyses of LSR along some cross-sections representative of the geological and morphological settings of the area. Finally, suitable areas were identified according to the following criteria: low or medium susceptibility to landslides, Housner intensity (Housner, 1959) not exceeding 2.0, appropriate dimension to host a village similar to the one destroyed by the earthquake (avoiding fragmentation of new settlements) and gently sloping, for cost-effective urbanization works.

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ESC2018-S29-886

SEISMIC RESPONSE ANALYSES IN THE DAMAGED AREA OF THE AMATRICE HISTORICAL CENTRE AFTER THE 24TH AUGUST 2016, MW 6.0 EARTHQUAKE

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This work presents results coming from numerical analyses in the damaged area of the Amatrice historical centre, aiming at discussing factors leading to the observed differential damages after the 24th August 2016 Mw 6.0 earthquake and the following aftershocks. After the first earthquake and during the entire seismic sequence, Amatrice municipality was in fact highly struggled. For this reason, the Italian Department of Civil Protection asked Universities and Research Centres to support and coordinate III level microzonation studies in favor of populations affected by seismic events of 2016 and 2017 (Art. 14 of the OCDPC, numb. 394 of the 19th September 2016) to ensure the homogeneity of the results. Geological field investigations were performed and used to define a series of detailed geological cross-sections. Following insights from the reconstructed geological cartography, 4 continuous coring boreholes were drilled and 4 down-hole tests were consequently performed in order to define the shear-wave velocity model aiming at constraining the Vs model. All these data were used to obtain the dynamic model for the numerical analyses. In addition, 2D ARRAY and several noise measurements were carried out for better evaluating any eventual geological variability along the cross-sections. Numerical analyses of seismic site response were carried out using both 1D and 2D approaches including linear and linear equivalent models. The analyses allowed comparing simulated versus empirical amplification functions. Moreover, the geological - geotechnical characterization of the historical centre may be useful for the following purpose: to challenge the problem of the realistic ground motion estimates, evaluating any eventual local effects able to enhance or modify the input motion. The performed analyses were partially supported by the Italian Department of Civil Protection (DPC) of the Presidency of Council of Ministers, while a CNR -IGAG, INGV, POLIMI-DICA, UNIFI-DICeA, CNR-IDPA, CNR–IMAA, UNIROMA1-DICEA and CNR- IRPI collaboration made possible the realization of this multidisciplinary study, which includes detailed seismological, geological and geophysical analyses.

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ESC2018-S29-947

THE CONTRIBUTION OF SEISMIC NOISE AND GEOLOGICAL DATA TO RECONSTRUCT THE INFILLING ARCHITECTURE OF THE NORCIA BASIN (CENTRAL ITALY)

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During the 2016-2017, a long and complex seismic sequence struck the Central Italy, involving four regions (Umbria, Marche, Abruzzi and Lazio) and causing important damages and victims in inhabited areas such as Norcia and Amatrice towns. Norcia is an historical town situated in an extensional inter-montane basin, and a MCS intensity level of 7.5 was estimated after the 30 October 2016 Mw 6.5 event. In order to shed light on the subsurface geology and seismic response of the Norcia basin, we have performed an integrated geological and geophysical study, focusing our efforts on its most populated northern sector. The results of the field geological survey and the collection of available well stratigraphic logs have allowed us to identify the main Quaternary lithostratigraphic units laying on the carbonate substrate. From the bottom to the top we find: i) clayey deposits typical of lacustrine deposition, intercepted only by deep boreholes; ii) cemented conglomerates outcropping in the NE sector, related to wide alluvial fans occasionally affected by pervasive fracturing and faulting; iii) unconsolidated conglomerates units in silt and clay matrix typical of alluvial plain environment, mainly outcropping in the SW sector of the alluvial plane; iv) unconsolidated carbonate units representing debris-flow deposits filling the valleys that connect the carbonate slopes with the flat morphology of the plain; v) marshy and clayey deposit related to the actual palustrine deposits; After identified the main Quaternary geology units, we performed a geophysical survey with the well-known Horizontal-to-Vertical Spectral Ratio (HVSR/Nakamura) method. We deployed 20 single-seismic stations to record some hours of ambient vibrations. We used two different equipments (Reftek130 digitizer with Lennartz-5sec and a SARA Geobox 4.5 Hz) deployed along two main orthogonal transects (ENE-WSW and N-S direction, respectively) covering the whole area of interest. HVSR analysis shows and heterogeneous pattern of “fundamental frequency” (F0) according to the different portions of the basin. F0 is varying in the Norcia basin from 0.55 to 10 Hz. HVSR results can be summarized in four main groups, suggesting a direct link with the different characteristics of the lithostratigraphic units and their variable thickness: 1) a relatively flat spectrum with a single peak at high frequencies (range 4-10 Hz) for stations located above the carbonate bedrock; 2) broad peaks and F0 larger than 1 Hz in the NE area with respect to Norcia town. We observed broad peaks between 1-4 Hz and often a secondary peak at about 10 Hz, that is likely related to the presence of alluvial fan; 3) very narrow sharp peaks at 0.5-1 Hz are characteristic of the stations located in the SW-zone, which is the part where the basin shows higher thicknesses of the infilling continental deposits; 4) a bi-modal behaviour of the spectra, with a first broad peak between 0.5-1 Hz and a second one over 10 Hz is observed in the area of the inhabited city centre The integration between the data provided by the geological survey, experimental geophysical H/V data and available information on the velocity allows us to infer the thicknesses of deposits underneath the basin, and the depth of the underlying carbonate bedrock. The integration of geological information and geophysical data, that show sharp lateral changes in the shape of peaks, suggest also a possible control of the main tectonic elements that characterize the area. Such new results, allowed us to carry out an integrated model of the substructure geometry of the Norcia basin. More specifically, the alluvial conoids present in the NE area seems to reach a depth variable from 20 to about 50 m, overlaying thick alluvial and lacustrine deposits throughout the basin. Below the Norcia inhabited area and in the SW part of the basin, which is the areas where the bedrock is suspected to be deeper, these “soft” deposits may reach a depth of 250-300 meters. The preliminary results of this study, also include some research products: an inedited digital geological map scale 1:10.000 created with QGIS software; a “Frequency-Amplitude” map from the HVSR analysis and two seismo-stratigraphic cross sections, highlighting the contact between infilling Quaternary units and the seismic "bedrock". Further acquisition of ambient vibrations trough 2D array of seismic stations will be carried out to better constrain the shear-wave velocity profile.

ESC2018-S29-949

PLANNING OF SURFACE FAULTING HAZARD STUDIES IN CALABRIA REGION (SOUTHERN ITALY)

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Calabria is one of the Italian peninsula Region historically affected by some of the major earthquakes in the whole Mediterranean area that characterize its high seismic hazard. The Calabria Region, in the framework of the National Seismic Risk Prevention Program (Art. 11 of Law 77/2009), has planned a virtuous seismic risk reduction program, including seismic microzonation (MS) studies and vulnerability assessment of strategic buildings. In particular, in collaboration with CNR IGAG, Calabria Region is carrying out seismic microzonation studies in 402 municipalities, following national guidelines and standards (SM Working Group, 2015a). To date, about 30% of the 402 municipalities have the so called "level 1" seismic microzonation (i.e., qualitative studies), while the studies are still on-going in the remaining municipalities. Moreover, seismic microzonation studies with a quantitative approach (so called "level 3" MS studies) are presently carried out for 13 of 56 reference municipalities characterized by high seismic hazard and exposure. By law, MS studies of level 1 funded by Government in the framework of Art.11 are mandatory tools for planning at municipal level, and instability-prone mapped zones deeply constrain land-use and planning. Taking into account that MS studies of level 1 are performed with a qualitative approach, the mapped boundaries of instability-prone microzones are affected by considerable uncertainties, mostly in historical centres, where data are often not available. In the case of Lamezia Terme, the MS of level 1 displays a so called "attention zone" (ZAFAC; SM Working Group, 2015b) related to an hypothetical active and capable fault (FAC), which affects a large portion of the historical centre. This attention zone is defined by a buffer of 600 m on the trace of the FAC derived by the ITHACA (ISPRA, 2018) catalogue, that reports the geomorphological trace of this fault. Given the quality level of the MS study, the Municipality of Lamezia Terme has to manage restrictions in land-use and planning in the attention zone. In order to unconstraint the large attention zone related to the hypothetical FAC, the level 3 seismic microzonation study of Lamezia Terme is currently curried out. The fault is presently studied through a multidisciplinary paleoseismological approach, that will allow to define in detail both the fault activity and a more accurate perimeter of the hazard zone. In this context, in addition to funding MS study of level 3 in Lamezia Terme, Calabria Region has defined a priority list of hypothetical active and capable faults to be studied in the framework of the 56 reference municipalities. This priority list is used by the Region to define funding priorities of the level 3 seismic microzonation studies. References:

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ESC2018-S29-955

ELASTODYNAMIC MODEL OF CAMPO DE DALíAS BASIN (SE SPAIN) FROM AMBIENT NOISE

RECORDS AND ESTIMATION OF SEISMIC RESPONSE

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The seismic velocity structure of Campo de Dalías, a coastal plain of 300 km2 in the southeastern mountain front of the Betic Cordillera, has been investigated by means of passive seismic methods. This work is aimed at improving previous geophysical models to increase knowledge on wave propagation and site effects in this basin, which is located in a seismically active region. The analyzed dataset consisted of H/V spectral ratios of ambient noise from 340 single-station broadband measurements, approximately on the vertexes of a 1000 x 1000 m square grid, and 10 surface-wave dispersion curves obtained from array measurements of ambient noise (maximum aperture ~ 850 m). Constraints to the stratigraphy and Vp structure provided by deep boreholes and multichannel seismic reflection data (95 km of along 7 seismic profiles) were considered. The spectral analysis of ambient noise shows clear peaks in the H/V ratio in a wide frequency range (down to ~ 0.25 Hz) associated to the main contrast in Vs caused by up to ~ 1000 meters of soft sedimentary rocks (mainly Miocene marls) overlying the stiffer basement. Modeling of H/V spectral ratios obtained from ambient seismic noise relied on the Diffuse Field Approximation. Incorporation of P-wave reflection data leads to better constrained Vs models since inversion of dispersion curves implies some trade-off between Vp and Vs and inversion of H/V ratios implies indetermination between thicknesses and velocities. The interpolation of inverted local models describes well the main structural features in this area such as the El Ejido Synform and the Guardias Viejas Antiform, both of them with ENE–WSW-trend, and provides reliable ranges for the seismic wave velocities of the main geological units. A 2.5D model capturing the main features of the structure has been built to simulate seismic wave propagation across the basin. Its three-dimensional response under incidence of plane P, S and Rayleigh waves has been modelled by using the Indirect Boundary Elements method (IBEM).

ESC2018-S29-1023

AMPLITUDE VARIABILITY OF GROUND MOTIONS OF EUROPEAN DENSE ARRAYS

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Spatial variability of seismic ground motions (SVGM) denotes the differences between two time histories of the ground motion recorded at different locations, generally at the ground surface. The modeling of SVGM and the understanding of its influence on the structural response are necessary so as design codes start to incorporate its effects in their provisions. SVGM may be quantified by means of amplitude variability using the standard deviation of difference of Fourier amplitudes. This study presents the estimation of amplitude SVGM using various in-situ rock and soil site measurements. The earthquake data comes from seismological experimental campaigns that have taken place on different counties in Europe. The dense arrays are the rock and soil site arrays in Argostoli, Greece, the soil site array in Grenoble, France, the soil site array in Fucino, Italy and the hard rock site array in Saint Guérin, France. The subset of events that has been selected for each of the arrays, consists of low to moderate magnitude local and regional earthquakes. Amplitude SVGM is quantified for each site and comparisons are made, providing a valuable inside of the physics behind ground motion variability. Correlation of the amplitude variability with the available Vs profiles of the sites is attempted. A commonly used parametric model of amplitude SVGM is also compared to in-situ observations. The findings of the present research are contributing to enhance our understanding of SVGM at different site conditions and proposing variability models to be used in structural design.

ESC2018-S29-1033

NON-LINEAR MODULATION OF SITE RESPONSE: SENSITIVITY TO VARIOUS LOADING PARAMETERS AND SITE PROXIES USING A NEURAL NETWORK APPROACH

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The impact of non-linear soil behavior on site response may be described by the non-linear to linear site response ratio so-called RSRNL-L. This ratio exhibits a specific shape with an amplitude above 1 below a site-specific frequency fNL and an amplitude below 1 above. This talk will present an investigation of the correlation between this RSRNL-L ratio and various parameters used to characterize the site or the seismic loading level. The data used in this analysis come from sites of the Japanese Kiban–Kyoshin (KiK-net) network, for which the nonlinear to linear site-response ratio (RSRNL-L) is obtained by comparing the surface/down-hole Fourier spectral ratio for strong events and for weak events. A neural network approach is used to investigate the performance of various loading parameters (PGA, PGV, PGV/VS30, CAV, etc.) and site proxies (VS30, f0, sediment thickness,...) in predicting the variability of the observed non-linear ratios RSRNL-L. The correlation analyses indicate that the parameters that better explain the observations of non-linear soil behavior are Vs30 and f0 for the site proxies, and PGA, PGV CAV for the loading level (which perform significantly better than the strain proxy PGV/VS30). Non-linear soil behavior is found to start at relatively moderate PGA values (even below 100 cm/s2), while the amplitude of the low-frequency increase and high-frequency decrease of the amplification exhibits a dependency on Vs30, reaching maximum values for high Vs30 (stiff) soil classes.

ESC2018-S29-1042

SEISMOLOGICAL ANALYSES AIMED AT 3RD LEVEL SEISMIC MICROZONATION OF THE 138 MUNICIPALITIES DAMAGED BY THE 2016-2017 SEISMIC SEQUENCE IN CENTRAL ITALY

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The evaluation of the seismic spectral response under earthquake excitation (i.e. the site response) represents a main step towards an accurate quantification of the seismic hazard and is a fundamental step for the highest level of seismic microzonation considered in Italy, i.e. the so-called 3rd level (MS3). The Italian Guidelines for Seismic Microzonation recommend, for the MS3, performing the assessment of local seismic response by experimental or numerical techniques based the former either on passive measures of environmental seismic noise or on strong and/or weak-motion events, while the latter on 1-D and 2-D numerical simulations, respectively. Following the destructive seismic sequence that struck Central Italy during 2016-2017, the Extraordinary Commissioner for the reconstruction, appointed by the Italian Government, promoted the MS3 of all 138 damaged municipalities, entrusting the Center for Seismic Microzonation and its applications (CMS) for the scientific coordination of the activities. The CMS organized the work into 6 transversal Thematic Units (UT), made up of experts of the individual fields, whose purpose was to investigate specific technical-scientific aspects, organize and harmonize all the existing or collected data and providehigh quality products in order to achieve the final goal. One of the 6 UTs was the Seismological Analysis Thematic Unit (UTAS). Four institutions have been involved in the UTAS: OGS - IstitutoNazionale di Oceanografia e di GeofisicaSperimentale, Seismological Section CRS, also with the role of coordinator; INGV - IstitutoNazionale di Geofisica e Vulcanologia, Sections of Rome and Milan; UNIGE - University of Genoa, DISTAV Department; and ENEA - AgenziaNazionale per le NuoveTecnologie, l'Energia e lo SviluppoEconomicoSostenibile.The mainUTAS purpose wasto providequantitative informationof the site response amplification useful for the MS3 of the localities belonging to the 138 damaged municipalities.For the analysis of seismological data, the first step was to make a census of the seismological stations (seismometric and accelerometric, permanent and temporary) existing in all the MS3 localities. Then, two buffer

areas of 1 km and 5 km, respectively, were built around eachmunicipal area (i.e. site), with the aim of selecting 1) the stations useful for the evaluation of site effects (included in the area extended with the 1 km buffer), and 2)the candidates to be set as a reference site (included in the area extended with the 5 km buffer). As a result of this procedure, 111 sites were identified as useful and then analyzed, out of a total of 247 existing stations. 109 stations were used for the evaluation of site effects (and in three cases also as reference sites) of 102 MS3localities (corresponding to about 20% of the total), while the remaining two stations were used exclusively as reference sites. At each station, four products were estimated: a) Spectral ratios between the horizontal and vertical components estimated from both earthquakes (EHV) and environmental seismic noise (HVSR) recordings; b) Spectral amplification curves, estimated by Fourier amplitude spectra or response spectra, for the horizontal and vertical components of the ground motion; these values were obtained by applying both the classical reference-site spectral ratio technique (RSSR), and the generalized inversion technique (GIT). c) Site-specific acceleration response spectraestimated by the spectral amplification curvesand the seismic input defined at each MS3locality; d) Amplification factors computed from the pseudo-acceleration response spectra for three period ranges, and amplification factors between the observed PGV and PGA and those predicted by a well-establishedGround Motion Prediction Equation. Each participant group carried out the analyses on different sets of stations using its own method. The results were harmonized and summarized into homogeneous site-specific forms, containing general (i.e. geographic, instrumental, geological, seismological) information, and the graphic representation of the four products. As a conclusion of theUTAS study, carried out in a very limited period (2 net months), a considerable set of quantitative information was delivered to CMS and authorities, providing important indications to be used for the 3rd level microzonation of thedamaged municipalities and their reconstruction. We eventually think that this experience can be taken as a reference model of technical/scientific activity for future post-earthquake interventions.

ESC2018-S29-1076

INVESTIGATION OF THE EFFECTS OF SITE-SPECIFIC TOPOGRAPHY ON DYNAMIC SOIL-STRUCTURE INTERACTION BEHAVIOR

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In this study, we provide preliminary results from an ongoing study (funded by The Scientific nd Technological Research Council of Turkey, TUBITAK) investigating the effects of sitespecific surface topography on dynamic soil-structure interaction (SSI) behavior of several structures located in Istanbul. This is achieved by examining the mechanisms of topographic site effects on SSI behaviors of given structures and sites by studying topography-induced changes in impedance functions (IF) and foundation input motions (FIM). Dominance of each mechanism is quantified through systematic parametric studies on detailed continuum finite element models. The nonlinear time-domain responses of various soil-foundation-structure systems subject to strong remote earthquake excitations for various site conditions are investigated using our opensource SSI simulation toolbox. The objective has been to test the hypotheses that (i) surface topography and irregular stratigraphy of sites would affect dynamic SSI behavior of a structure; (ii) the topography effects could be completely captures through modified IFs and FIMs for a given soil-foundation system; (iii) incorporation of multi-axial soil nonlinearities are essential in accurately capturing topographical SSI effects. The future elements of this effort include the creation of a map of topography-induced SSI response amplification factors for the south European side of Istanbul by performing 3D simulations using real site topography and soil stratigraphy data, and realistic bedrock ground motions, which are available from a comprehensive earthquake scenario and seismic micro-zonation study that was completed in 2007.

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ESC2018-S30-39

ESTIMATION OF NEAR-SURFACE ATTENUATION IN THE NORTHWESTERN EXTERNAL DINARIDES

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Ground motion at the site is influenced by source, propagation path, and local site conditions. One of the most important parameters describing ground motion during earthquakes is the Fourier-amplitude spectrum. Spectral parameter kappa is used to describe spectral amplitude decay at high frequencies. Over the last several decades, the researchers are consistent that near site attenuation kappa (site kappa) is affected primarily by site conditions. In this research spectral parameter kappa is estimated from the acceleration amplitude spectrum of shear waves (recordings of local earthquakes with magnitudes higher than 3, epicentral distances less than 150 km, and focal depths less than 30 km from four seismological stations situated in western part of Croatia – Northwest External Dinarides) from the slope of the high-frequency part where the spectrum starts to decay rapidly to a noise floor. The spatial distribution of individual kappa's is compared with azimuthal distribution of earthquake epicenters. Also, the obtained results are compared with Vs30 values (from geophysical measurements) and published coda-Q values for each station, as well as with isoseismal maps of stronger events in the investigated area and geological features. These results are significant for extending the knowledge of the attenuation of near-surface crust layers in the Nortwest External Dinarides and providing additional information on the local earthquake parameters for updating seismic hazard maps

ESC2018-S30-190

SOURCE-CONTROLLED FMAX OF SOURCE SPECTRA FOR EARTHQUAKES OF NORTHERN KAMCHATKA

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The source-spectra of 3.5–6.5 earthquakes of northern Kamchatka (Gulf of Kamchatka and the Bering fault zone), during 2010–2017, are studied. The Kamchatka seismic network (D0 in FDSN), deployed in 2006–2010, covers a broad frequency range, including 0.2–30 Hz, used for spectral analysis of S-waves group. Input data are >1100 events recorded by 3–5 semi-hard-rock stations (equipped with accelerometers CMG-5TD) at hypocentral distances of 25–250 km. None of hard-rock stations are within the study area. To recover source spectra, observed spectra were corrected for geometrical spreading (1/r), attenuation Q(f) and frequency-dependent site effects, including kappa. Site effects correction was estimated beforehand using both regional and teleseismic records. The source spectra were analyzed using the three-cornered template, where fc is split into fc1 and fc2 (splitting is observed in 70% cases), and fc3 is the "source-controlled fmax", which was studied earlier for subduction earthquakes of Avacha Gulf for the same magnitude range, recorded by hard-rock stations [Skorkina, Gusev, 2017]. The data were processed in automatic and interactive modes. Corner frequencies sets were obtained for each spectrum, consisting of {fc1, fc2, fc3} triples. In automatic mode {fc1, fc2, fc3} are observed in {50%, 72%, 64%} cases; in interactive – {58%, 100%, 73%}. Preliminary, scaling properties (dependence on the seismic moment) of corner frequencies were checked using common and orthogonal regressions. Seismic moment values were estimated using the flat low-frequency part of source displacement spectra. The fc1(M0) follows the similarity hypothesis (scaling exponent b is close to 1/3, the interval estimate is [0.29 0.35]). However, fc2(M0) and fc3(M0) clearly disagrees with the similarity hypothesis, with scaling exponents being 0.25 and 0.11, correspondingly. The study was supported by the grant from the Russian Foundation for Basic Research (project 18-35-00029).

ESC2018-S30-197

STABILITY OF CODA QUALITY FACTOR AT THE GEYSERS GEOTHERMAL FIELD, CALIFORNIA, AND ITS EFFECT ON SOURCE PARAMETERS ESTIMATIONS

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In this study we use over 1000 seismic events, recorded at different sites at The Geysers geothermal field, California, to estimate representative coda quality factor (Qc) mean-curves valid for the study area. The analyzed induced earthquakes with duration magnitudes from Md 1 to Md 4 and depth locations between 1 and 5 km have been recorded using the Berkeley-Geysers network, consisting of 31 short-period surface instruments. The epicentral distances between events and stations range from approx. 0.7 to 15 km. To calculate the coda quality factor (Qc), we use the single scattering model extended by Phillips and Aki (1986), where the recorded S-wave coda is believed to result from direct S-wave scattering on numerous randomly distributed heterogeneities in the earth's crust. The assumption of scattered S-waves at The Geysers is verified by the observation of shear wave splitting and a delayed S-wave amplitude peak after the S-onset. The S-wave coda is analyzed (at different lapse times) using a sequence of overlapping time windows. For each window, the average Power Spectral Density is calculated and the coda amplitude is extracted at fixed center-frequencies ranging from 1 to 69 Hz. In the following, the decay of the S-coda signal with time around a set of octave band frequencies is analyzed by applying the regression analysis, leading to Qc estimates and their associated uncertainties for particular frequencies. Simultaneously, we investigate the sensitivity of Qc estimation to different input parameters including lapse time, magnitude, window width of moving windows and seismic sensor components. We confirm that on average our estimates are insensitive to the magnitude and sensor components. Small variations in Qc estimates are observed testing different window widths and lapse times. We identify major variations in our Qc estimates while testing different levels of signal-to-noise ratios and while restricting the slope uncertainty (confidence interval) of the regression analysis. The resulting high-quality Qc estimates were further tested in the context of their spatio-temporal behavior in the reservoir. Therefore, we investigate the distance and azimuthal dependence of Qc, and relate it to the observed induced reservoir anisotropy and local geothermal features. In addition, we analyze the influence of seasonal changes in the injection rates on our Qc estimates. Finally, we compare the stability of our coda-Q results with estimated direct S-wave quality factors from the spectral analysis and discuss them in the context of source parameters and stress drop uncertainties and the potential bias of their estimations. The stress drop estimates are prone to quality factor miscalculations. By using unstable quality factor estimates to correct the seismic source spectra, the uncertainties will propagate and will result in unreliable source parameters estimates. Especially uncertainties in corner frequency (fc) will lead to a large scatter of stress drop estimations and therefore also to overestimated ground motion predictions. Hence, using a stable quality factor is important to calculate a reliable stress drop which is furthermore an essential parameter for ground motions prediction equations.

ESC2018-S30-211

ESTIMATION OF KAPPA-SITE FOR A HARD ROCK SITE IN THE UK

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For a probabilistic seismic hazard analysis (PSHA) on a hard rock site, one of the main uncertainties is the description of the ground motion attenuation. Generally, either ground motion prediction equations (GMPEs) based on stochastic simulations are adopted or empirical GMPEs on rock are corrected for both the site-specific soil profile and the kappa-site parameter. The latter represents the attenuation of shear waves when travelling vertically through the shallow geology at the site. This correction is called VS-kappa adjustment. Empirical correlations between VS30 (average shear wave velocity in the upper 30m) and kappa-site are available in the literature, however only few data for very large VS30 exist. When available, recorded ground-motion time histories at the site can be adopted to define kappa-site. From each recording, the attenuation parameter kappa, which defines the decay of the high frequency part of the acceleration Fourier amplitude spectrum (FAS), is computed. The kappa values are then plotted against distance and fitted by a linear regression and kappa-site is estimated as the intercept of the fit at zero

distance. In this study, we compute kappa-site for a very hard rock site in the UK, where recorded ground motions with local magnitude, ML, between 0.1 and 3.6 are available. Two methods are adopted: in the first method, kappa is computed from the acceleration FAS of records with magnitude greater than 2, while in the second method from the displacement FAS of records with magnitude lower than 1.5. In both cases, records at distances greater than 300km are excluded since (a) the path will tend to be refracted along the Moho and (b) the waveform can be dominated by surface waves. kappa-site is evaluated by extrapolating the results to zero distance. The extrapolation to zero distance has been performed using two different regression techniques: a robust fit and a weighted least-squares regression. The former is preferred since it is less influenced by outliers in the data. For the acceleration FAS method, three subsets are adopted: (1) all records with ML>=1.5 (30 earthquakes); (2) all records with ML>=2 (20 earthquakes) and (3) only records with ML>=3 (7 records). The results from the above subsets of data show that the best estimate of kappa-site varies between 0.005 and 0.013s. The variability of these estimates of kappa-site ranges from 0.004 to 0.009s, increasing when the number of data points in the regression decreases. In the displacement FAS method, records at very short distances that provide large kappa values and records that appear to be outliers were singularly checked to ensure their reliability for the regressions. Regressions of two subsets of data have been performed: (1) all records with ML

ESC2018-S30-234

LESSONS LEARNED FROM A SITE-SPECIFIC PSHA CONSIDERING HOST-TO-TARGET ADJUSTMENTS

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In the framework of the PEGASOS Refinement Project (PRP) - a site specific PSHA for the Swiss nuclear power plants - one of the key issue was adjusting existing ground motion prediction equations for being used in the very hard rock conditions as found in the plant sites. During the PRP several sensitivity studies were performed with respect to the impact of the host-to-target conversion and it turned out that Vs-Kappa corrections are playing a key role with a large impact on the seismic hazard results at higher frequencies. The corrections were evaluated in terms of median corrections and all associated uncertainties. The research work done under the PRP resulted in several new findings and new approaches for the host-to-target adjustment. Nevertheless, there are still some challenges and issues to be resolved when applying host-to-target corrections. Those are e.g. the dependency of the correction on the host and target Vs-profile estimate and shape, the VS30 estimate and uncertainty, the Kappa estimate and associated uncertainty as well as the consistency of the correction method with the way how the GMPE was developed. Furthermore, the need to address host-to-target adjustments in the application of V/H ratios to the horizontal component of the hazard to derive the vertical hazard. There are a few engineering aspects involved, especially considering the high-frequency content and the understanding for which pieces of systems and components this represents a risk. This contribution is intended to share the lessons learned and insights from a large scale application project with the scientific community in order to continue to make progress and improvements in the field of host-to-target corrections for ground motion predictions.

ESC2018-S30-236

SEISMIC WAVE ATTENUATION IN THE CRUST BENEATH THE AREA FROM THE BEND OF THE CARPATHIAN ARC

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We investigate the shear wave attenuation in the crust beneath the area from the bend of the Carpathian Arc by modelling the high-frequency waveforms (maximum frequency 5 Hz) from weak-to-moderate local earthquakes. We determine 1-D models of the quality factor of the medium Q using a non-linear inversion procedure in spectral domain: the amplitude spectra of records of low-to-moderate magnitude earthquakes are compared with synthetic signal spectra, generated for sources with the same location and mechanism as the recorded events. The synthetic waveforms are calculated by modal

summation, a method which allows the synthesis of the complete wavefield. The structural models for the elastic parameters – density and seismic wave velocities – needed to generate the theoretical seismograms consist in several homogeneous layers for the sedimentary cover and two layers for the crystalline crust. The input attenuation structures keep the layer configuration of the velocity and density models, the Q-factor being allowed to vary within a wide range. The observed and theoretical waveforms are low-pass filtered, with the cut-off frequency at 5Hz. The best-fitting Q-structures are determined by minimizing the sum of squares of logarithmic residuals between observed and theoretical amplitude spectra, calculated for time windows centered on the most energetic part of the signals, are smoothed by averaging the amplitudes over a bandwidth of 1 Hz. In general, the non-linear inversion of geophysical data does not yield a unique multi-valued solution, a set of models may be compatible with the observed data. To define the acceptance threshold for the 1-D attenuation structures we performed synthetic experiments simulating reasonable / expected errors of the hypocenter location, focal mechanism and velocity models. For the representative Q-structure we choose the 'median model'– the middle of the ensemble of all acceptable solutions; the half-width of the corridor of acceptable Q-values specifies, at each depth, the model uncertainty. The study area comprises several juxtaposed tectonic units: the Carpathian Orogen, the sedimentary Focsani Basin (component of the Carpathian Foredeep), the stable Moesian and Scythian Platforms. We investigated ray paths spanning all these crustal provinces and the results reveal distinctive attenuative properties among the structural units. High shear wave attenuation in the considered frequency range is observed beneath the southwestern part of the sedimentary Focsani Basin, as well as beneath the nappes of the Vrancea region orogen; in contrast, high Q-values are obtained for the rays crossing the stable platforms. Several studies investigating the characteristics of the attenuation of the seismic waves generated by the intermediate-depth earthquakes of Vrancea region pointed out similar lateral variations, i.e. significantly lower quality factor beneath the Vrancea epicentral zone, than in the Extra-Carpathian area. Our results indicate that the crystalline upper crust has a significant contribution to this attenuation pattern.

ESC2018-S30-262

HIGH FREQUENCY ATTENUATION OF S-WAVES IN ALLUVIAL DEPOSITS OF THE CENTRAL PO PLAIN (NORTHERN ITALY)

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The spectral decay parameter k (Anderson & Hough, 1984) has been estimated to assess the high frequency attenuation of thick alluvial deposits which characterize the shallow geological structure of the Po Plain (Northern Italy). Data comes from a microseismic network that samples a uniform lithological condition in the Central Po Plain near Cortemaggiore (Piacenza). The network is composed of three surface and four 100 m deep borehole stations, all equipped with 1 Hz seismometers, with an inter-station distance of about 2 km. Starting from a recordings dataset that comprises earthquakes with ML magnitude between 2.0 and 5.2 and epicentral distance (Re) between 20 and 200 km, seismograms showing a signal to noise ratio greater than 3 were selected for the analysis. A standard procedure (Gentili & Franceschina, 2011; Ktenidou et al., 2014) has been applied to assess $k = k0 + kR \cdot Re$, giving k0 values of about 70 ms at surface and 55 ms at 100 m depth. Taking into account shear-wave velocity (Vs) measures obtained by cross-hole tests performed in similar lithological conditions not far from our network, we can consider an average Vs of 300 m/s in the shallower 100 m. This value, which can be also inferred from the analysis of spectral holes found in down-hole recordings, allows to estimate an average value of about 20 for the shear-wave quality factor (Qs) of the shallower 100 m alluvial deposits.

ESC2018-S30-339

APPLICATION OF NON-INVASIVE ACTIVE AND PASSIVE METHODS FOR DETERMINING THE SHEAR WAVE VELOCITY PROFILE AT HARD ROCK SITES IN EASTERN CANADA

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Hard rock sites should exhibit no amplification but some amplification occurs at higher frequencies due to weathered and fractured layers in the near surface. We aim to retrieve shear-wave velocity (Vs) depth profiles at multiple seismograph stations located on hard rock across Eastern Canada using various non-invasive seismic methods. We performed up to three seismic array measurements at each site: compression-wave refraction, multi-channel analysis of surface waves (MASW), and ambient vibration array (AVA) array methods. Site characterization at seismograph sites of the Canadian National Seismograph Network (CNSN) is not robust or systematic. We aim to improve site characterization at these hard rock seismograph sites including velocity depth profiles in this study and seismic kappa in a parallel study. According to the National Building Code of Canada, hard rock sites are classified by a Vs30 (time averaged shear wave velocity of the upper 30m) greater than 1500 m/s compared to softer rock and/or stiffer soil sites being less than 1500 m/s. Layer velocities are retrieved from the observed slopes in refraction traveltime-distance analysis. The AVA recordings are used to extract dispersion curves using frequency-wavenumber (f-k) and/or modified spatial autocorrelation (MSPAC) methods as well as horizontal-to-vertical-spectral ratios (HVSRs). MASW recordings are used to extract dispersion curves with a f-k method and merged with any dispersion data from the AVA analyses. Dispersion curves and HVSR amplification functions are inverted to acquire Vs profiles for each site. We aim to retrieve Vs profiles that capture the high frequency amplification of near-surface sediments or weathered/fractured rock layering above more competent bedrock below. All of the sites explored have a surficial layer Vs of at least 400 m/s. We find additional processing and interpretation is required for these stiffer sites to extract reliable dispersion and/or amplification characteristics in comparison to typical soft soil conditions. Preliminary results show that MASW captures the high frequency amplification of the near surface sediments more efficiently than AVA in order to acquire a Vs profile. At some sites we are unable to resolve dispersion characteristics through AVA methods, but MASW methods are successful. This study allows us to diversify and expand these non-invasive methodologies at more geologically complex sites in the acquisition of Vs30. A summary of seismic kappa results will also be provided in the conference presentation.

ESC2018-S30-608

HIGH-FREQUENCY GROUND MOTION SCALING AND GROUND SHAKING SCENARIOS FOR EARTHQUAKES IN THE CORINTH GULF AREA (GREECE)

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Assessing seismic hazard is important to consider whilst studying the seismology of a region. The prediction of earthquake ground motion has always been of primary interest for seismologists and structural engineers. Planning and design should be based on available national hazard maps, which, in turn, must be produced after a careful calibration of ground motion predictive relationships (computed as a function of magnitude, distance from the source, and frequency) for the region using various mathematical and data processing techniques such as regression analysis. The aim of this study is to provide a complete description of the characteristic of the ground-motion in the Corinth Gulf region (Greece). We employed a general form for a predictive relationship including the source excitation term, an attenuation operator and an operator to account for the site effect. The functional form of the crustal attenuation term depends principally on the attenuation parameter and on the geometrical spreading. Excitation terms are modeled by using a Brune spectral model. Simulations were carried out using EXSIM and ground motion scenarios (in terms of peak ground acceleration peak ground velocity, and Spectral Acceleration as a function of distance and magnitude) are computed for the study area. Furthermore, the results obtained can later be used for upgrading seismic hazard maps and for engineering designs as well as implementing tools like ShakeMap.

ESC2018-S30-611

HIGH-FREQUENCY GROUND MOTION PARAMETERS FROM WEAK-MOTION DATA IN

THE SICILY CHANNEL AND SURROUNDING REGIONS

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In this study we characterize the high frequency seismic wave crustal attenuation and the source e excitation in the Sicily Channel and surrounding regions using background seismicity from weak-motion database. We used 15995 waveforms related to earthquakes occurred between 2006 and 2012 recorder using broadband stations. The magnitude of events was ranged from Mw=2.0 to Mw=4.5 and travel path was ranged from a few kilometers to about 250 km. The observed ground motions form the weak-motion data are evaluated in several narrow frequency bands from 0.25 to 20.0 Hz. The filtered observed peaks are regressed to derive a proper functional form for the regional attenuation, excitation and site specific term separately. A frequency-dependent quality factor and a geometrical spreading are computed. The source excitation terms are defined at a selected reference distance with a magnitude independent roll-off spectral parameter, keff = 0.04s and with a Brune stress drop parameter increasing with moment magnitude ranging from 2MPa for Mw =2.0 to 13 MPa for Mw = 4.5. For the larger magnitudes outside the range available in the calibration dataset where we do not have recorded data we extrapolate our results through the calibration of the stress parameters of the Brune source spectrum over a ground motion prediction equation selected as a reference model. Finally, the weak-motion based model parameters values computed in this study are used through the Random Vibration Theory in order to predict a set of region specific spectral ground motion parameters (Peak Ground Acceleration PGA, Peak Ground Velocity PGV, and 0.3, and 1.0, and 3.3 Hz Spectral Acceleration SA) relative to the generic rock site as a function of distance between 10 and 250 km and magnitude between M2.0 and M7.0. More details related to this study can be found in D'Amico et al. (2018).

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ESC2018-S30-614

ATTENUATION OF BODY WAVES IN THE ELBRUS VOLCANIC CENTER AND ON SURROUNDING TERRITORIES

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The territory of the North Caucasus, being part of the extended Crimea-Caucasus-Kopetdag zone of the Iran-Caucasus-Anatolian seismic region, is characterized by the highest seismic hazard in the European part of Russia. As a complementary to seismic hazard several active volcanic centers are known in Northern Caucasus. The largest volcanic center featuring the Elbrus volcano is characterized by high population density, developed infrastructure and economic activity as well as tourism. Results of recent studies designate the Elbrus volcano as is still in active status. The Elbrus volcanic center is also the area of potential seismic hazard. Both types of hazardous activity have been manifested repeatedly during the Holocene and in the Late Pleistocene. At the same time, extended intervals of recurrence of strong earthquakes and catastrophic eruptions may be the cause of Elbrus's actual quiet state and can be associated with the special rheological conditions of the earth's crust. One may suggest, that the accumulation of significant stresses in the earth's crust does not occur because of the extensive crustal magmatic pocket. At the same time, the lack of strong actual seismicity may indicate the emergence of the potential for an explosive volcanic eruption of mount Elbrus. Seismic hazard is naturally estimated by the map of the "General Seismic Zoning of Northern Eurasia" (OSR-97) and is characterized mainly by 8 and 9-levels of seismic intensity (on average soils in terms of the MSK-64 scale). The study of the attenuation of seismic waves with distance provides fundamental information on the inelasticity and scattering properties of the earth's environment, as well as the actual attenuation properties in a particular region. Information on the intensity of attenuation of seismic waves is also necessary for the estimation of focal spectra, seismic energy, seismic moments and other focal parameters of

earthquakes, for modeling possible strong ground motions, etc. The attenuation of the amplitudes with distance includes two effects-the total energy losses of the wave for absorption (inelastic losses) and the divergence. By divergence we mean the decrease of the amplitudes with the hypocentral distance which occurs not only because of the geometric spreading (increase in the surface of the wavefront) but also by conversion on the earth's surface, by reflection loss during the passage of the refracting boundaries, and by the influence of the focus orientation. In this article, such fundamental problems as the relative role of the actual path (ray) and ground-and-geological conditions near the site (site effect) have not been studied. The quantitative estimate of the absorption has been carried out. The following methods were used for calculations: 1. Method of simultaneous determination of the absorption coefficient and divergence by means of amplitude curves. The divergence of the direct waves is described by an exponential function with a variable exponent n (r); however, insufficiently detailed experimental data on the amplitude variation with distance are forced to describe the divergence with the help of a constant n. 2. Observations of changes in the shape of the spectrum of earthquake records with distance were used to estimate the absorption regardless of the discrepancy. The initial data is the catalog of earthquakes in the North-Western Caucasus, obtained in the results of instrumental observations of the network of seismic stations of FRC GS RAS. For work, earthquake records recorded from 2013 to 2018 were selected. The signal-to-noise ratio was more than three. All the recorded earthquakes are upper crusts and their depths do not exceed 40 km. Hypocentral distances up to 100 km, local magnitudes ML = 1.6-5.5 As a result of the study, a summary table of the absorption coefficients determined by different methods was obtained. The attenuation of body waves and the quality factor Q is estimated. The values obtained were compared with those calculated earlier by other authors for other seismically active regions of Russia and the World. The results of the study of the attenuation of seismic waves in the environment make it possible to clarify the spatial configuration of local fluid-magmatic structures, based on the information that high absorption of secondary waves is observed in volcanic regions, which may be due to volumes partially filled with melts. This work was carried out with the financial support of the grant of the President of the Russian Federation for the support of scientific schools No. SS 5545.2018.5.

ESC2018-S30-620

ANISOTROPY OF ATTENUATION OF HIGH-FREQUENCY BODY WAVES IN THE SOUTHERN EXTERNAL DINARIDES

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The Dinarides are a part of the complex Alpine–Carpathian–Dinaric orogenic system characterised by NW trend and SW vergence of compressional and imbricated structures. The External Dinarides, their western part, is derived from the Adriatic microplate, i.e. the Adriatic carbonate platform. Recent seismicity in the area varies from moderate to high with the rare occurrence of strong earthquakes. Prevailing compressional stresses result in mainly reverse faulting, with or without a dextral strike-slip component. The southern part of the External Dinarides is the seismically most active area in the External Dinarides, where one of the strongest events occurred: Ston–Slano (1996, ML = 6.0), Montenegro (1979, Mw = 7.1) and Dubrovnik (1667, IX EMS). Therefore, the area shows one of the highest seismic hazard in Croatia. The extended coda normalization method was applied to local earthquakes' high-frequency body waves in order to estimate attenuation of direct P- and S-waves, i.e. the quality factors QP and QS. The preliminary results of the azimuthal analysis of the attenuation factors clearly indicate anisotropy of seismic attenuation in the high-frequency range, with higher attenuation in the direction perpendicular to the strike of the Dinarides and lower attenuation parallel to it. These quality factors reflect the total attenuation of the direct body waves in the crust and therefore reflect its features. Furthermore, these results indicate strong attenuation of the direct P- and S-waves in general.

ESC2018-S30-662

CAN WE TRUST IN HIGH-FREQUENCY CONTENT OF ACCELEROMETRIC DATABASE SIGNALS?

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The high frequency content of ground motion records has become an increasingly important topic in the last decade within the seismological engineering community. The way in which high frequencies are estimated within a site-specific seismic hazard study can have a high impact on ground motion level to consider. A lot of studies, involving kappa parameter concept, scattering analysis, etc., are using the high frequency part of the accelerometric signals provided by seismological networks. However, can we trust in these high frequencies? Are they reflecting the physical phenomenon these studies attempt to model? In addition, are the station metadata provided by accelerometric network websites complete enough to allow an accurate high frequency analysis? In this paper, we will present several cases where the high frequency content of accelerograms can be biased or modified by various factors. Of course, the presence of a local, shallow and thin soft layer (as for example a weathered zone) can induce a high frequency amplification. Recordings of stations that are installed in manholes on small concrete slabs may be biased by the resonance frequency of the slabs themselves that could lead to high frequency amplification up to a factor of two or three. The depth of station installation also has an important impact on the response of the station because of the up- and down-going wave interferences. This phenomenon is well known but numerous accelerometric stations (for example in France) are installed in tunnels, without any information about the height of the soil column above the station being reported as part of station metadata. We emphasize the need to improve the accelerometric station characterization, not only in terms of soil profile determination, but also in terms of depth of installation, coupling methods, etc., and the corresponding information dissemination through web services to allow scientists a better use and comprehension of high frequency content of ground motions.

ESC2018-S30-707

EARTHQUAKE DIRECTIVITY AND ITS ADVERSE EFFECT ON ATTENUATION VALUES DERIVED FROM SEISMIC SPECTRA

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The shape of the earthquake source spectrum has strong spatial variation, particularly in the case of source directivity. Numerical models have long suggested that the source corner frequency and spectral falloff rate should vary across the focal sphere, and observational studies also support this behaviour. Additionally, the source spectral falloff rate can differ quite markedly from the omega-square decay. However, studies that derive attenuation parameters from seismic spectra assume that the spectral shape is constant around the focal sphere, and that source displacement spectra have an omega-square decay above a characteristic corner frequency. Using synthetic examples, we show the degree to which attenuation values can theoretically be biased as a result of source directivity. We then examine aftershocks of the November 2016 Mw7.8 Kaikoura, New Zealand Earthquake, to determine whether these biases can be observed in recorded earthquake data. We also test whether calculating spectra from earthquake coda mitigates the adverse effects of source directivity on attenuation values. Some recommendations are provided for future estimation.

ESC2018-S30-716

A SIMPLE ANISOTROPIC MODEL OF MACROSEISMIC FIELD

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We present a simple model of anisotropic macroseismic field for the small and moderate earthquakes and a new method for model validation. The model has been developed for the sites with uniform soil conditions, which are characteristic for the Outer Dinarides area, so it does not take into account the soil effects. It is based on an assumption that local and regional geological structures such as the fluid saturated

fault zones modulate the isotropic macroseismic field. The model also assumes a point source with an isotropic radiation pattern and energy transfer by the S waves [1]. The attenuation function of intensity was Koevesligethy's function [2] modified with an additional distance in attenuation term. The added term depends on spatial distribution and the average width of the fault zones as well as the attenuation coefficient inside fault zones. The map of faults is used as the main input. Since the average fault zone width depends on the map scale, the model introduced is valid for the input map only. Fault zones can decrease macroseismic intensity by decreasing amplitude and by changing spectrum of the wave, since the rupture in the rock acts as a low-pass filter. The coefficient of attenuation of the basic rock was calculated from a teaching set in which the coefficient of attenuation inside the fault zones was estimated from the published values of quality factors and velocities of S waves [3]. Although the computed macroseismic field appears quite similar to the empirical one, a visual method is not appropriate for the comparison of results in graphic form. Also, the standard statistical tests like t- and F-test are not sensitive enough for such rough data as intensities. In order to demonstrate how good the model is, the pattern recognition approach for comparation of the isoseismal maps was applied [4]. The introduced method compares two isoseismal maps by using affine transformations of the isoseismal images. Ten empirical isoseismal maps were compared with the isoseismals computed by using the model proposed in this work and also by isotropic circular model. Results obtained show that the isoseismals computed by proposed model are 31.4% more similar to the empirical ones than the isoseismals obtained by isotropic circular model [5]. References

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ESC2018-S30-831

INTRINSIC AND SCATTERING ATTENUATION OF HIGH-FREQUENCY S-WAVES IN THE SOUTHERN PART OF THE EXTERNAL DINARIDES

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The southern part of the External Dinarides (SED) is a geologically and tectonically complex region formed in the collision between the Adriatic microplate and the European plate. The area is characterised by moderate to high seismicity with the rare occurrence of strong earthquakes. Previous studies on coda and direct body waves attenuation for the area suggest highly attenuating crust. In order to estimate the contributions of the intrinsic and the scattering attenuation (1/Qi and 1/Qsc) to the total S-wave attenuation, we applied the multiple lapse-time window analysis (MLTWA method). The method is based on the assumptions of multiple isotropic scattering in a homogeneous medium with uniformly distributed scatterers. We analysed events with hypocentral distances between 20 and 90 km and local magnitudes greater than 2.0 recorded on the broadband stations of Croatian Seismological Network in the SED area. Results show seismic albedo less than 0.5, as well as 1/Qi > 1/Qsc, therefore implying the intrinsic attenuation as the dominant process of S-waves energy loss in the study area. The results are very similar to the ones obtained for the northern and especially for the central part of the External Dinarides.

ESC2018-S30-920

HIGH FREQUENCY ATTENUATION FOR THE BODRUM PENINSULA, MUGLA, TURKEY

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A strong motion network is in operation at the Bodrum Peninsula since 2015.The 20 July 2017 Earthquake (Mw6.6) and its following aftershocks are well recorded by five strong motion stations deployed very close to epicenter.Such a rich dataset provides opportunities to investigate horizontal spectral decay parameter kappa(κ). The motivation of the study has risen from the fact that, to authors' knowledge, no study is available estimating the spectral attenuation parameters at this region with a reasonably large strong motion data set. In this studynear surface attenuation parameter kappa (κ) of S-waves is calculated from more than 50 earthquake acceleration recordings with magnitudes (Ml) from 3.5-6.6 occurred within 200 km epicentral distances.Anderson-Hough method is used with newly proposed constrains for spectrum processing. Analysis is performed for each component of acceleration spectra separately. High frequency portion of S-wave acceleration spectra from each recording is visually detected and kappa is computed. Path dependent (κ_R)and site dependent (κ_0)components of κ are calculated from epicentral distance (Repi)-κ correlations.Correlation of kappa to source-station dependent variables as well as strong motion parameters is discussed and consistency of these results with other studies available in literature is investigated.Estimated κ0 values are found to range from 20-40.0 ms for soil sites. Ground motion intensity measures of the 2017 Bodrum-Kos Earthquake (Mw=6.6) at five stations are calculated throughrecent ground motion prediction equations (GMPE) taking into account κ0 effects. Estimations are compared with those recorded at the network. This paper will present and discuss the results of this study. The research for this paper is supported by Boğaziçi University Research Fund Grant Number 10260.

ESC2018-S30-922

HIGH-FREQUENCY ATTENUATION (KAPPA, K) ESTIMATIONS FROM THE RECENTLY-COMPILED-TURKEY STRONG GROUND MOTION DATABASE FOR WESTERN TURKEY

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Modeling of near-surface attenuation has significance in a wide range of seismological applications such as site characterization, site-specific hazard assessment for critical facilities and ground motion predictions. Kappa (k) factor is often used to represent the rate of the attenuation in spectral amplitudes at high frequencies (f > 10 Hz) and it is also one of the essential parameters for stochastic strong ground motion simulation method. Although the origin and physical components of k is still under debate, it is considered to be a combination of site and path effects. Moreover, a source component could also contribute to variability in kappa estimates. Zero-distance kappa value (k0) is computed as an indicator of the spectral attenuation due to top soil layers, eliminating the path effects. In this study, we used the recently-complied strong ground motion database of Turkey which consists of records from mostly small and moderate-size earthquakes with a smaller number of records from large events. k factors are manually computed from the S-wave portion of both horizontal and vertical components for each record as we observed variations in k values for different components. Next, magnitude and epicentral distance dependence of the k values are studied. We use multivariate linear regression analyses to describe the relationships between the studied kappa dataset and selected independent variables such as the site class, distance and magnitude. Kappa estimates reveal that there is a significant scattering at the majority of the investigated sites. The scattering of these initial kappa estimates could be attributed to the influence of the source and wave propagation effects associated with the complex tectonic structure of the region.

ESC2018-S30-950

ON THE EFFECT OF NOISE ON KAPPA ESTIMATION

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The amplitude of the Fourier acceleration spectrum decays rapidly at high frequencies. This has been modeled by the parameter Kr (Anderson

and Hough, 1984). The site-specific component of Kr, named K0, describes the contribution of the first few km of the geological profile beneath a certain site. K0 is an important parameter in characterizing high-frequency ground motion, crucial for certain structures such as nuclear facilities and small concrete dams. Large scatter has been observed in the values of K0 published in literature, which may be due to different analysts, different approaches and frequency bands used for its estimation, and the different regions data may come from, the trade-offs with the source (stress drop) or the site (amplification). As it is the case with any parameter estimation problem, the presence of noise in the data constitutes an important factor of uncertainty in the obtained estimates. Nevertheless, despite the extensive research on the topic of kappa, a detailed study treating the impact of noise on the problem of kappa estimation is missing from the literature. This is exactly the goal of the present work. To this end, we conducted a series of experiments using various synthetic noise models, both correlated and uncorrelated, as well as noise from real records. The kappa estimations were based on 'noisy' versions of a high-quality real dataset. We used recordings from an accelerometric downhole array in the Corinth Gulf, Greece, whose high sampling rate and high SNR render it 'best-case' scenario in practice. Kappa estimates obtained from this 'pure' dataset constituted our control sample. The results confirm our belief that the present study constitutes a significant step towards the ultimate goal of quantifying the effect of noise on the estimation of kappa and correcting for the biases it introduces on the obtained estimates.

ESC2018-S30-982

GRONINGEN NEAR-SURFACE Q

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The Netherlands is host to gas fields that are seismically active. The production of gas and the resulting pressure depletion in these reservoirs may lead to differential compaction and reactivation of existing faults. By far most seismicity is induced in the largest gas field of northwestern Europe: the Groningen gas field.
Seismic waves induced near the reservoir level (about 3 km depth) are amplified near the Earth's surface, while propagating through an ~800 m thick blanket of sediments. This amplification, which is well described by a field-wide model based on non-linear site response analyses, geological information, borehole and passive seismic data, is somewhat inhibited by energy loss of the incoming waves due to scattering and anelastic attenuation. Quantification of these losses is an important constituent for the hazard assessment. Seismicity in the Groningen area is monitored primarily with a network of vertical arrays. In the nineties a network of 8 boreholes was deployed. Since 2015, this network has been expanded with 70 new boreholes. Each new borehole site consists of an accelerometer at the surface and four downhole geophones with a vertical spacing of 50 m. With these vertical arrays we can well isolate the wave propagation in the near surface. We apply 3 different techniques to estimate anelastic losses (intrinsic Q) in a high frequency band (1 to 30 Hz): 1. We apply seismic interferometry by deconvolution to isolate propagation between the various depth levels in the near surface. Subsequently, we estimate effective Q from the amplitude reduction on the direct waves and apply a scattering correction to obtain intrinsic Q. 2. For a few large earthquakes we estimate t-star at different depth levels, and invert from these the intrinsic losses between the depth levels. 3. For prominent noise sources we estimate surface-wave attenuation away from the sources. From this attenuation we invert for intrinsic Q. We compare the results from the different methods and analyze which underlying assumptions best hold in this unconsolidated sedimentary setting.

ESC2018-S30-1017

REVISITING CLASSICAL HARD-ROCK K0 VALUES FROM THE CENTRAL US

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At high frequencies, the Fourier amplitude spectrum (FAS) of acceleration decays rapidly.

Anderson and Hough (1984) introduced the spectral decay factor (K) to model the rate of this decay. Its site-specific component, K0, comes from attenuation over the top few km of the crust, and is an important input parameter in the simulation and prediction of ground motion. In addition to amplification effects, K0 is the principal site parameter controlling the limitation of high frequencies (>5 Hz) at close-in distances (out to ~50 km), and thus is important in characterizing strong ground motions for engineering design, particularly in regions of sparse seismicity. Current uncertainty in the estimation of K0 is high. In practice, this can have significant implications on seismic risk for safety-related equipment in nuclear facilities, and for the seismic behaviour of small concrete dams. Considering typical values of K0 from literature, analytical studies suggest large increases in response spectra at high frequencies (> 10 Hz) for hard-rock sites in CEUS compared to soft-rock sites in the WUS. Yet observed ground motions suggest less of an increase (Ktenidou et al., 2016; 2017). Within this context, we revisit some of the data used in the 1990s to investigate again the values of K0 that are currently considered as typical for hard rock. We apply a range of estimation methods including broadband and band-limited approaches, and we investigate method convergence, the range of K0 values obtained, and the resulting uncertainty. We also discuss issues encountered, such as source corner frequency/stress drop, high-frequency amplification effects, instrument response effects, and usable bandwidth.

ESC2018-S30-1046

EFFECT OF SOIL-STRUCTURE INTERACTION ON THE HIGH-FREQUENCY SPECTRAL DECAY PARAMETER K

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The high-frequency spectral decay parameter K, introduced by Anderson and Hough (1984), is a frequently used parameter for many applications in Engineering Seismology such as prediction and adjustment of ground motion, generation of synthetic ground motions, etc. The site component of K, namely K0, has been correlated with different site characterization parameters, such as the average shear wave velocity at the top 30 m (Vs,30) and the resonant frequency (fres). Vs,30 is widely used in building codes for site classification so that appropriate design response spectra are adopted for a site. Soil-structure interaction (SSI) has long been an open research topic in the engineering community. Seismic SSI refers to the effect of the foundation soil on structural response and vice versa during an earthquake. One of the main consequences of SSI is to modify seismic ground motion at the base of the foundation with respect to the free field, ground surface seismic excitation (kinematic SSI). This modification consists of a high-frequency filtering effect on the incident seismic waves and the development of rotational components, to an extent that depends on the foundation depth/area, the angle of incidence and coherence of seismic waves, and soil rigidity (kinematic SSI is more pronounced at soft soil sites for buildings with at least one underground floor). The Greek National Accelerometric Network run by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) includes not only free-field stations, but also several instruments installed in building basements/ground floors. Most stations lie on soft or hard soil sites, classified as B or C per EN 1998-1 (Eurocode 8). The motions recorded at the base of such structures are modified with respect to the corresponding free field motion. This study attempts to compute and compare K at the building base and nearby free-field stations, to assess the effect of SSI on the spectral decay at high frequencies. To this end, several accelerometric stations are studied, including instruments inside and outside buildings at close distances, and various characteristics of the buildings and soil profiles are considered. The consequences of modification of K on various engineering applications are discussed.

ESC2018-S30-1053

TOWARDS A BETTER PHYSICAL INTERPRETATION OF THE KAPPA PARAMETER: EMPIRICAL AND NUMERICAL INVESTIGATIONS AND APPLICATION IN A HOST-TO-TARGET STUDY

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The goal of our project is to link seismological approaches of the waves attenuation (elastic and anelastic) and engineering ones, which often use a parameter called Kappa. Anderson and Hough (1984) introduced the Kappa parameter as representative of the attenuation of the seismic wavefield emitted by the source and travelling to the recording site through the crust and superficial geological layers. Kappa is directly measured on the seismic signal at high frequency. Anderson and Hough (1984) decomposed Kappa in local (K0) and regional attenuation (KR), respectively. In the last years, the K0 parameter has become important in engineering seismology, in particular to take into account local site conditions in ground motion prediction studies. Our project sponsored by the French RESIF-RAP organization is composed of three main parts that will be presented at the time of the meeting. The first two parts aim at better understanding the physical meaning of the Kappa parameter, using both empirical and numerical approaches, through a comparison of Kappa values and attenuation properties of the medium. The third part is devoted to explore the importance of Kappa values in an engineering application. We first applied the approach of Anderson and Hough (1984) to assess Kappa at some stations located in mainland France. The seismotectonic regime of the region under study is mainly characterized by small-to-moderate activity. We possibly also extend our exploration in more seismic active regions. As a first outcome, values of K0 and KR can be compared to intrinsic attenuation (e.g., Mayor et al., 2017 for France). Since the attenuation is the combination of scattering (elastic attenuation) and absorption (anelastic or intrinsic attenuation) as illustrated in the pioneering work of Aki & Chouet (1975), we also look at the dependency of Kappa (K0 and KR) to intrinsic attenuation and scattering through numerical simulations of seismic wave propagation. To reach this goal, we study the waves emitted by point sources at depth and recorded at the free surface for different properties of the propagation media. Seismic wave propagation is either numerically simulated in 2D (PSV and SH) or 3D. Finally, in an engineering perspective and using values of Kappa determined in the first part, we use the Kappa parameter in a host-to-target study around the city of Nice, located in the southeast of France. By selecting various GMPEs, we compute site-specific response spectra following the approach of Al Atik et al. (2014). We test different hypotheses regarding the use of K and assess their influence on the final spectra. The resulting computed-spectra are compared with spectra obtained from seismograms of different earthquakes recorded both at rock and sediment stations.

ESC2018-S30-1059

ESTIMATION OF KAPPA (K) AND QUALITY FACTOR (Q) FOR THE REGION OF ISTANBUL

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We attempt to estimate parameters that are related to path and near-surface effects caused by earthquakes associated with the northern strand of the North Anatolian Fault in the Marmara Sea region, by drawing on data from the Istanbul Earthquake Rapid Response System (IERRS) that is operated by the Department of Earthquake Engineering at Bogaziçi University's Kandilli Observatory and Earthquake Research Institute. Our data set includes over 4000 strong motion recordings from 116 stations of the IERRS. The records are associated with events having local magnitudes ranging within 4.0

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SESSION 31

ESC2018-S31-55

SELF-CENTERING SMA-REINFORCED CONCRETE STRUCTURES

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The need to develop resilient structures that can respond to seismic events is being driven by the research and engineering communities, and by stakeholders given what appears to be increased high seismic activity on a global stage. In response, new structural systems and emerging materials have been suggested as potential alternatives to the current conventional structural solutions. Over the last decade, one such material that has gained interest by researchers is Shape Memory Alloys (SMAs). This material can provide two distinctive responses that is contingent on the intended application. SMAs are used either in the Shape Memory form, where an external heat source is required to initiate a recovery of residual strains in the material, or as a Superelastic (SE) material, where the recovery of strains initiatives during the unloading phase. Shape Memory SMAs can be used to develop active prestressing in a structural element. The material is first prestrained and then applied, for example, as internal reinforcement in beams or as external spirals in columns. Thereafter, either an electric current or heat source is applied directly to the material triggering a recovery of the prestrain. The recovery is restrained by the concrete, causing the SMA to develop tensile stresses and the concrete to experience compressive stresses. For reinforced concrete applications, the majority of research with Superelastic SMAs has focused on using the material as the principal reinforcement in

ESC2018-S31-59

EFFECTS OF SOIL MODELLING IN SIMULATION OF SOIL STRUCTURE INTERACTION

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In order to simplify the mathematical problem, in the analysis of structures subjected to earthquake forces, it is usually assumed that the structure is fixed which leads to error in overall response of dynamic loads. It is the soil structure interaction which favors the behavior of the structural system under earthquake excitations. The soil structure interaction phenomenon is basically affected by the energy exchange between the soil and the structure during the earthquake excitations. The inclusion of the soil structure interaction effects influences the results considerably in both positive and negative ways. In analysing frame structures considering the earthquake acceleration Input as time dependent acceleration there has been significant advances in softwares. The missing point however has been the treatment of soil structure interaction SSI effects considering the presence of soil medium. The past earthquakes have shown that the seismic response of a structure is considerably influenced by the soil structure interaction. The main difficulty in the soil-structure interaction problems is the correct numerical simulation of the soil media and its interaction with the structure standing on it. Simulation of soil medium as linear elastic material simplifies and decreases the correctness of the simulation results. In recent years the development of computers has enabled the usage of sophisticated computer programs for numerical non-linear simulation of soil media. In this work three types of soil are taken into consideration as hard, medium dense and soft soils as stated in Eurocode 8 part 1. In order to examine the SSI effects on the structural rigidity, RC models of one, three and five storey frames are modelled and time history analysis is performed. In the analysis soil medium is subjected to acceleration time history of Imperial Valley EQ, El Centro record, 1940-May-18 (El Centro) earthquake. Coupled soil-structure system is subjected to acceleration time history and the results of structural response are compared accordingly. The dynamic analysis is done by using the general finite element program ANSYS where it is possible modelling of both soil and structure and taking into consideration the soil-structure interaction. The variation in structural response for acceleration, displacements and internal forces are presented and comparisons are made accordingly.

ESC2018-S31-86

SEISMIC BEHAVIOUR OF RUBBERISED CONCRETE FILLED STEEL COLUMN FRAMES

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The reuse of solid waste is now a subject of critical importance in developed societies. Scrap tyres are just one example of solid waste demanding special attention. It is estimated that about 300 million scrap tyres reach their end-of-life each year in the European Union. One of the possible ways of using recycled rubber from car tyres is through its application in the development of new construction materials. In this seminar, a research study will be presented that aimed at evaluating the feasibility of using rubberized concrete in composite steel-concrete tubular solutions for seismic resistance. The research comprised an experimental campaign carried out on concrete-filled steel tubular (CFST) elements made with conventional and rubberized concrete, subjected to monotonic and cyclic bending conditions. The test results revealed that the hysteretic flexural behaviour of CFSTs is practically insensitive to the type of concrete. The results were then employed on the calibration of 3D detailed FE models developed in ABAQUS. Parametric studies were performed aiming at i) the characterization of the effects of multi-axial stress states on the behaviour of concrete and steel materials and at ii) the evaluation of the cross-section slenderness limits prescribed in Eurocode 8 and AISC 341 provisions. The results of these studies led to the proposal of an improved procedure for the evaluation of the cross-sectional resistance of CFST elements subjected to combined compression with bending. The presentation will conclude with a comparative study of the seismic performance of composite moment-resisting frame buildings made with CFST elements and conventional steel moment frame buildings. The results obtained indicate that, in addition to contribute to a more sustainable environment, composite lateral loading resisting systems made with rubberized concrete are an attractive solution for structures located in high seismicity regions.

ESC2018-S31-89

PRE-DESIGN OF EXPERIMENT ON OUT-OF-PLANE BEHAVIOUR OF FRAMED-MASONRY WALLS WITH OPENINGS

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Structural systems of seismically sensitive high story buildings are commonly consisted of either reinforced concrete or structural steel frames infilled with masonry walls/panels that can contain various openings. When subjected to seismic action, frames behavior is affected with additional stiffening from the infill wall. It is common to divide the frame – infill interaction to: in-plane, out-of-plane and their interaction. The in-plane research has systematically studied the inclusion of openings in regards to its size, position and confinement. It has been shown that openings do affect failure mechanism, ductility and the capacity of frames for the in-plane interaction. However, in the case of out-of-plane interaction, the effects of openings are still unknown as the field itself is less studied in comparison to in-plane research. There is no systematic study on out-of-plane behavior of infill walls considering various openings sizes, placements and confinements. This paper reviews out-of-plane experimental tests that have separately considered openings as: window, door and full high opening. Test setup (e.g. loading regime, measuring points), frames & infills geometrical and mechanical characteristics, and study findings are examined and summarized. Additionally, supplementary tests without openings are reviewed in order to design experiments that will be conducted by authors in part of the research project FRAme-MAsonry Composites for Modelling and Standardization (HRZZ-IP-2013-11-3013). In counterbalance with the majority of out-of-plane experimental setups - conducted with airbags to add loading only to the infill walls, the designed experiment will utilize the frame. The method to be applied resembles the realistic seismic actions where the frame is also loaded. The same is done in in-plane tests (frame – beam loading) and out-of-plane tests on shaking tables. The studies will be carried out on 1:2.5 scaled specimens with door and window openings

positioned centrically and eccentrically in the clay block infill walls surrounded by RC frame.

ESC2018-S31-193

VISCOUS DAMPER DESIGN CONSIDERING SOIL-STRUCTURE INTERACTION

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In building design, infrastructure and superstructure are sometimes handled independently of each other. Only superstructure design using terms remain missing. The optimization research of the viscous dampers has a trend that has risen in recent years. In studies conducted in this respect, the supports of building models are generally regarded as rigid. The design of the dampers, which finds the place and the amount of the dampers, is based on these principles. Soil effects are ignored. In this study, while the optimum design of the viscous dampers was made, the optimum damping distribution of the structure interaction model was investigated. This study reveals the effect of relative density of sandy soils on the damper problems. The optimal distribution of viscous dampers and the effect of relative density of sandy soils for an n-storey shear-building model are examined. The objective function which is the sum of the damping coefficients of dampers at each storey is minimized under the some constraints. While the passive constraints are taken as upper and lower limit of each damper, active constraints are considered as a target damping ratio in terms of the damping coefficients. Proposed algorithm includes time history analyses that test the candidate optimal design. Interstorey drift ratios under the design earthquake are checked in a design step. Fundamental mode response is considered in calculating the added damping. The optimal design corresponding to the first mode of structure is found and then the time history analyses are tested by using El Centro (NS) earthquake acceleration record. The effect of relative density of sandy soils on the responses of structure with optimal design and the effect of the variation of total damper capacity used in the optimization stage are investigated. Considering three types of sandy soil types, which are dense sand, medium dense sand and loose sand, the optimum damper designs are found for each situation. The effect of the upper limit of the damper capacity on the damper design is investigated to guide the production standard of the dampers. According to the results obtained in the study, it is possible to eliminate the negative effects of the ground on the structural behaviour by placing the dampers. The results of analyses have shown that the soil effects should be taken into account in the damper optimization problems. Keywords: Soil-structure interaction, viscous dampers, optimal dampers, earthquake response

ESC2018-S31-202

MONITORING SEISMIC DAMAGES IN CONCRETE DAMS USING PZT SENSOR NETWORK

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A novel methodology of monitoring the seismic damages in concrete dams detection system is presented by using of the distributed PZT sensor network. The PZT sensor was developed to measure the dynamic stress during the earthquake in a real-time manner, as well as to actuate the stress wave in the dam. And then the actuator–sensor network was formed by embedding the PZT transducers in the dam. To achieve the distributed detection of the seismic damage, the placement of the PZT transduces was proposed in the dam. The scaled model tests on the shaking table were performed to investigate the feasibility of the presented method. By analyzing the sensor signals, the occurrence and development of the structural damages could be monitored timely. A damage index matrix was presented to evaluate the damage status of the dam in different paths. The experimental results indicate that the distributed PZT sensor network can monitor the seismic damages in the concrete dam caused by the strong ground motion.

ESC2018-S31-208

STRUCTURAL HEALTH MONITORING OF THE KURPSAI DAM IN THE KYRGYZ REPUBLIC

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Plans to construct hydroelectric dams in the Kyrgyz Republic and the need to assess the state of existing structures, especially with respect to earthquakes and landslides, requires structural and slope monitoring systems that provide fast and robust information to decision makers in the event of emergencies. The project MI-DAM (Multi-parameter monitoring and risk assessment of hydro-electric dams in the Kyrgyz Republic) aims at developing, installing and testing a robust, cost-effective and flexible monitoring system for the Kurpsai Hydropower Station (HPS) in Kyrgyzstan including a multi-parameter risk assessment due to earthquakes and landslides. The concept of SHM on the Kurpsai dam in the MI-DAM project distinguishes two time scales: the long-term monitoring of static deformations over days, months and years and the short-term monitoring of structural response to earthquake shocks and extreme operational regimes. The long-term monitoring includes a combination of three different techniques, i.e. (1) absolute static displacements measured by special GPS sensors placed on each block on the dam crest, (2) opening of the slits between concrete blocks by the fibre optical strain sensors, (3) deformation measured by means of the Interferometric Synthetic Aperture Radar (InSAR). The short-term changes of the dam and the surrounding hillsides are monitored by means of multi-parameter sensors placed on selected characteristic points of the structure and surrounding based on a fully decentralised approach. Such approach allows for the fragility curves to be directly integrated into the on-site calculations, allowing some degree of decision-making without the necessity of a remote centre. Moreover, the continuous recording of seismic noise, i.e., the persistent vibration of the ground due to a multitude of natural and anthropogenic causes, allows for the continuous assessment of the mechanical characteristics of a dam (and hence, fragility curves) and/or landslide body and any changes therein. For example, considering landslides, the cross-correlation of seismic noise traces can allow the precise location of changes at the base of the sliding layer.

ESC2018-S31-264

PASSIVE ENERGY DISSIPATION SYSTEMS AND THEIR APPLICATIONS- A REVIEW

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During an earthquake, inertial forces are generated in structures forcing them to oscillate with amplitudes proportional to the input energy. If it is possible that an amount of this energy be dissipated during the motion of the structure, the seismic response could considerably be reduced. The behavior of structural systems when responding to seismic loads is mainly associated with the ability of the structural systems to dissipate the kinetic and the potential energy through hysteretic and viscous mechanisms of energy dissipation. Nowadays, there is a wide range of systems for dissipating input energy in the structures, and their selection depends on the primary structural system of the building, the main external forces that they need to resist, and the performance criteria that the building needs to meet. The current available damping systems can be subdivided into two main categories: passive and active systems. The passive systems work without application of additional external energy, as it is case for active control systems. In these systems, irrespective of whether they are dynamic absorbers of vibrations or systems for additional energy dissipation or even seismic isolation systems, the controlling forces develop at the locations of installation of the mechanism itself. The power necessary for generation of these forces is provided through the motion of the mechanism during the dynamic excitation. The relative motion of the mechanism defines the amplitude and the direction of the controlling force. The primary use of energy dissipation devices is to reduce earthquake displacement of the structure. Energy dissipation devices will also reduce force in the structure provided the structure is responding elastically but would not be expected to reduce force in structures that are responding beyond yield. For most applications, energy dissipation provides an alternative approach to conventional stiffening and strengthening schemes, and would be expected to achieve comparable performance levels. In

general, these devices would be expected to be good candidates for projects that have a target Building Performance Level of Life Safety or perhaps Immediate Occupancy, but would be expected to have only limited applicability to projects with a target Building Performance Level of Collapse Prevention. Other objectives may also influence the decision to use energy dissipation devices since these devices can also be useful for control of building response due to small earthquakes, wind, or mechanical load. Large number of different passive systems is developed and part of them are used successfully in real structures. Their efficiency is conformed during wind load and earthquakes. In this paper will be reviewed different types of passive control systems and their practical usage in designing new structures and retrofit old ones.

ESC2018-S31-278

A TEXTILE RETROFITTING SYSTEM WITH A SOFT POLYURETHANE MATRIX -DYNAMIC TESTING AND NUMERICAL SIMULATION

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An innovative textile retrofitting for masonry under seismic loading is introduced. The key feature of the system is its very soft water based polyurethane matrix which enables high load transfer by minimizing shear stress peaks transferred to the brittle substrate. A test program consisting of dynamically loaded masonry walls under out-of-plane action is discussed. Textile retrofitted and bare walls are simultaneously tested to compare their performance. A 2D modeling approach on mesoscale with Abaqus is introduced, reducing the test setup to a one-way bending situation. This model focuses on the modeling of bond between the textile retrofitting system and the substrate. Discrete cracking is implemented by defining contact states between bricks. The results of the numerical simulation agree well with respect to the maximum input acceleration, failure mode and displacements. The model makes it possible to estimate the degree of utilization for the masonry as well as for the textile retrofitting system.

ESC2018-S31-352

RECORDINGS OF ROTATIONAL MOTIONS RESULTING FROM ARTIFICIAL DETONATIONS BY SET OF FIBER-OPTIC ROTATIONAL SEISMOMETERS

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The topic of this paper deals with fiber-optic rotational seismometers suitable for rotational seismology. Rotational seismology is the rapidly developing direction in seismology and falls within rotational ground movements from earthquakes, explosions, and ambient vibrations [1]. These motions are interesting for several reasons [2]. They might have some effect on the rocking and torsion of engineering construction as well as on the distortion of long structures [3]. It can provide additional constraints on the seismic source as well [4]. In spite of growing popularity of the rotational seismology there are still lack of appropriate rotational sensors for its field application as well as collections of experimental data. None precise scientific field including rotational seismology is conceivable without measurements and real data processing. One can distinguish several technologies of rotational sensors, i. e. MEMS gyros [5], ring laser [6], mechanical systems basing on pendulum seismographs [7] or geophones [8, 9]. Nevertheless, rotational seismometers used in field application should meet a number of technical requirements forced by rotational seismology which one can find in paper [10]. The issue of data relatability is also very most significant. In order to gather reliable data one must apply at least two system designed according to the same technology, like for instance in well-known paper [11]. In order to meet the new directions of research in the field of rotational seismology the authors constructed two fiber-optic rotational seismometers named

Fibre-Optic System for Rotational Events& phenomena Monitoring (FOSREM). They are completely insensitive to linear motions due to utilization in their construction technical realization of the fibre loop interferometer detecting Sagnac effect. The electronic system, involving specific electronic solutions, calculates and records rotational events data by realizing synchronous detection. Storage data and system control are realized over the internet by using connection between FOSREM and GSM/GPS. The most significant attribute of FOSREM is possibility to measure rotation in wide range both amplitude up to 10 rad/s and frequency up to 328.12 Hz. Application of a wideband, low coherence and high power SLED with a long fibre loop and suitable low losses optical elements assures the theoretical sensitivity of the system equal to 2·10^-8 rad/s/√Hz. Moreover, the FOSREMs are fully remote controlled as well as is suited for continuous, autonomous work in very long period of time (weeks, months, even years), so they are useful for systematic seismological investigation at any place. Thus, they fully meet all technical requirements for rotational seismology. This work presents exemplary relevant measurements which were conducted using two FOSREMs in the geophysical observatory in Książ area, Poland. Mainly the near-field shocks were studied caused by microshocks. The measured ground rotational movements were generated by the artificial explosions by dynamite loads aimed at the execution of tourist tunnels leading to Książ castle in near field of the geophysical observatory. The obtained data have been comprised with results from a rotational mechanical seismometer named Twin Antiparallel Pendulum Seismometers (TAPS) which gives information about linear, as well as rotational movements. Moreover, meanwhile we also recorded tilt and torsion effects resulting from mining seismic quakes induced by copper ore mining operations. The obtained results show very good correlation between two FOSREMs which confirmed their records' reliability. Moreover, the calculated signals' maximal amplitude as well as energy using a method of rectangles of the Riemann integral indicated that tilt effects are rapider than torsions effects due to the tilt's source of generation, i. e. caving. The presented FOSREMs are appreciate for realizing the growing interest in rotational seismology by providing significant data. References

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ESC2018-S31-361

ANALYTICAL VERIFICATION OF RESULTS FROM FORCE VIBRATION TESTS BY ENHANCED FREQUENCY DOMAIN DECOMPOSITION METHOD

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Experimental identification of modal parameters (experimental modal analysis) is a research topic with fruitful six-decade history. There are two methodologies for identification of structural modal parameters. The first technique is known as forced vibration tests where simultaneous measurements of one or more dynamic excitation and the corresponding structural response is measured. The other methodology is ambient vibration technique which is more practical, economical and not time consuming. The presented paper aims at providing overview of the theoretical background behind obtaining information about the most important modal properties of any structure (mode shapes and

modal damping) using different techniques. Damping estimation using the well know half-power bandwidth and logarithmic decrement methods is briefly described. Also, modal estimation using Frequency Domain Decomposition (FDD) and Enhanced Frequency Domain Decomposition (EFDD) methods is given in more details. Due to feature limitations of commercial programs, a custom software has been developed in IZIIS. The main aim of the software is signal processing and operational modal analysis where FDD and EFDD methods are implemented. The aim of the developed custom application is to create a tool for signal processing and EFDD analysis. The main benefit of this application is ability to improve the methodology and to implement some additional parameters for obtaining a more reliable result. The algorithm is written in c+ language with full support for parallel processing. Graphical visualization of the input and output data is done in windows presentation foundation WPF environment. The application contains a full 3D graphical interface which is used for 3D mode shape presentation. The software is briefly described and its application in estimation of the dynamic properties of a nine-story reinforced concrete building is elaborated. Regarding the performed tests on the structure itself, forced vibration and ambient vibration tests have been performed. For the forced vibration testing, the structure was tested with 5 levels of masses in the shakers. Before and after each set of forced vibration testing 10 minute intervals of ambient vibrations were recorded. From the forced and ambient vibration methods the following dynamic parameters were obtained:

- Frequency response curves for the first three modes of vibration of the structure.
- Damping coefficient for each mode
- Identification of the mode shapes.

The results from ambient vibration tests were used to identify the first three natural frequencies and mode shapes of the structure using FDD method. On the other hand, results from the forced vibration tests were used to identify the first three natural frequencies of the structure as well as the mode shapes using the peak-picking method. Comparison of the results for the modal damping obtained experimentally by force vibration method and analytically by the EFDD method is given in the last part of the paper. There is a good matching in natural frequency, mode shapes and damping. The obtained results showed that the implemented methodology in custom computer algorithm calculated the modal parameter of the structures with a high accuracy.

ESC2018-S31-386

COMPARATIVE ANALYSIS OF DIFFERENT SEISMIC HAZARD MODELS FOR MACEDONIA

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A successful mitigation of physical damage and social and economic losses due to potential future earthquakes depends primarily on the reliable estimation of the seismic hazard and its strategic implementation in risk management policy and practices. The subject of this research is a comprehensive upgrade of the probabilistic seismic hazard for the Republic of Macedonia. An integral analysis of data from geological, tectonic, neo-tectonic and seismological investigations was combined with the existing regional seismic hazard studies, databases of national and regional strong motion records and GPS measurements in a qualitatively new approach for modeling of the spatial distribution of the seismicity. Three different analytical models for seismic hazard assessment were developed: gridded seismicity model (referred to as M1), zoned seismicity model with source delineation using the distribution of historical seismicity (M2), and analysis of seismotectonic features (M3). The standard seismic hazard parameters (λ, b and Mmax) in the M1 and M2 models were generated based on Kijko-Sellevol (1998) approach. The M3 model applied the method of spatially distributed seismicity (M3a; Frankel, 1995) and spatially-oriented seismicity (M3b; Lapajne et al., 2003), whereas b and Mmax were estimated traditionally from the available seismotectonic information in combination with GPS measurements. Four ground motion prediction equations: AB2012 (Akkar and Boomer, 2012), BA2008 (Boore and Atkinson, 2008), BINDI2009 (Bindi et al., 2009) and CF2008 (Cauzzi and Faccioli, 2008), recommended within the SHARE project (Segou and Akkar, 2010), were implemented as models suitable for the seismotectonic settings in Southern Europe. The analyses were performed for four distinct

exceedance probability levels: 10% in 10 years (return period of 95 years, referred to as RP95), 10% in 50 years (RP475), 2% in 50 years (RP2475), and 1% in 100 years (RP10000). Aggregation of the results was performed for each model separately with the "logic tree" approach combining the componential results derived from the four ground motion prediction models. An original approach was proposed for quantification of the weighting factors. The spatial distributions of all componential and final results were mapped into a regular 0.1 degree (10 km) grid. Hazard curves and deagregation diagrams were calculated and displayed for selected 15 discrete locations (downtown): Bitola, Veles, Gevgelija, Debar, Kavadarci, Kicevo, Kriva Palanka, Kumanovo, Ohrid, Pehchevo, Prilep, Skopje, Strumica, Tetovo and Stip. The major findings of the research are as follows:

o The results obtained by the model with gridded seismicity (M1) most adequately reproduce the current
knowledge of regional tectonics and kinematics;

o The method of spatially oriented smoothed seismicity (M3b), if solely applied, does not provide satisfactory results, especially in regions that are affected by high energy seismic sources (Pehchevo-Kresna, Skopje, Ohrid, Valandovo);

o A relatively low normalized historical seismicity was identified in the central part of the Vardar Zone, which, to some extent, redefines the general opinion that it is the primary carrier of seismicity in central Macedonia;

o The identified lack of normalized historical seismicity in the Kustendil - Kriva Palanka region, yet characterized with active faulting system, evidence of modern displacements (scarps, deflected rivers, etc.), and faults with well-developed or week morphological evidence of recent activity, may indicate potential kinematic interlocking. The research presented is a part of doctoral thesis: Salic, R. (2015). Advanced Approach to Seismic Hazard Assessment for Republic of Macedonia. Institute of Earthquake Engineering and Engineering Seismology (UKIM-IZIIS), Doctoral Dissertation, March, 2015.

ESC2018-S31-458

APPLICATION OF ENDURANCE-TIME METHOD IN SEISMIC QUALIFICATION TEST OF POWER SUBSTATION EQUIPMENT

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This paper explores the application of Endurance Time Method for shake table qualification of high-voltage substation equipment. In practice, shake table testing of substation equipment is performed at a number of steps, from low intensity up to the so called Required Response Spectrum (RRS), which is 50% of the qualification performance level suggested by IEEE 693-05 standard. The results of RRS motion are extrapolated (i.e., doubled) to obtain the performance at qualification level. The main issues with this procedure are: a) repeat of tests at different intensity levels can result in accumulation of damage leading to conservative evaluation results; b) repeat of tests is very costly; and c) shake table testing provides the performance at discrete intensity levels, while no information is available regarding the exact intensity associated with different damage states. To improve the evaluation procedure as well as to reduce shake table testing costs, this study suggests the use of intensifying motions specially optimized according to the concept of Endurance Time Method. By correlating the time variable of the motion to its intensity, seismic evaluation of equipment can be performed by only one test. The seismic demands recorded under this unique motion provides peak demands as a continuous function of intensity making it possible to: a) extrapolation the demands more accurately; b) observe initiation of nonlinearity in the response due to micro damages; c) accurately capture the intensities (i.e. times in this concept) at which certain damages occur; d) avoid accumulation of damage due to repetition of tests; and e) reduce the costs by reduction in the number of tests to one. This paper presents the procedure used to obtain Endurance Time motions satisfying all the IEEE 693-05 standard requirements and compares the resultant motions with the synthetic motions suggested by the standard. At the end, a practical example is presented on the application of this type of intensifying motions for seismic evaluation of substation equipment.

ESC2018-S31-495

STRENGTH AND STIFFNESS DETERIORATION MATERIAL INFLUENCE ON SEISMIC SHEAR DEMAND OF STEEL MOMENT FRAMES

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1 Introduction

The moment resisting frames (MRF) are one of the three main structural steel typologies used for seismic design of steel frames along with the concentrically and eccentrically braced frames (CBF and EBF). The MRFs are characterized as the most ductile structural type possessing a large number of possible dissipative zones, following the fact that plastic hinges can develop both in the beams and the columns. Possessing the feature of being the most ductile type, these structures exhibit very large deflections before the structural damage occurs. Additionally, the strength and stiffness deterioration of the steel material due to cyclic loading increases the effect of the lateral forces and represents the most realistic behaviour of this structural system. Hence, in this research study an improved approach using updated material model for evaluating the steel moment frames' behaviour is implemented in order to tackle the deficiency in the assessment of this type of structures. Using the finite element program OpenSees, a six story – three bay moment resisting frame is modelled and analysed. The focus of the examination is the base shear demand of the steel moment frames analysed with respect to the drift levels exhibited. In order to investigate the influence of various structural parameters for different levels of nonlinearity incremental dynamic analysis (IDA) is used.

2 Definition of models and analysis procedures

Firstly, the modelling is performed using the nonlinear beam - column elements with distributed plasticity for both the beams and the columns. These elements permit the spread of plasticity along the element using pre-defined number of Gauss points and are quite useful for capturing the axial force-moment interaction. On the other hand, their main characteristic is the fibre discretization which is very sensitive and needs pre-calculations and additionally the stiffness deterioration phenomenon cannot be modelled. In fact, the material used for modelling of these elements is represented through a bilinear steel diagram. Consequently, the same frame model is developed using the elastic beam - column elements ending with zero-length plastic hinges modelled by a stiffness deteriorating steel material developed by Ibarra, Medina & Krawinkler (2005) and referred to as Ibarra - Krawinkler (IK) model. The only shortcoming from the use of these elements is that they are not capable of capturing the force-moment interaction. However, this deficiency is overcome by modelling the columns as nonlinear beam – column elements and have them incorporate the axial force-moment interaction. Two sets of seven acceleration records are chosen as realistic earthquake loading to represent the medium seismicity and high seismicity scenarios. Incremental nonlinear dynamic analysis of the frames is conducted by scaling the records in order to attain various levels of relative intensities. They are extracted from the database and scaled to match the EC8 elastic spectra for the two hazard scenarios with PGA = 0.25g and PGA = 0.35g. The files containing the acceleration-time history are incorporated into the OpenSees analysis models and run with the software in order to obtain the required structural response parameters.

3 Concluding remarks

The lumped and distributed plasticity models' seismic shear and drift demands vary differently at different performance levels investigated. In general, the lumped plasticity model experiences greater drift demand which might be negligible within the lower loading intensity degrees. The main difference between the models is evaluated to occur at greater levels of inelasticity represented with more intense seismic loads and roof drift value of around 3%. That value presents the global frame's deformation zone when the strength and stiffness deterioration property of the lumped plasticity hinge regions occurs and starts deviating the structure's response from the one modelled following the distributed plasticity approach. Finally, general compliance of the models with previous study parameters and design codes provisions is observed. The elastic behaviour of the structure satisfies the code limitations which it is being designed for with a space for minor optimization available.

ESC2018-S31-511

ASSESSMENT OF ALTERNATIVE GROUND MOTION SIMULATION TECHNIQUES IN NONLINEAR TIME HISTORY ANALYSES OF BASE ISOLATED MULTI-STORY FRAME BUILDING: A CASE STUDY

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In recent decades, base isolation system for buildings has been commonly used as retrofitting strategy. Evaluation of structural responses for such a system subjected to severe earthquakes is challenging since some regions have very few and scatted ground motion data set. Simulated ground motions can be an alternative to overcome this issue. There are several ground motion simulation methods available that provide varying levels of goodness fit between observed and synthetic data; therefore, it is important to investigate the efficiency of synthetics in predicting seismic responses of structures before using them for engineering purposes. In this study, a six-storey steel moment-resisting frame is selected from the SAC Steel Project and retrofitted with lead rubber bearings (LRB) in accordance with ASCE 7-10. Then, nonlinear time history analysis of the structure is carried out using the real and simulated records of the 6 April 2009 L'Aquila (Italy) earthquake (Mw=6.3). For this purpose, simulated records of the 2009 L'Aquila earthquake generated based on both the Hybrid Integral-Composite method and the Stochastic Finite-Fault method are employed. The results of analyses from observed and the synthetic records of this event are compared in terms of maximum inter-storey drifts, displacements, accelerations at each story level and input energy. Overall, the results show that the difference in terms of the real and estimated demand parameters from two alternative ground motion simulation techniques is negligible.

ESC2018-S31-513

DEVELOPING THE COMBINED METHOD OF KANAI-TAJIMI MODEL AND HILBERT-HUANG TRANSFORM FOR GENERATING ARTIFICIAL EARTHQUAKE TIME HISTORIES

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Time history analysis is one of the most reliable methods for seismic evaluation of structures, and most of standards and codes emphasize using this method for different kinds of structures. For this purpose, a series of appropriate earthquake time histories are needed. As enough earthquake records are not available in many building sites, generating accelerograms is an alternative approach. This research proposes a method included two empirical and analytical parts for simulating earthquake time histories. In the analytical part, Kanai-Tajimi combined with Hilbert-Huang transform is employed, and in the empirical part, the borehole data is used to calculate the site amplification and applying to the analytical part. The application of this method is illustrated by numerical example. Two near-field records El-Centro and Tabas are considered as original records for simulating time histories as well as two far-field earthquakes Northridge and Chi-Chi. By using this method and a natural record many representative earthquake accelerograms could be generated. This advantage helps to generate enough time histories in a site where just one earthquake record is available.

ESC2018-S31-515

APPLICATION OF ITERATIVE FORMULA IN OPTIMIZING THE MASS AND DAMPING RATIO OF THE TUNED MASS DAMPER

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Tuned Mass Damper is one of the passive control approaches for structures where by assigning a small percentage of the effective mass, stiffness and damping to the damper of the main system, a significant reduction of structure response is achieved. Therefore, finding optimum quantities for parameters such as mass, stiffness and

damping is an important objective in analyzing and also designing the tuned mass dampers. In the present study, based on the equation of structure energy balance for a single-degree-of-freedom model and an iterative formula that tends to minimize the kinetic energy of the structure, a wise or in other words targeted method has been developed to find the optimum parameters of the damper that reduce the maximum response of the system under harmonic and earthquake base accelerations. Eventually, a decent agreement was seen between the results of present study and those obtained by previous related studies that provide the possibility of optimal design of the damper through a simple iterative process.

ESC2018-S31-531

WATT'S LINKAGE BASED MONOLITHIC SENSORS FOR BROADBAND LOW FREQUENCY APPLICATIONS

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The development of broadband mechanical sensors capable to satisfy the increasingly stringent applications requirements in different fields (geophysics, seismology, earthquake engineering, civil engineering, monument and cultural heritage preservation, etc.) is presently a relevant research task. A synthesis of the requirements that general purpose sensors would have to satisfy demonstrates the difficulty of this research: measurement bandwidths, extended in the low frequency regions (often as large as 10^-7 Hz ÷ 1 kHz), sensitivities (down to 10^-14 m/√Hz in displacement), high directivity (> 10^4), compactness (< 10 cmside), lightness (< 0.5 kg), high thermal stability, and, as often required by the most recent applications, ultra-high vacuumand/or cryogenic compatibility. The implementation of new ideas, made easier by the recent scientific and technologic advancements, have led to the design of different typologies of high quality sensors, but often focused to specific fields and/or applications and, therefore, capable to satisfy only subsets of the above synthetized requirements. A solution to this problemcan be provided by the UNISA Folded Pendulum technological platform, developed for the design and implementation of monolithic mechanical sensors. Based on theWatt's Linkage (1774), the folded pendulum mechanical architecture is very simple and direct: it is a combination of a simple pendulum and of an inverted pendulum both connected by means of hinges to one end to a bar (inertial mass) and to the other end to a structure fixed to the ground (frame). The technological progress in precision micro-machining and electric discharge machiningcoupled to a better understanding of the folded pendulum dynamic behaviour, allows now the implementation of compact and small monolithic linear and angular sensors, characterized by high sensitivity, broadband in the low frequency region, and capability of working in UHV and cryogenic conditions.Typical performances obtained with standard horizontal UNISA Folded Pendulums are low natural resonance frequencies (values of 60 mHz have been obtained with a 14 cm x 13 cm x 4 cm size sensor), large measurement bands (10^-7 Hz ÷ 1 kHz), high sensitivities (typically of the order 10^-12 m/√Hz with optimized LVDT (Linear Variable Differential Transformer)), but better with optical readout systems (e.g. laser interferometric readouts). This innovative approach has also allowed the implementation of native inertial systems, with sensitivities and bands limited only by the thermal noise of the mechanics, described in terms of displacement density noise by the Fluctuation/Dissipation Theorem, and by the sensitivity of the readout systems. Last but not least, this technological platform allows also large miniaturizations of the sensors, according to the folded pendulum scalability property: all the folded pendulum characteristics, like for example band and sensitivity, can be tuned with a suitable choice of its physical and geometrical parameters. We present the Extended Folded Pendulum Model (EFPM), a model, based on the Tait-Bryan angular reference system developed for a quantitative description of the dynamical behaviour of a foldedpendulum generically oriented in space, aimed at the description of its dynamic behaviour for linear and angular displacements and/or accelerations. We show, in particular, how the EFPM links thefolded pendulum orientation with respect to the local horizontal to its natural resonance frequency, a characteristic that is the keyelement for the implementation of high sensitivity stand-alone tiltmeters. Furthermore, we show that the EFPM, at least within the limits of validityof the model, demonstrates that

simultaneous independent measurements of linear and angular displacements can be made with a single folded pendulum, a property that opens new applications for this typology of sensors. Then we focus the attention on three state-of-the-art sensors (model GF15, model GE15 and model GI16), developed according to the UNISA Folded Pendulum technological platform, describing their architecture and scientific performances. In particular, we introduce the GI16 sensor, designed using the scalability property, characterized by dimensions 5 cm x 5 cm x 1.8 cm, weight 40 g and natural resonance frequency as inertial mechanical oscillator tunable down to 0.4 Hz.Finally,we present and discuss some interesting and new applications.

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ESC2018-S31-538

INFLUENCE OF SOIL STRUCTURE INTERACTION ON SEISMIC ANALYSIS RESULTS

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More often, soil layers under structures are neglected in numerical analysis. In most of the cases, there are two main reasons for this: soil modeling difficulty and, as commonly considered, the positive soil influence on structural behavior.

The prediction of the structural behavior under seismic loads is of a great importance for structural design and analysis of existing structures. In practice, a fixed model is often assumed for seismic analysis. In many cases, this assumption is correct, but according to different researchers, in some special cases, this type of models can underestimate the structural response to seismic loads. In order to overcome the uncertainties related to the fixed models, analyses that take into account the foundation deformation and its influence on soil stress distribution are carried out. These models are referred to as non-rigid models and their usage enables the obtaining of more accurate values of soil stresses and foundation settlement. This type of analysis is more complicated because of the need for consideration of soil-structure interaction and not so simple soil stress distribution. Seismic design codes often neglect soil-structure interaction, or provide some poor recommendations regarding its usage without any explicit explanation as to when and how it should be taken into account. This is the reason why soil-structure interaction is automatically included in structural design without taking into account the soil strength- deformation characteristics, the foundation stiffness, the activated half-space depth, the foundation type and dimensions, the contact pressure. This paper work provides a brief presentation of the influence of soil-structure interaction on the results of seismic analysis performed according to Eurocode 8. The soil-structure interaction problem has been elaborated and the basic components have been identified. The modeling approaches have been explained and the soil characteristics have been defined through determination of the subgrade reaction coefficient. The Winkler model has been selected as a model for practical application. A numerical example of an eight-storey reinforced concrete structure resting on a mat foundation has been considered. The structure has been modeled by structural elements with adopted dimensions by applying the TOWER 6 software package. The structure has been analyzed under permanent, variable and seismic loads. Nine models have been developed for the purpose of comparison of the results. Three fixed models, three non-rigid models with constant distribution of the subgrade reaction coefficient and three

non-rigid models with different distribution of the subgrade reaction coefficient have been considered. To include the effect of soil flexibility, three soil types classified on the basis of shear wave velocity have been considered in the study. Soil types B, C and D have been adopted in accordance with the Eurocode 8 soil classification. In order to get an insight into the influence of soil-structure interaction on seismic analysis results, comparison of the results obtained for the fundamental periods, modes shapes, storey drifts, inter-storey drifts, seismic force values, activated effective masses of mode shapes and the effect upon the redistribution of bending moments in the beam elements and the mat foundation structure has been made.

ESC2018-S31-539

ESTIMATION OF DYNAMIC PARAMETERS OF SELECTED RC BUILDINGS IN BUCHAREST AREA FROM AMBIENT VIBRATIONS

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All the buildings from the city of Bucharest (Romania) are exposed to high seismic hazard, the main source being Vrancea region. In the perspective of a future strong local seismic event, a very useful tool is to evaluate and track the dynamic parameters of buildings (fundamental frequency and damping ratio). Using this information we are able to monitor the state-of-health of a structure before and after an earthquake, or have insights on the long-term degradation. One inexpensive and promising method to determine these parameters is based on ambient vibration measurements. In this study, we analyzed the ambient noise recordings from three buildings located in Bucharest area and extracted their fundamental frequencies and the corresponding damping values. Two of the structures are eight-story and ten-story reinforced concrete dwellings (13 Septembrie building and Rotar building), while the third one is a ten-story reinforced-concrete office building (IFA building). Rotar building was completed in 2016, IFA building in 1974 and retrofitted twice, in 1978 after 1977 MW 7.4 earthquake and in 1992, and 13 Septembrie building was constructed in 1986, meaning that the design regulations were different for each of the three buildings considered. In order to highlight the consistency of the parameters for different sources and noise levels, we performed ambient vibration measurements during working days and weekends. The acquisition campaign was conducted using a 3-component velocity sensor and consisted of 30 minutes long recordings at the basement, top and middle story of each building. To extract the natural frequencies of the buildings we performed different analyses: the Fourier Spectra on each direction, the Difference Spectra and the Transfer Function of the signals from higher floors with respect to the reference (basement). We tested different window lengths and smoothing parameters, in order to increase the reliability of the results. Moreover, we compared the signals recorded at the top floor with the ones at the middle-story, and the signals recorded during daytime and nighttime, both in time domain and frequency domain, to investigate if there are any variations. Another important dynamic parameter we analyzed was the damping ratio (% of critical damping), computed using the Random Decrement Technique. We first applied a narrow band filter centered on the fundamental frequency of the building and then obtained the frequency and the corresponding damping ratio.
The results show small variations of the dynamic parameters, regardless of the different noise sources and levels and are consistent with similar observations from other studies. This preliminary work will be developed and tested on more buildings and will represent a useful tool for earthquake engineering in Romania.

ESC2018-S31-551

EARTHQUAKE PROTECTION OF DUMPS

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The importance of seismic monitoring od dams is widely accepted. There are numerous historic examples of a dam failure that could have been avoided if a good seismic monitoring program was

provided. Seismic monitoring od dams gives needed information for an understanding of the current work of the dam. Seismic monitoring, including instrumentation and visual inspection ensures that the dam behaves as expected, and enables on time detection of any change. Therefore, good seismic monitoring should be a key part of the management of each dam. For the purpose of the red mud deposit (dump) that comes as a product of the production process in the factory "Alumina" Zvornik, embankment dam was built in 1978 with clay core and 45 meters of height. The dam has been overbuilt on several occasions, last time in December 2015 and currently it has a height of 60 meters. The dam crest level is 233.00 height above sea level, and the level of the overflow structure is 231,00 height above sea level. The length of the dam in the crest is approx. 720,00m. As the capacity of the dump is nearly reached, a new overbuilt of the dam is planned that is a rise of 5,00 m, so that it will reach fully design height of 65m or a crest level of 238,00 height above sea level and an overflow structure level of 236.00 height above sea level. Each overbuild of the dam means changing its geometric and dynamic characteristics Having in mind that the territory of Bosnia and Herzegovina is exposed to significant seismic activity, and the materials stored in the dump represent major threat to the environment downstream of the dam, preparation of project for seismic monitoring of the dam is proposed. This paper shows all stages of implementation of the dam's seisimic monitoring, definition of the technical characteristics of the necessary equipment, method of installation, integration and data processing, as well as definition of the strong ground motion instruments' locations.

ESC2018-S31-552

EVALUATION OF DAMAGE AND STRENGTHENING EFFECTS IN HIGH-RISE BUILDINGS USING ONE MODAL EIGENPAIR

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A development of the "initial stiffness alter index" (ISAI) of conventional high-rise buildings is presented herein. The proposed approach is an expansion of the "first-order storey pseudo-stiffness-based damage index" (pSDI) that has been developed as a practical non-convergent damage detection methodology for achieving the third level of structural health monitoring - consideration of structural damage occurrence and estimation of the structural damage location and severity. The traditional damage detection methodologies are based on the principles of structural dynamics, precisely on the structure's dynamic properties, extracted from ambient vibration measurements. However, only a limited number of dynamic properties can be extracted by processing ambient vibration records due to contamination of the records by noise containing frequencies spreading over a wide band of frequency spectra. The proposed index has been developed to provide accurate structural health estimation in case of the highest limitation in operational modal analysis - identification of an input set of one modal eigenpair, consisting of one modal frequency and the corresponding mode shape, which is usually the first eigenpair. The proposed methodology overcomes the need and the difficulties of identifying multiple sets of eigenpairs in operational modal analyses of multistorey buildings. The calculation of the ISAI-index is expressed as a simple and straight-forward numerical procedure for comparison between the dynamic parameters of undamaged and damaged, undamaged and repaired/strengthened or damaged and repaired/strengthened structures. Theoretically the range of possible ISAI-index value stretches from -1 to +infinity. A positive value of ISAI-index represents a strengthened structure. If the value of the index is 0, the structure is in its initial health state (no damage and no strengthening effects). An ISAI-index value between -1 and 0 represents a damaged structure. For the state of total stiffness deterioration and collapse the ISAI-index value is -1. The accuracy of the proposed structural health assessment approach has been verified in experimental test. The test consists of ISAI-index accuracy evaluation on the structure of a scaled laboratory model of a two storey traditional masonry building during a parallel research containing experimental verification of innovative technique for seismic retrofitting. The experimental model in structural manner was a two storey brick masonry structure with reinforced concrete floor slabs. It was proposed as prototype structure, representative for the large number of residential, but also public buildings

that have been usually constructed in the second half of XX century on the territory of former Yugoslavia and beyond in the Balkan region. The laboratory model was subjected to several shaking table tests within the dynamic testing laboratory in the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) in Skopje. The same testing procedure was applied for the original and for retrofitted model consisting of two main phases: 1) defining dynamic characteristics of the model before and after performing seismic tests at each phase, in order to check stiffness degradation of the model produced by micro or macro cracks developed during the tests and 2) seismic testing by selected earthquake record until the model suffers heavy damage. The tests are performed in several steps, increasing the input intensity of the earthquake in order to obtain the response in linear range, as well as to define the initial crack state, development of failure mechanism and possible collapse of the model. The seismic response tests were performed applying three different earthquake records: Petrovac, Montenegro, 1979 and El Centro, California, 1940, as far distance earthquakes and earthquake Northridge, California, 1994, as a local type of earthquake. After the testing of the model on the shaking table had been carried out and the expected damage observed, repair and seismic retrofitting of the damaged model was undertaken. The dynamic characteristics of the model in all three health states (initial, damaged and retrofitted) were identified applying ambient vibration tests. The ISAI-index, as based on one eigenpair of a particular mode, is verified by comparison with the previously developed and proven accurate damage detection approach - storey damage index (SDI) and provides accurate stiffness loss or gain estimation in the most general, restricted and common case of operational modal analysis - limited only on the first identified eigenpair for each orthogonal direction. The test results have shown that the proposed ISAI-index, based on the first modal eigenpair, can be applied as an instant damage or strengthening evaluation method in structural health monitoring of multistorey buildings, providing the location and severity of structural damage, or the achieved effects of strengthening techniques applied on real structures.

ESC2018-S31-558

EFFECT OF DAMPERS IN SOIL STRUCTURE INTERACTION PROBLEMS

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The problems in soil structure interaction arise when computing the structural response to seismic response. The inclusion of the soil structure interaction effects influences the results considerably. In numerical simulation of frame structures considering the earthquake input as time dependent acceleration there has been significant advances in softwares. The missing point however has been the treatment of soil structure interaction SSI effects considering the presence of damper elements. Namely the presence of damper elements changes the response of the structural response although in definite conditions the results might not be promising. On the other hand, in numerical simulation of soil medium as a wide region the boundaries should be given special concern not to impact the results by reflection of the traveling waves in the soil medium. In dynamic analysis the situation is additionally complicated by the inertia terms such the radiation of the wave should be considered. This paper deals with both damper and soil effects in the SSI problem of a three-story frame. In this work the coupled computational method of finite and infinite elements has been used in soil structure interaction problems. For the numerical simulation the local region of interest is modeled by finite elements which enable simulation of more complex geometries. In order to make the comparison complete, different materials for frame namely, concrete, steel and wood have been used. On the other hand the surrounding filed of the domain is considered using the infinite elements which have the capability to simulate the infinite region very well. In numerical simulations ANSYS software is used where using its programmable features it is possible of programming new elements such as the infinite elements. The obtained results demonstrate that the influence of damper elements have mainly effects on displacement of the frame structures. Thus it is recommended that in seismic prone regions the usage of damper

elements is suggested as a promising tool for decreasing the displacement in case of earthquakes. Key words: Dampers, soil structure interaction

ESC2018-S31-579

PERFORMANCE OF PILE GROUP SUBJECTED TO LATERAL FLOW OF LIQUEFIED GROUND

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Permanent displacements of ground induced by seismic liquefaction often caused severe damages to structures. Many case reports have shown damages and collapses of pile foundations during past earthquakes. Investigations carried out after the Niigata 1964 Earthquake showed that damages observed on pile foundations were strongly related to large permanent ground displacement which was induced by intensive liquefaction, (Hamada et al, 1986). A large number of pile foundations were deformed and damaged during the Kobe Earthquake 1995 due to movement of quay walls and revetments toward the sea which brought extensive flow of the ground behind them. These and also other case histories clearly (Yasuda and Berill, 2000) demonstrate that pile foundations are susceptible to seismic damages. Pile foundation which is mainly designed to carry the vertical loads, during the earthquakes loses the lateral support of surrounding liquefied ground and at the same time is exposed to large lateral ground deformation induced by flow of liquefied soil. Extensive studies were done after the 1995 Kobe Earthquake to investigate the mechanism of pile damages. Tamura et al. performed back analysis of damaged bridge foundations and shaking table tests. Based on their results they concluded that the ground flow force acting on pile foundation can be estimated as the sum of the passive earth pressure of the surface non-liquefiable layer and 30% of the overburden pressure of the liquefiable layer which had been incorporated into the Specifications for Highway Bridges in Jaan, PartV, Seismic design. Imamura et al. conducted several centrifuge model tests investigating the pile group behavior subjected to lateral flow of liquefied ground. Their study demonstrated that when the pile spacing is more than 3 to 4 times of pile diameter there are no interactions between piles, so the pile responses can be treated as single pile response. Most of the present information about seismic behavior of pile foundation in liquefied soils is still based on results of studies which represent the pile foundation as single pile or small group pile (2x2 or 3x3). Knowledge of the group pile response on lateral spreading of liquefied soil is very limited. This paper presents results of shaking table tests on large pile group behavior under the liquefaction induced ground flow. The present study consists of several series of 1G shaking table tests on pile foundation embedded in gently sloped liquefiable soil layer. Two models of group piles were investigated: i.e. 6 x 6 and 11 x 11 group pile models. The kinematic effects of liquefaction induced horizontal displacements and influence of pile spacing on pile response were the primary goals which were observed during the tests. Results from the experiments show that the piles responses upon liquefaction induced flow greatly depend on the location of the pile in the pile group. Distribution of liquefaction-induced soil horizontal displacements was affected by presence of the pile group. Maximum soil displacements were observed far from the pile group while the magnitude of soil movement between piles was decreasing, from front row toward inner row of piles. This was more significant with 2.5D than 5D pile spacing. With these findings it is suggested that piles in pile group were subjected to different lateral loading due to liquefaction-induced ground flow. This idea could be used also as mitigation measures to design protective row(s) of pile around the pile foundation against lateral spreading of liquefied soil.

ESC2018-S31-713

NONLINEAR VIBRATION OF SUPER HIGH-RISE BUILDING DURING TYPHOON SOUDELOR IN 2015

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The TAIPEI 101 skyscraper (508-m) is comprised of 101 floors and five floors above and below ground,

respectively. It is located in the Hsinyi District of Taipei, Taiwan. The skyscraper is equipped with a 660-metric-ton tuned mass damper – the largest of its type in the world. The fundamental-mode frequency of the skyscraper is about 0.15 Hz. Both the skyscraper and the tuned mass damper swayed during Typhoon Soudelor on 8 August 2015. The maximum vertical, E-W, and N-S displacements measured on the 90th floor are approximately 1.5, 32.2, and 44.5 cm, respectively. The Morlet wavelet technique is applied to analyze the dominant periods of three-component seismograms recorded at the 90th floor. The fundamental period of the skyscraper increases by up to 7% during the strong shaking caused by heavy winds. Numerical simulation of the fundamental vibration signals for the TAIPEI 101 skyscraper based on the Duffing equation demonstrates that change in the fundamental period is mainly caused by the nonlinear vibration characteristics of the high-rise building.

ESC2018-S31-737

INNOVATIVE BUILDING MATERIALS FOR SEISMIC STRENGTHENING OF EXISTING BUILDINGS

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Many buildings have experienced different levels of damage during past earthquakes. Most of these buildings were constructed before the introduction of the modern building codes. They usually cannot provide the required ductility, lateral stiffness and strength, which are definitely lower than the limits placed by the modern building codes. Deficiencies that emerge in reinforced concrete buildings in terms of stiffness, strength, ductility and redundancy led to studies intended to strengthen buildings against earthquakes. Taking into consideration the requirements of the new codes, different strengthening solutions have been established as referent in order to increase the capacity of the buildings. Over the last two decades, new construction materials for strengthening and design have emerged. These are referred to as fiber- reinforced polymer (FRP) composites and have unique mechanical and in-service properties. FRP composites comprise fibers of high tensile strength within a polymer matrix. The fibers are generally carbon, glass or aramid, in a matrix such as vinylester or epoxy. The most important property of the fibers is their high elastic modulus. The FRP composites can be manufactured in different shapes as a: plates, FRP sheets, circular and rectangular bars and pre cured laminates etc. These kinds of material are characterized with: big ultimate strength, lightweight, the sheets are thin and can fix the problem in two directions, good durability and improved fire resistance as well as reduced freezing risk. The FRP seismic strengthening strategy is based on: avoiding brittle failure mechanisms(shear failure, lap splice failure, instability of longitudinal reinforcement in compression), avoiding soft-storey mechanisms and increasing the global deformation capacity by enhancing the ductility of the plastic hinges and relocalization of the plastic hinges. In many cases local strengthening on the external joints of the structure should be done in order to improve the capacity of the structure. The procedure consists of installation of diagonal uniaxial steel sheets designed to resist to partition actions, quadriaxial sheet in order to increase the shear strength, uniaxial sheets which increase the ultimate strain and rotational capacity and U-shaped sheets on the beams. Several aspects influence the effectiveness of FRP material used as externally bonded systems for strengthening RC members. The relative importance of each of these aspects depends on whether reference is made to applications defined as “bond-critical” (flexure or shear) or “contact-critical” (confinement). There are different methods of strengthening, but the FRP system installation generally consists of: cleaning, repair and protection of the surface, adding primer and adhesive, installation of the FRP system and top cover protection. According to many researches can be concluded that the strengthening solution including innovative building materials significantly increases the deformation capacity of the existing buildings. To summarize, the FRP composite strengthening solution is associated with short time required to install which results in high costs. Furthermore, the fabrication technologies for the production of FRP composites have been revolutionised by sophisticated manufacturing techniques. These methods have enabled polymer composite materials produce good-quality laminates with minimal voids and accurate fibre alignment, as well as a more acceptable price.

ESC2018-S31-794

CELLULAR STRUCTURES AS AN ENERGY DISSIPATING DEVICE IN STRUCTURAL SYSTEMS

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Cellular solids and structures have been nature's conventional building material ever since the first plants and animals have evolved from the microorganisms. Bones, honeycombs, wood, plants, are very serious representatives of this type of so called metamaterials whose mechanical properties highly depend on the internal structural configuration of the constitutive cells. Although complicated do be fully reproduced by humans, their limited shape serial mass production positioned them as an inevitable part in automotive, airplane, packaging industries. Steep slope rapid development of additive manufacturing technologies, the range of materials and methods for their 3D printing allows a new revolution era in production and materials i.e. metamaterials and cellular structures. Low weight and very big deformation capacity due to the nature of cellular structures create a good basis for exploiting the energy dissipation characteristics in the framework of structural systems of the civil engineering structures. Hence, by producing energy dissipating device i.e. structural damper by additive manufacturing techniques yields opportunity to reinvent passive structural control, dedicated to reduce the unfavorable effects of horizontal forces, typically earthquake and wind effects on structures. A single regular hexagonal cell, theoretically extracted from a composition of hexagonal honeycombs has been analyzed in terms of energy dissipation potential. Several in plane load cases scenarios have been taken into account resulting in analytical prediction of the in plane behavior of the cells. Finite element analyses were performed using ANSYS (ANSYS Inc., Canonsburg, PA) software. Cell walls were modeled as 3D eight node element type with three degrees of freedom at each node. In order to validate the FEM analysis in the linear range a hand calculation according to the mechanics theory of honeycombs has been also been performed. Regarding the nonlinear deformations and behavior of the cell unit in plane, a set of constantly increasing forces was applied. Hence the force-displacement plots were obtained and thus the behavior and energy dissipating potential was concluded. The parametric analyses conducted stress strain diagrams based on whom the in plane deformations of honeycombs and their potential energy dissipation has been explored. The behavior of the cell built by elastic-plastic material, steel, is ductile and the collapse mechanism is by formation of plastic hinges at the section of maximum moment in bent members. Both in tension and compression the honeycomb behave almost the same way, plastic hinges form allowing large deformations at nearly constant stress. Main difference is that in compression a certain densification due to the nature of the structure is evident and thus higher forces can be experienced. The sensitivity of the response on the change of main parameters such as wall thickness and wall height leads to conclusion that tunable performance could be achieved in order to obtain desired level of damping. The results confirm the hypothesis that cellular structures i.e. honeycombs as constitutive elements can be a potential energy dissipating device in the structures prone to dynamic excitation such as seismic activity or wind effects.

ESC2018-S31-804

STRUCTURAL CONTROL - CHALLENGE IN 20 CENTURY, AND THE REALITY IN CIVIL ENGINEERING NOWADAYS- INVITED L.

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The earthquakes and hurricanes that have occurred for the last years have reminded us about the enormous energy released by the natural forces and the loss that it might inflict referring to human lives and properties. The earthquakes, particularly the strong ones, cause severe damage and even total failure of structures. Considering the high quality and very expensive equipment for certain technological processes that might be installed in these structures as well as the high concentration of people when talking about public and residential buildings, one can assume the size of the losses inflicted by failure of such structures. As a result from such possible phenomena, structural

engineering has faced the challenge of development of another concepts for design and construction of structures with better protection against damage caused by destructive natural forces including wind, waves and earthquakes. The philosophy of design and construction of buildings based on providing safety via high capacity of strength, depending on the intensity and frequency content of earthquakes is not fully appropriate. This was shown by the latest earthquakes in Northridge (1994) and Kobe (1995) when a lot of structures characterized by high strength capacity but minimal, i.e., insufficient capacity for energy absorption suffered serious damage or complete failure. The great progress in technology and industrialization of construction as well as the fast development of electronics, the achievements in the field of controlled structures, particularly in the field of passive systems for control of seismic response were the main motive for starting with investigations leading to application of new methods in design of economical aseismic structures of a higher level of safety. The concept of passive control of seismic response of structures represents a progressive change and an important qualitative modification of the approach to design and construction of seismically resistant structures that, at the same time, offers possibilities for direct application in construction of new structures and strengthening of the already existing ones. Therefore, this concept has been subject of intensive investigations in a great number of research centers worldwide for the last two decades. These investigations resulted in development of several different systems for passive control (base isolation, eccentrically placed diagonals, systems with disposable elements, systems with mechanisms of damping through friction, metal dampers, viscous-elastic dampers etc. Some of these systems have already been applied in practice. Considering that it is a relatively new concept of seismic protection of high-rises, these are very much of a current interest and the greater part of the activities of the research centers worldwide (particularly USA and Japan and lately in Europe) has been dedicated to improvement of the existing systems and development of new ones. The research activities of IZIIS in the field of structural control have been directed for transferring and gathering the knowledge and achievements in this filed, needed for practical application of the industry. Furthermore, these investigations have been undertaken for development of new economically justified technologies for controlled behavior of structures, as well as, new methods of aseismic design and construction of new buildings and upgrading of the existing ones. The systems that have been investigated in IZIIS-laboratory for the last fifteen years belong to the category of systems for passive control of dynamic response of structures. These systems are of a particular importance for the possibility of their practical application and their advantages over the active systems that consist of the following:

• They do not require application of high technology (systems for fast acquisition of data, algorithms for simultaneous definition of optimal effect, systems for generation of controlling forces, etc.);

• They do not require permanent maintenance of the system, which on the other hand, conditions engagement of highly educated staff and support by industry as to providing spare parts and alike;

• These are reliable and do not depend on external-additional source of energy that might fail when it is needed the most;

• They are applied in design and construction of structures of different purpose as well as construction of the so-called "pilot" structures and structures of vital importance. Their efficiency has been proved in practice by the behavior of structures under actual earthquakes of different intensity.

ESC2018-S31-816

EXPERIMENTAL "IN-SITU" TESTING OF HISTORICAL MONUMENT IN SKOPJE

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Recently, many scientific and research activities are aimed to protection of historical heritage against earthquakes. Most of these historical monuments are designed and built in the past, not taking into account the impact of earthquake. These structures are usually constructed of brittle materials, with high rigidity which limits the possibilities for ductile behavior. Consequently, for estimation of their seismic behavior and dynamic response several crucial aspects should

be considered. The strength and the characteristics of the materials, as well as the interaction between the soil and the structure are expectedly among these aspects. Secondly, the estimation of earthquake ground motions based on amplitudes as well as on the frequency content of both local and far earthquake sources is another aspect. Furthermore, the dynamic properties of the structure – the natural frequencies, mode shapes, and damping capacity in each mode should be also taken into consideration as one of the main aspects. Experimental "in situ" testing methods, ambient or forced vibration testing methods, have very wide range of application in the definition of the actual state of the structure in respect to its dynamic properties. In particular, ambient vibration testing has become the main experimental method available for assessing the dynamic behaviour of full-scale structures. The ambient vibration testing methodology is based on ambiental excitation such as wind, traffic and other influences. Sensitive seismometers are used for detecting the produced vibrations which are of a random type of signal, consisting of excitation frequencies in a broad frequency range, sufficient to excite several modes of structural vibration. The advantages of this method are the light and simple equipment as well as the non-destructive procedure involving a minimum interference with the normal use of the structure. The Institute of Earthquake Engineering and Engineering Seismology—IZIIS from Skopje has a very long experience in the field of ambient vibration testing starting from 1978 with more than 250 tests performed. In this abstract are presented methodology and results from experimental "in situ" testing obtained by ambient vibration measurements of an old historical monument in Skopje, R. Macedonia. The structure-monument was built in the period of 1930-1932 with masonry structural elements. It is located in the city centre, consisting of basement, ground floor and first floor. For measuring the ambient vibrations, 8 accelerometers (PCB ICP Seismic accelerometer model 393B12) and National Instruments data acquisition system CDAQ-9178 chassis with 3 NI-9234 modules, were used. Measurements were performed in transversal and longitudinal direction at 12 points of the structure, four points on every floor. During the tests, all accelerometers were placed in the same direction and one point was chose as a referent. The measurements were conducted using the high speed data acquisition system. Software for data processing has been used to plot the time histories of recorded accelerations by the sensors together with the Fourier amplitude spectra of the response at any recorded point. The modal analysis was performed using ARTeMIS software where the natural frequencies and the mode shapes of vibrations can be determined using the Peak Picking technique and the Frequency Domain Decomposition technique. The natural frequencies as well as the shapes of vibration were clearly expressed representing very good and comprehensive base for verification of the numerical model of the structure using SAP2000 and further evaluation of their seismic behaviour and stability of this historical monument.

ESC2018-S31-857

JOINT DAMPING IN FRAMES

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This talk will present investigations on rotational joint damping in frames under dynamic loading. The theory takes into account the viscous type of damping in joints of frames due to differential rotation of members connected to the joints. Computer programs were constructed to implement the theory. The complex natural frequencies of different two-dimensional frames are determined, with this type of joint damping. Dynamic response for the frames under earthquake type loading will also be illustrated.

ESC2018-S31-939

EXPERIMENTAL METHODS IN SUPPORT OF EARTHQUAKE ENGINEERING - INVITED

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The in-depth knowledge of the geological phenomena driving seismic events is the first step for any earthquake-hazard structural mitigation process. Progress in research on ground motion modelling has been significant and will, at some point, reduce existing uncertainties. Nevertheless, this would represent a progress on only the "input" term of a structural-response equation.

The "output" term is represented by the structural performance itself, as it is indeed the response to seismic events that constitutes the main source of threat to human life. Owing to extensive research and the evolution of building codes, new structures enjoy a rather predictable response and appreciable safety margin against seismic events. However, not only this is valid for up to a certain level of excitation, but does not account – at least to the same degree - for the very vulnerable class of existing structures. New technologies may offer some opportunity, which though – for the case of existing structures - has to be further explored. As a result, our testing techniques have to be in position to provide better insight of the structural response. The paper presents the state-of-the-art in structural testing, goes through the portfolio of methods employed and focuses on innovative approaches dealing with the testing of structures at full size.

ESC2018-S31-992

NEW COUPLED APPROACH IN SIMULATION OF SOIL CONSOLIDATION

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The aim of this paper is to present a mathematical framework and its corresponding coupled finite element discretization for saturated porous soil media. The model is developed as a coupled finite element formulation in which the porous medium is composed of a soil skeleton and fully saturated pores. The considered problem in this paper is the consolidation of a saturated soil layer subjected to uniform pressure. The coupled mathematical model addressed in this work considers both drained and undrained boundary conditions in the consolidation problem, and the results are presented in a manner to clarify the distinction between them. The consequent mathematical model involves equations of mass and momentum balance for the whole system. Interesting outcomes are achieved from the numerical simulation and results are discussed thoroughly.

ESC2018-S31-1061

SPT METHOD FOR LIQUEFACTION POTENTIAL ASSESSMENT

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The liquefaction phenomena is a complex issue, and its assessment is widely researched and continuously updated. While laboratory tests provide valuable information about the liquefaction potential of a soil sample, in situ based methods are the first step in the assessment of specific sites. SPT based liquefaction assessment in situ methods can be considered as the dominant approach for defining liquefaction potential. They have an advantage against the difficulties and costs associated with high-quality undisturbed sampling for high-quality laboratory testing, and one of the few must in-situ tests according to several codes, for site investigations, which is very convenient. Also, the same factors that affect SPT resistance also affect liquefaction resistance (i.e. overconsolidation, non-uniformity, density, fines content etc). The SPT based method for liquefaction assessment has been analysed by several authors (Youd et al. 2001, Cetin et al.2004, Idriss and Boulanger 2006, 2010) and it relies and is based on selected case histories. The liquefaction potential can be expressed with the factor of safety (Fs) or as probability of liquefaction (PL). Boulanger and Idriss have proposed both deterministic and probabilistic models for liquefaction assessment. The Fs and PL are evaluated by the CRR/CSR relation, where the CRR correlation is a function of the (N160)cs number, which is the corrected SPT N (N measured) number, by several correction factors.
A number of locations with previously available SPT results, have been subjected to liquefaction assessment by the mentioned models, for selected characteristic seismic scenarios. It can be concluded, that the deterministic approach can be considered as the upper bound for locations with high seismic hazard or for long return periods, while the probabilistic models are relevant for medium seismic hazardous locations.

Keywords: Liquefaction potential assessment, SPT, deterministic models, probabilistic models

ESC2018-S31-1068

CROSS PHYSICAL INTERPRETATION OF THE DYNAMIC RECOVERY PROCESS OBSERVED IN CIVIL ENGINEERING STRUCTURES AFTER EARTHQUAKES AND THE FLUCTUATION-DISSIPATION THEOREM

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During strong seismic loadings, structures may be damaged, characterizing by cracks and then a reduction of apparent elastic properties of structures (i.e. resonance frequencies and damping ratio). During weak motion, frequency and damping variations can be transitory, followed by a slow recovery to their initial values. This non linear phenomenon is called Slow Dynamics, explained by the gradual closing of the cracks which were initially present in the material and which were opened during the loading. The study of the Slow Dynamics in civil engineering structures during strong earthquakes demonstrated also the possibility to detect the damage. Moreover, the continuous monitoring of the damping highlights a linear relationship between damping and the intensity of the ambient vibration in the case of real case structures. We explain this relation by applying the Fluctuation-Dissipation to these structures. The proximity of the expression of the linear relationship with the equations used in the theory of the Slow Dynamics suggests a dependency of both phenomenons on the density of heterogeneities in the structure. The main objective of this abstract is to highlight recent results on the slow dynamic and fluctuation-dissipation relationship applied to civil engineering structures, as a proxy of the level of heterogeneities and number of cracks.

ESC2018-S31-1071

EXAMINATION OF BEHAVIOR OF MASONRY ARCH BRIDGE MODEL SUBJECTED ON SEISMIC LOAD INCLUDING THE DETERMINATION OF LOAD CAPACITY OF THE CONNECTION ELEMENTS.

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Until the development of modern materials, the construction materials of masonry structures were stone elements together with filling of mortar. Due to their characteristics, primarily low tensile strength, heterogeneousness, anisotropy, and high compressive strength, massive structures that did not have the problem of sliding between stone blocks. However, construction of arch structures made of such materials required good understanding of the flow of forces within the arch structure, which had to ensure the proper transfer of forces from the arc crown to the arch springs, where the load were transferred to the arch foundations or supports. Examination of behavior of masonry arch bridge model subjected on seismic load were provided to obtain a realistic picture of the efficiency of the elements of the stone masonry in intense vibration conditions, as well as the way of the bridge damage distribution. Laboratory tests performed at Institute of Earthquake Engineering and Engineering Seismology-IZIIS, Skopje, give results in the form of shifts, accelerations, deformations and all other dimensions of interest to assess the seismic stability of arch bridges walled with stone. Further, determination of load capacity of the connection elementswere provided in order to describe the behavior of all connection elements participating in the transfer of loads that can occur on the load-bearing vault of arch masonry bridges, and to establish the laws of their interaction in the structure.

ESC2018-S31-1072

ENVIRONMENTALLY RUGGED OBSERVATORY GRADE BROADBANDSEISMOMETERS FOR VAULT USE, CASED HOLES, AND DIRECT BURY PORTABLE ARRAYS

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In the past broadband sensor deployments could be compromised by environmentally challenging environments including expensive purpose built vaults deployments. There is now a new broadband sensor, the Horizon that is ready for wet or dry vaults, wet ordry cased holes or direct bury deployments. The majority of deployments

don't need more than a degree of operational tilt range and for those that due there is the postholetype. These first posthole instruments have been deployed in a wide range of extremely challenging environments such as dynamic ice and snow environments, extreme wetand dry conditions in soils of high clay content, and steep or creeping terrain. In examples of all these use cases the direct burial approach has consistently provided high quality data when compared to shallow vault installations. These field experiments demonstrate that while higher tilt tolerance is required for operational outcome certainty in some installations such as deep holes or dynamic glacial environments, the majority of installations can be addressed by a smaller instrument with a narrower tilt range of reduced size and cost. The lessons learned from this real world field data have guided the development of a new smaller, less expensive broadband instrument, the Trillium Horizon. Based on this field data and user feedback from many direct burial deployments, the Trillium Horizon seismometer has been developed as a simple versatile instrument to span the majority of deployment scenarios and specific use cases including shallow direct bury deployments, traditional piers and problematic wet vault installations. With its small size, robust waterproof case and connector, +/-1.5° tiltrange, dual-purpose cable and accessories for both posthole and vault installation, the Trillium Horizon is optimized for usability as well as performance.

ESC2018-S31-1083

LOAD TESTINGOF EXISTINGPRESTRESSED CONCRETEGIRDER BRIDGE STRUCTURES

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The method of load testing is an essential segment in defining the safety of bridge structures. One of the methods of load testing is the diagnostic load testing. This method enables comparison between the real behavior of a bridge structure and the results obtained from its analysis. Such a comparison is particularly important for the newly built structures for which this method is used as a test that proves the behavior of the structure. In this article, the overview of the studied problem,information and conclusion of the measured results from the diagnostic tests performed by static and dynamic loads on three newly built bridge structures are presented. The objective of diagnostic loading of bridges is to define the behavior of bridges under static and dynamic loads: checking whether the bearing capacity and deformability of the built structures are in compliance with the results from the main and the working design; checking of the quality of the works done, preciseness of manufacturing and geometry of elements;checking of the quality of the built-in materials; checking of the usability of the structure. All three bridge structures represent monolith pre-stressed continuous slab systems with two spans and length of 45.7m; 34.0m and 43.5m and height of the pier 6.0m; 8.4m and 8.0m respectively. A simplified mathematical model of all bridge structures was formulated, characteristic data regarding design loads were obtained from the design documentation and static influences under design live loads and trial loading used for testing were obtained for the bridges. For testing of the bridges, there were simulated more than 50% of the design internal static quantitates (deformations and/or stresses/strains) at each characteristic cross-section of the structure. The value of the simulated percentage depended on the design live load, which was correlated to the category of the road and the dimensions of the structure itself. The trial load was provided by trucks filled with sand. The arrangement and distance between the axes was also predefined and measured on site. In this way, the trial load was properly deployed and enabled causing of the maximum internal static quantities (as a large percentage compared to the design values). The number of trucks, their weight and location on the bridge as well as the total number of loading schemes depended on the type of the structure, i.e., its width, number and length of spans as well as its structural system. Regarding the instrumentation used for measuring the static quantities of interest, strains and deflections at both mid-spans were measured together with strains at the middle support. Furthermore, continuous measurement of accelerations was also done. All quantities were measured continuously and at discrete times when the maximal values for characteristic quantities were reached. Each cross-section of interest was tested

by use of two loading schemes (symmetrical and non-symmetrical).The loads was applied in 5 phases ("0"-"P/2"-"0"-"P"-"0"): phase 1: Unloaded condition, phase 2: ½ of the full loading (P/2), phase 3: Unloading, phase 4: Full loading (P), phase 5: Unloading. Based on the tests performed by trial static and dynamic loading of the three overpasses and the obtained results, the following can be concluded:

- The strains in the field of the right span obtained under the trial loads compared with the analytically obtained strains for the same defined load are of the order of 50%-83% for bridge 1, 59-67% for bridge 2, 76%,for bridge 3 and69.3% for bridge 4. The greatest agreement was found in the case of the bridge with the least length.
-The strains in field of the left span obtained under the trial loads compared with the analytically obtained strains for the same defined load are of the order of 47%-60% for bridge 2 , 65% for bridge 3, and 75,3% for bridge 4.
-The vertical deformations in the midst of the left span obtained experimentally under the trial load amount to 62%-88% for bridge 1, 72%for bridge 2 and58%-70% for bridge 3 of the analytically obtained deformations for the same load.
- Total residual deformations upon completion of the testing, immediately after unloading, amount to 0.7 mmfor bridge 1, 0.7 mmfor bridge 2, 1.87 mm for bridge 3 which are less than the maximum allowed 1.26mmfor bridge 1, 0.78 mmfor bridge 2 and2.1 mmfor bridge 3.
- The experimentally obtained mean dynamic coefficient at vehicle speed of 10km/h, 20km/h and 30km/h amounts to 1.17for bridge 1, 1.25for bridge 2, i.e., 1.19for bridge 3. The maximum computed design dynamic coefficientfor all three bridges ranges within the limits anticipated in the project.
- The obtained damping of the structure for a speed of 10 km/h, 20 km/h and 30 km/h amounts to 1.16%, 1.23% and 1.56%, respectively,for bridge 1 and1,14%, 1,21% and 1,63%, respectively, forbridge 3, whereas for bridge 2, it amounts to 1.16%, 1.23% and 1.56%, respectively.

Based on the testing performed by trial static and dynamic loading for all overpasses and the results obtained from the performed sample measurements, it can be concluded that the overpass structuresbehave in the elastic range under the applied load in accordance with the road category which complies with the technical regulations (MKS U.M1.046) for such type of structures.

ESC2018-S31-1084

COLLAPSE CAPACITY SPECTRUM METHOD: AN ENHANCED APPROACH

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In this study an enhanced collapse capacity spectrum method is presented, applied and compared with the springboard collapse capacity spectrum methodology (Adam and Jäger 2012a; 2012b). The primary goal of earthquake engineering (i.e., the safeguard of an adequate margin of safety against structural collapse during extreme earthquakes for a modern engineered building located in an earthquake environment) can be accomplished only if tools for predicting seismic collapse with sufficient confidence are well understood, readily available and easy to apply in engineering practice. The collapse capacity spectrum method in a probabilistic framework targets to such a prediction with simplified measures of the global collapse capacity of regular P-delta sensitive moment-resisting frame structures, whose cyclic component deterioration can be omitted. The main ingredients of this method are collapse capacity spectra, providing the seismic demand of P-delta vulnerable single-degree-of-freedom (SDOF) systems on a collapse limit state, and an equivalent SDOF (ESDOF) system that captures the P-delta vulnerability of the actual structure based on a first mode pushover analysis. The first improvement concerns the definition of the relative collapse capacity for SDOF systems, in further consequence also for collapse capacity spectra, and multi-degree of freedom systems. Since in the presence of the gravity loads the initial period of vibration is elongated and the yield strength (correspondingly also the base shear coefficient) of the system is reduced, the P-delta affected structural parameters are suggested to serve as reference parameters instead of the initial one, i.e. those before the gravity loads are applied. The use of the conventional initial parameter based Intensity Measure (IM) (i.e. spectral acceleration at the fundamental period)

instead of the proposed P-delta affected parameter based IM (i.e. spectral acceleration at the fundamental period considering gravity loads) is an additional source of inaccuracy of the predicted collapse capacity. A fluctuation of the record-to-record variability around 0.23 was evaluated for the proposed IM instead of 0.37 for the conventional IM (Tsantaki et. al, 2017). The concept of the ground motion uncertainty and the application of the selected IM as the interface between seismology and earthquake engineering is further discussed. The second enhancement concerns the pushover analysis. The crucial assumption of the ESDOF system is that a constant shape vector describes sufficiently accurate the horizontal displacements of an earthquake excited frame structure in its elastic and inelastic range of deformation, and in its limit state. In a P-delta sensitive structure a story mechanism may develop when approaching the limit state (Bernal 1992). Therefore, the P-delta vulnerability of the structure will be evaluated based on an envelope pushover analysis (as suggested by Brozovic and Dolsek, 2013) instead of a first mode global pushover curve. The envelope pushover curve is based on the outcomes of three pushover analyses for the three first modes to capture the potential of higher modes effect. From each pushover analysis two ESDOF systems, a conventional one and a collapse-based ESDOF, are obtained. The main difference is that the transformation factor and the effective mass for the collapse-based ESDOF is based on the displacement vector on a collapse limit state (Brozovic and Dolsek, 2013) instead of the natural vibration mode shape. The discussed enhanced approach of the collapse capacity spectrum method aims at the identification and elimination of the sources of inaccuracy of the predicted collapse capacity. The collapse capacity spectrum method is particularly useful in engineering practice because the structure can be evaluated with respect to its seismic collapse capacity in the initial design process without detailed dynamic analysis (i.e., non-linear time history analyses).

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SESSION 32

ESC2018-S32-71

SEISMIC DETECTION AND LOCATION OF ROCKFALLS AT THE STEEP SLOPE OF SPITZ (LOWER AUSTRIA)

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Rockfall is an inevitable natural phenomenon, which happens suddenly in different environmental scenarios with a wide range of volumes, and has become a key issue in nature disaster reduction. In the recent past, significant rockfalls that posed a danger to persons, railways and roads occurred in the quarry of Spitz (NÖ-Austria). A new methodology based on seismic methods, which enables the detection and location of rockfalls above a critical size, is presented. In order to perform this task, a small-scale seismic network, comprised of seven monitoring seismic stations acquiring data in continuous mode and covering the hazardous study area, was established in the quarry of Spitz. On the 2nd of October 2015, an induced rockfall experiment was performed. The entire data set was analysed using the pSysmon software. In order to locate the impact point of the rockfalls, we used a procedure based on the back-projection of the maximum resultant amplitude recorded at each station of the network within a time window. These maximum amplitudes are projected to every grid-point covering the whole area of interest, [Robust method to detect and locate local earthquakes by means of amplitude measurements, M.d.P Papí-Isaba et al. ,Vol. 18, EGU2016-10354, 2016]. The novelty of the current approach is that it provides fast information about the rockfalls source parameters. This allows the implementation of a reliable real-time alarm system based on determination of the rockfall location and the impact strength, SourceMap and pseudoMagnitude. The reliability of the rockfall alarm system will depend on the coverage of the whole area of interest by a sufficient number of sensors and a threshold value based on the pseudoMagnitude, which must be defined in order to minimize false alarms. In order to verify the performance of the employed algorithm for detection and localization, we provoke several sequences of man-induced rockfalls. A terrestrial laser scanner and a camera were also used, not only to draw the rockfall block trajectories, but also to determine the lost or gained volume of rock in the different areas of the quarry. This allowed us to relate the lost mass to the strength of the collision (pseudoMagnitude) of the rockfall, and draw and rebuild their associated trajectory. The location test performed using induced rockfalls indicates that with the deployed network and the developed location method, it is possible to provide a reliable estimate of the impact point of the falling blocks, as well as the strength of the collision.

ESC2018-S32-99

BENIOFF STRAIN RELEASE BEFORE LARGER EARTHQUAKES IN UNDERGROUND HARDCOAL MINES

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We test the concept that induced seismicity prior to relative large mining tremor (ML >2.5, E >10^6J) can be inferred from the cumulative Benioff strain release as power law time-to-failure before the strong event. This study represents the application of accelerating seismic moment/energy release prior to large earthquake, widely used in global seismicity, for analysis of this phenomenon in induced seismicity. The Benioff strain release is quantified as accelerated releases of cumulative (square root sum) of seismic energy in the time series. For the events that we have analyzed, all preceding sequences that have an accelerated energy release distribution prior to the mainshock and resulted in “accurate” power law models have two criteria in common. First, the record of events is complete for an appropriate time interval before the large tremor. We assumed the completeness magnitude, basing on the goodness-of-fit test, that is the criterion matches the completeness of the sequence. The second criterion is that there are no interfering events which are the tremors occurring in the same time period, and location, and have similar or greater magnitudes (generally within one magnitude unit and >2.5). According to mentioned criterions 4 sequences were extracted from

seismic catalogues from two Polish hardcoal mines: exhausted "Bobrek-Centrum" Mine (the data form IS-EPOS Platform) and from the still operating one. Next, a search radius was used to select precursory events and to indicate the type of processes occurring in the coal seam and its vicinity. The fitted power law of cumulative Benioff strain release (accelerating energy release, AER) showed the changes of m-parameter (a power). According to other observation, if the value of m is smaller than 1.0, then the cumulative Benioff strain release curve is regarded as accelerating-like. If m is larger than 1.0, then the cumulative Benioff strain release curve is regarded as quiescence-like. The investigation of m-parameter vs. the search radius showed the general behavior of rock mass in the studied areas. If all fitted curves (for one time sequence, different search radius) were accelerating-like the ''target earthquake'' was regarded as to be accompanied by preshock AER. If the curves were quiescence-like, then the ''target earthquake'' was regarded as to be accompanied by quiescence-like preshock energy release. If the curves showed different characteristics, then it was regarded as having no stable property of accelerating or decelerating. The presented study are an attempt to deal with the seismic hazard in mine and could be useful to investigate future earthquake prediction in areas where accelerating-like processes will occur.

ESC2018-S32-106

HOW FAULTS WAKE UP: INSIGHTS FROM INDUCED EARTHQUAKES

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Large-scale wastewater disposal has led to a fast-paced reawakening of faults in the central United States. High-resolution earthquake relocations for induced earthquakes in the states of Oklahoma and Kansas show that ancient basement faults are being activated by a modest (0.5 MPa or less) increase in pore fluid pressure. These earthquakes characteristically occur at about 4 km depth below the top of the basement and do not reach the sedimentary cover where the injection occurs. Some faults wake up in sequences that propagate along a fault or jump from fault to fault, while others remain fixed in length from the onset. None of the sequences in this area initiate with the largest event, suggesting a progressive weakening of the fault. Hydrologic modeling indicates that activity frequently initiates after a time lag of several months to a few years relative to the onset of injection activity. Once initiated, earthquake interactions contribute to the propagation of seismicity along the reactivated faults. As a result, the spatio-temporal evolution of the seismicity mimics a diffusive pattern that is typically thought to be associated with injection activity. Analysis of the Fault Slip Potential shows that most faults are critically stressed in the contemporary stress field. Activity on some faults, for which we find low slip probability, suggest a significant contribution of geomechanical heterogeneities to the reawakening of these ancient basement faults.

ESC2018-S32-121

SEISMIC ACTIVITY AND CHANGES OF COULOMB FAILURE STRESS ASSOCIATED WITH RESERVOIR FILLING

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The presented work is part of a Phd tesis and is the result of a new collaboration initiated between the Instituto Costarricense de Electricidad (ICE), Universiadad Nacional Autónoma de México (UNAM) and the Universidad Politécnica de Madrid (UPM) for the investigation of the seismicity associated with energy development technologies. Recently, induced and triggered seismicity associated with energy production is becoming an increasingly important issue worldwide for the hazard it poses to the exposed population and structures. Indeed, new developments and contributions are constantly being made with the aim of achieve a better understanding of their characteristics and genesis. Different human activities can affect the natural environment and the stress state on the field: mining, extraction of conventional or unconventional hydrocarbons, CO2 underground storage, geothermal energy operations, injection of gas in the subsoil, fracking, filling of large reservoirs, etc. We focus on the seismic activity

related with the filling of artificial water reservoirs. On the one hand, we present the spatio-temporal evolution of the seismic events recorded around the Pirrís reservoir (Costa Rica). We differentiate between the events occurred before, during and after its filling. With this seismic analysis, we try to know and control the effects that the reservoir operations have on the seismic activity in the area. On the other hand, we evaluate the spatio-temporal evolution of the changes of Coulomb Failure Stress (CFS) due to the surface water load and its correlation with the seismicity. With this assessment we explain the possible influence that the reservoir filling has on the subsurface state of stress to detect any possible anomaly. Moreover, we study the effects that tectonic moderate-earthquakes have on the field stress state near the reservoir area. We perform an innovate analysis in which we combine the coesismic stress changes produces by different tectonic earthquakes and the elastic Coulomb stress changes due to the water load in the Pirrís reservoir Overall, the results of this study will provide important conclusions about the sensitivity of certain parameters to evaluate and model the effects that filling operation in reservoirs have on the seismic activity in the close reservoir area.

ESC2018-S32-189

DISCRIMINATING INDUCED FROM TECTONIC SEISMICITY NEAR ROOSEVELT HOT SPRINGS, UTAH, U.S.A.

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An important goal of induced seismicity studies is to clearly discriminate induced earthquakes from naturally occurring earthquakes. Here, we present a case study where we analyze seismicity located in close proximity to the Roosevelt Hot Springs. The hot springs are located in the eastern Great Basin, part of the Basin and Range physiographic province, in south-central Utah. A 34-megawatt geothermal power plant has been in operation here since 1984. A temporary seismic network located in the area caught an energetic swarm (1044 microearthquakes, M less than 1.5) during the summer of 1981 that located in an east-west striking orientation beginning roughly from the location of the power plant to ~5 km to the east into the Mineral Mountains. Analysis of the University of Utah Seismograph Stations (UUSS) earthquake catalog shows that the areal extent defined by the 1981 swarm is the most seismically active area in the region. Explanations for the swarm and other seismic activity in the area include fluid migration associated with the geothermal body or associated with pumping at the power plant or thermal contraction of rocks at depth from heat transfer. Alternatively, events in the area are the consequence of tectonically driven east-west extension in the Basin and Range, as was concluded for the 1981 swarm. To explore potential mechanisms for seismicity in the area and discriminate between different seismic source types, we use the UUSS earthquake catalog 1981–2016 magnitude of completeness ~1.5, and 2017–present magnitude of completeness ~0.5. Events on the western side of the swarm area tend to locate near injection wells associated with the power plant and are more shallow than those located to the east. In this study, we first enhance the local catalog by using events in the UUSS catalog (1981–2016) to construct subspaces that are run across continuous data to detect small magnitude events missed in routine processing, and we add events detected by two large-N experiments. We use GrowClust to get relative locations and use principal component analysis to identify potential faulting structures. We use the time progression of swarms to look for effects of diffusion, and we compare earthquake rates to the pumping history at the power plant. We also look at available focal mechanisms to deduce maximum stress orientations. Results from this analysis suggest that there is both seismicity associated with activities at the power plant and natural seismicity. However, the natural seismicity may be induced by the underlying geothermal system.

ESC2018-S32-191

REPROCESSING THE SEISMICITY OF THE ROTENBURG, GERMANY REGION - INDICATION FOR DIFFERENT SOURCE PROCESSES

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The seismicity in the Rotenburg region is reprocessed by correlation techniques, adjusted

velocity models with changing vP/vS ratios, identification of later phases, and master event relocation. Results show improved match to mapped faults, and resolve seismic activity in different depths. The 2004 ML 4.5 main shock is postulated as probably tectonic event at the western Schneverdingen Graben fault, while some later aftershocks and the recent activity in 2016/17 appear at the central Söhlingen fault in reservoir depth, outside the main shock fault plane. The 2012 ML 2.9 Visselhövede event exhibits both properties of depletion-induced and tectonic earthquakes.

ESC2018-S32-230

COMPARABLE MOMENT MAGNITUDES FOR INDUCED AND TRIGGERED EARTHQUAKES

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Regulations often require measuring comparable magnitudes for low magnitude earthquakes occurring at shallow depths and in regions, where no historical seismicity occurred. Estimated magnitudes of such microseismic events depend on sensor properties, network geometry and site conditions, and are often not comparable from one operation to another and between operators. We therefore suggest an approach to estimate moment magnitudes and their uncertainties from peak amplitudes employing full waveform synthetic seismograms. Not only does the new method preserve established routines of traditional procedures for magnitude determination, it also overcomes some of the limitations as saturation, high variability of station magnitudes and source complexity. Attenuation functions are derived on-the-fly for each station and source location from synthetic seismograms using Green's function databases. Different velocity models can be used to calculate these Green's functions, and sensors may be placed at the surface or at depth. Source depths, network geometry, dynamic and kinematic parameters such as stress drop and rupture velocity are randomly selected in a bootstrap approach within ranges that are realistic for the studied problem. After calibration with a set of observations, attenuation functions can be extrapolated to distances, depths, regions and magnitudes for which no observations exist. Additionally, individual frequency filters and sensor types can be applied independently of any definition of traditional magnitude scales. Uncertainties of attenuation functions are estimated for every source-station geometry taking into account sensor characteristics and possible frequency saturation. Thus, realistic uncertainties of mean magnitudes can be estimated even in case of only few existing measurements. The method is especially useful to estimate local and moment magnitudes for temporary deployments or for monitoring induced seismicity in regions or for source depths, where only few tectonic events occur. We demonstrate the approach employing an example from a mining area in Germany and a gas field in the Netherlands.

ESC2018-S32-265

INVESTIGATIONS OF RESERVOIR TRIGGERED SEISMICITY (RTS) AT KOYNA, INDIA

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Reservoir triggered seismicity (RTS) is one of the most damaging consequence of human interventions. So far RTS has been observed at over 100's sites globally. At four of these sites triggered earthquakes exceeded magnitude 6 occurred. These were locally damaging. Koyna earthquake of M 6.3 on December 10, 1967, near the west coast of India is so far the deadliest RTS event having claimed over 200 human lives and destroying the Koyna Township. Unlike other RTS sites, where triggered earthquakes ceased to occur in an year to a few years time, RTS at Koyna has continued till now, including 22 earthquakes of M ≥ 5; about 200 earthquakes of M ≥ 4 and several thousand smaller earthquakes. Detailed studies of RTS sequences have lead to identification of their common characteristics that differentiate them from normal earthquakes and also help in finding safer sites to construct artificial water reservoirs. At Koyna, correlation between reservoir levels, the rate of loading/unloading, how long high water levels are retained and whether the previous water level maximum has been exceeded and RTS is well established. However, due to lack of near field observations, the role of the reservoir in triggering earthquakes

is not well understood. As earthquakes occur in an area of 30 km x 20 km, are shallow (mostly between 2 and 9 km depth), there are no other sources of earthquakes within 100km of Koyna Dam, the temperatures at a depth of 6 km are estimated to be ~ 120° C, and the region being accessible for all kind of experiments and observations, the Koyna site has been found to be the most suitable RTS site for near field studies. This issue was discussed in two International Continental Drilling Program (ICDP) workshops held at Koyna and Hyderabad in 2011 and 2014. A 3 km deep Pilot Borehole has been completed in June 2017 and necessary measurements have been conducted. Inputs from these observations would help in designing the proposed 7 km deep borehole.

ESC2018-S32-270

ASSESSING THE INDUCED SEISMICITY BY HYDRAULIC FRACTURING AT THE WYSIN SITE (POLAND): A MULTIDISCIPLINARY MONITORING APPROACH

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The induced seismicity response of shale gas exploration and exploitation is assessed for a real-scale hydraulic fracture (HF) experiment in Europe at the Wysin site, Poland. This is the first case where an independent, dense, dedicated multidisciplinary monitoring has been set up. The monitoring system, deployed and operated in the framework of the EU project SHEER, includes seismic, water and air quality monitoring. HF operations were carried out along two horizontal boreholes at a depth of ~4 km, during 10 days each in June and July 2016. We present here the outcomes of the seismological analysis. Shallow artificial seismic noise sources are detected and located at the wellhead, active during the fracturing stages for periods of 1.5-2 h. These noise transients affect the signal-to-noise ratios at shallow borehole installations closest to the injection well, increasing the magnitude of completeness during day hours by ~0.25. We detect, locate and characterize weak microseismicity, culminating in two events of Mw 1.0 and 0.5, occurring days after the stimulation in the vicinity of the operational well, but at very shallow depths. The simultaneous water and air monitoring reveals a sharp methane peak ~19 hours after the Mw 0.5 event, while no correlation is found among seismicity and groundwater parameters.

ESC2018-S32-271

NEAR-REAL TIME DETECTION AND LOCATION OF MICROSEISMIC EVENTS WITH PARALLEL COMPUTING

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A robust solution to the problem of the prompt detection and characterization of micro-seismic events is of great interest in the monitoring of the seismicity at local scale and is essential in the application of possible safety procedures related to induced seismicity. Given the large number of events handled by microseismic monitoring, automated procedures for detecting and locating micro-events are mandatory. The main difficulty in the implementation of these procedures consists in the low signal to noise ratio which characterizes the traces of the micro-events collected by a local seismic network. we describe an automatic earthquake detection and location procedure that we implemented with the parallel computing approach and which allows the simultaneous detection and location of micro-seismic events in near-real time using waveforms from a local seismic network. The implemented technique is based on the migration of waveform data and consists in the following steps: 1) the enhancement of possible P and S arrivals in noisy signals through an appropriate characteristic function, that is evaluated by means of the Frequency-Time analysis of the seismic records; 2) the blind application of the location method based on the delay-and-sum approach with a systematic scan of an arbitrarily large spatial grid of potential hypocenters; 3) notification of detection according to the statistical characteristics of the image obtained on the spatial grid. We tuned the

technique with synthetic data and tested it by applying it to a couple of swarms of low magnitude events that occurred recently in Veneto region (Italy), in the area monitored by the Collalto seismic network . Our procedure detected almost 97% of the manually recognized events with a reduced number of false alarms. Our automated locations are consistent with those obtained using manual picks. In order to ensure a near-real time execution with a grid of almost xy-millions of potential hypocenters, the procedure required to run on xy cores of an up to date computational server.

ESC2018-S32-272

SEISMICITY BASELINE AND MONITORING GEOTHERMAL ACTIVITIES IN THE GREATER GENEVA BASIN, WESTERN SWITZERLAND

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Switzerland is promoting the development of renewable resources of energy. In particular, the Canton of Geneva and the Industrial Services of Geneva (SIG) are investigating the geothermal energy potential of the Greater Geneva Basin, Western Switzerland. Before exploration starts it is crucial to study the local seismicity and its relationship with local tectonic structures. Additionally, it is important to monitor the seismic activity that may occur due to geothermal activities. Historical and instrumental seismic catalogues indicate sparse and disperse seismic activity in the area. This could partially be a result of the scarce seismic stations deployed in the basin. Thus, in a first step we deployed 20 broadband stations around and within the Greater Geneva Basin to set the baseline for the seismicity before geothermal exploration begins. We used LASSIE, a new open-source software, capable to automatically and efficiently detect and locate weak seismic events, even in a high noise contamination environment. With the densification of the regional network and using LASSIE we detected small magnitude events

ESC2018-S32-315

BRIDGING GAPS IN INDUCED SEISMICITY HAZARD FORECASTING IN ALBERTA, CANADA

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A sharp increase in the frequency of earthquakes near Fox Creek, Alberta began in December 2013 in response to hydraulic fracturing. Using a hydraulic fracturing database, we explore relationships between injection parameters and seismicity response. We show that induced earthquakes are associated with completions that used larger injection volumes (104-5 m3) and that seismic productivity scales linearly with injection volume. Injection pressure and rate have an insignificant association with seismic response. Further findings suggest that geological factors play a prominent role in seismic productivity, as evidenced by spatial correlations. Together, volume and geological factors account for ~96% of the variability in the induced earthquake rate near Fox Creek. This result is quantified by a seismogenic-index modified frequency-magnitude distribution, providing a framework to forecast induced seismicity. To account for geological factors, we train a machine learning algorithm to systemically evaluate tectonic, geomechanical, and hydrological proxies suspected to control induced seismicity. Feature importance suggests that proximity to basement, in situ stress, proximity to fossil reef margins, lithium concentration, and rate of natural seismicity are among the strongest model predictors. Our derived seismogenic potential map faithfully reproduces the current distribution of induced seismicity and is suggestive of other regions which may be prone to induced earthquakes. The refinement of induced seismicity geological susceptibility may become an important technique to identify significant underlying geological features and address induced seismic hazard forecasting issues.

ESC2018-S32-318

ACCURATE ESTIMATION OF SEISMIC SOURCE PARAMETERS OF INDUCED SEISMICITY BY A COMBINED APPROACH OF GENERALIZED INVERSION AND GENETIC ALGORITHM: APPLICATION TO THE GEYSERS GEOTHERMAL AREA, CALIFORNIA

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The accurate determination of stress drop, seismic efficiency, and how source parameters scale with earthquake size is an important issue for seismic hazard assessment of induced seismicity. We propose an improved nonparametric, data-driven strategy suitable for monitoring induced seismicity, which combines the generalized inversion technique together with genetic algorithms. In the first step of the analysis the generalized inversion technique allows for an effective correction of waveforms for attenuation and site contributions. Then, the retrieved source spectra are inverted by a nonlinear sensitivity-driven inversion scheme that allows accurate estimation of source parameters. We therefore investigate the earthquake source characteristics of 633 induced earthquakes (Mw 2–3.8) recorded at The Geysers geothermal field (California) by a dense seismic network (i.e., 32 stations, more than 17.000 velocity records). We find a nonself-similar behavior, empirical source spectra that require an ?? source model with ? > 2 to be well fit and small radiation efficiency ?SW. All these findings suggest different dynamic rupture processes for smaller and larger earthquakes and that the proportion of high-frequency energy radiation and the amount of energy required to overcome the friction or for the creation of new fractures surface changes with earthquake size. Furthermore, we observe also two distinct families of events with peculiar source parameters that in one case suggests the reactivation of deep structures linked to the regional tectonics, while in the other supports the idea of an important role of steeply dipping faults in the fluid pressure diffusion.

ESC2018-S32-319

TEMPORAL CHANGE IN SHEAR-WAVE ANISOTROPY FROM INDUCED SEISMICITY IN THE US MIDCONTINENT LINKED TO CHANGE IN PORE FLUID PRESSURE

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The midcontinent of the United States has seen a dramatic increase in seismicity over the past decade. It is widely believed that this increase in seismicity is caused by the increase in wastewater injection into the Arbuckle carbonate saline aquifer, directly above the granitic basement. The increased injection volume is causing an increase in pore fluid pressure in the Arbuckle as well as the underlying fractured basement. However, in-situ pore pressure measurements are sparse, only sufficient to confirm a regional increase in fluid pressure, but not monitor it spatially. Here, we test non-invasive shear-wave anisotropy methods to identify changes in anisotropy that correlate to an increase in pore fluid pressure. S-wave anisotropy, the phenomenon which describes the splitting of shear-waves in two components (Sfast and Sslow) traversing the medium with different velocities, is known to be sensitive to pore fluid pressures. Data is taken from the Wellington Monitoring Network in southern Kansas (U.S.A.) from 2015 through 2017. S-wave anisotropy shows a change in the orientation of the fast S-wave over this time period, indicative of a change in pore fluid pressure. This methodology could be used to monitor for pore fluid pressure changes over a region, providing cost-efficient, denser spatial coverage compared to pressure monitoring wells. Acknowledgements: The study was partly supported by the Greek Diaspora Fellowship Program (GDFP), funded by a grant from the Stavros Niarchos Foundation (SNF).

ESC2018-S32-322

FAMILIES OF REPEATED EARTHQUAKES IN SOUTHERN KANSAS, CENTRAL UNITED STATES, INDUCED BY WASTEWATER DISPOSAL: WHAT CAN THEY TELL US?

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Seismicity catalogs that are complete to small magnitudes are valuable for investigating the relationship between seismicity and saltwater disposal (SWD). In southern Kansas, Central United States, the rate of earthquakes rose rapidly starting in 2013 following expansion of energy production into the area, demanding the disposal of large volumes of fluid by-products (saltwater) into deep wells. Rubinstein et al. (2018) developed a catalog of earthquakes for southern Kansas from mid-March 2014 through December 2017 using routine earthquake detection techniques. We use that catalog and a matched-filter algorithm to expand the available catalog from 5,831 to more than 130,000 earthquakes. From the matched-filter catalog we identify template events with a large number of associated detections and examine the characteristics of these families of earthquakes. For the most prolific families, we examine the spatial and temporal distribution of these events within the study area, their recurrence times, and spatial relationships to larger magnitude earthquakes and disposal wells. We find that families close to areas with significant volumes of injected fluids tend to have more regular recurrence times, lower median magnitudes, and are more likely to occur throughout the duration of the study period. We infer that in regions near large-volume wastewater disposal, the higher fluid pressures act to drive repeated failure of fault patches.

ESC2018-S32-342

DESIGN AND IMPLEMENTATION OF A TRAFFIC LIGHT SYSTEM FOR GEOTHERMAL STIMULATION IN FINLAND

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St1 Deep Heat is developing a geothermal doublet for the purpose of delivering deep geothermal heat to local district heat networks. As part of the project, two circa 6.5 km deep wells are intended to be drilled as a geothermal doublet in the Otaniemi neighbourhood of the City of Espoo, which is located just west of Helsinki in Finland. The first well will be stimulated in early summer 2018 in order to improve the rock permeability in contact with the wells. In order to reduce the seismic hazard and mitigate the associated risk, the City of Espoo's buildings department has required that a seismic Traffic Light System (TLS) be developed and approved before permission is granted for st1 Deep Heat to perform well stimulation activities. The stimulation will take place in a densely populated area with multiple sensitive receptors, where historically-low levels of natural seismicity and hard-rock local geology contribute to a high local perception of potential induced seismicity. From a regulatory point of view, the absence of existing local data prevents the design of a TLS solely based on forward-looking models, as there is no guarantee that such models will apply in the case of the stimulation in Otaniemi. The TLS in Otaniemi therefore relies on conservative thresholds and associated hazard mitigation measures. Two seismic monitoring networks have been put in place, which are used to inform the TLS: a 'surface' monitoring network designed to identify where surface expressions of seismic events exceed thresholds and a 'satellite' monitoring network to estimate the source parameters of potential induced seismic events. The surface monitoring network is composed of 13 1Hz 3-component geophones located at the surface and in the basement of sensitive receptors in order to quantify peak ground velocity (PGV) and peak ground acceleration (PGA). The satellite network is composed of 12 4.5Hz 3-component gimballed geophones installed in boreholes at depth ranging from 240 to 1,200m. The TLS amber and red thresholds are based on the surface expression of induced seismicity, together with associated magnitudes, where the associated thresholds have been established following a probabilistic approach. The combination of both seismic monitoring networks and the dual stream of data prevents false alarms related to surface expression not due to an induced seismic event. Both geothermal specific ground motion prediction equations (GMPEs) from Doulas et al. (2013) and GMPEs developed specifically for Finland have been used in the design of the TLS. The TLS triggers are therefore based on either of two scenarios: a surface expression associated with stimulation-induced seismicity or potential surface expression associated with stimulation induced seismicity. The PGV levels used to design the TLS have been developed in accordance with Finnish Building Code and British Standards on surface vibrations. However, Finnish standards are

only related to construction blasting activity and therefore needed to be adapted for the determination of PGV thresholds. Specific PGV and PGA thresholds were gathered for sensitive receptors and related to earthquake magnitudes in a probabilistic way. More specifically, the selection of associated magnitude thresholds is based on the probability that a seismic event at depth will translate to an exceedance at ground surface. Magnitudes were selected based on a conservatively low probability of 2% that the seismic event would result in a PGV at surface sufficient to cause a TLS exceedance. The selected magnitudes are as follows: for an amber PGV threshold of 1 mm/s, a magnitude of 1.0 was selected while for a red PGV threshold of 7.5 mm/s, a magnitude of 2.1 was selected. TLS exceedances solely based on magnitude have also been adopted in order to address data gaps in the surface network. Magnitudes were initially selected on the basis that there is at least a 10% probability that the magnitude results in a PGV at surface which exceeds a TLS threshold and were then lowered to magnitude 1.2, in order to account for possible magnitude drag effect. For the red threshold, the conservative probability of 2% that the magnitude results in a PGV at surface which exceeds a red threshold was selected. Communication and reporting plans have also been developed with the TLS, together with the mitigation measures associated to the event of a TLS exceedance.

ESC2018-S32-350

INTERPRETATION OF MICROSEISMICITY OBSERVED FROM SURFACE AND BOREHOLE SEISMIC ARRAYS DURING HYDRAULIC FRACTURING IN SHALE - BEDDING PLANE SLIP MODEL

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Passive seismic monitoring of microseismic events induced in oil or gas reservoirs is known as microseismic monitoring. Microseismic monitoring is used to understand the process of hydraulic fracturing, which is a reservoir stimulation technique. We present a geomechanical model explaining microseismicity induced by hydraulic fracturing in shales developed from datasets acquired with two most common types of seismic monitoring arrays, surface and dual-borehole arrays. The geomechanical model explains the observed source mechanisms and locations of induced events in two stimulated shale reservoirs. We observe predominantly shear dip-slip source mechanisms with one nearly vertical nodal plane aligned with location trends. The locations of events are propagating from the injection well(s) in direction of maximum horizontal stress in the region. We show that such seismicity can be explained as a slippage along bedding planes activated by aseismic opening of vertical hydraulic fractures. The model explains also the large difference between seismic and hydraulic energy.
We have processed two datasets acquired during hydraulic fracturing in shale. The first dataset is from a stimulation of vertical well monitored with dual borehole array and the second dataset was acquired during a stimulation of four horizontal wells with a dense star-like array of receivers deployed at the surface. There were detected tens and hundreds of events in borehole and surface dataset, respectively. The observed seismicity from both surface and downhole monitoring of shale stimulations is very similar in terms of locations, source mechanisms, and inverted stress fields. The locations of induced microseismic events are limited to narrow depth intervals (within the uncertainty of their locations) and propagate along distinct trend(s) showing fracture propagation from injection well(s) in direction of maximum horizontal stress and perpendicularly to minimum horizontal stress in the area(s). The source mechanism inversion was applied only to selected high-quality events with sufficient signal-to-noise ratio. We inverted P- and P- and S-wave arrival amplitudes to deviatoric and full-moment tensor solutions and decomposed it to shear, volumetric and compensated linear vector dipole components. We carefully tested the quality of obtained results comparing L2-misfits between deviatoric and complete full-moment tensor solutions. We also tested an effect of noise presented in the data to evaluate the reliability of non-shear components. We see a dominant shear component with small or almost none percentage of the non-shear component, which can be partly explained as an effect of noise in the data. We observe predominantly dip-slip events with a strike of the steeper (almost vertical) nodal plane

parallel to the fracture propagation. Therefore, the second possible nodal plane is almost horizontal. The rake angles of the observed mechanisms divide these dip-slips into two groups with opposite polarities. It means that we observe opposite movements on the nearly identically oriented faults. Realizing a typical structural weakness of shale in horizontal planes, we interpret observed microseismicity as a result of shearing along horizontal bedding planes caused by seismically silent (aseismic) vertical fracture opening caused by fluid injection. For the surface dataset, we get also events with the strike-slip type of source mechanisms. These strike-slips have higher non-shear component but still dominant shear sense of motion but they occurred after the fracturing during so-called the flowback, therefore, we think they are not directly connected to new fracture creation. We have inverted also the orientations of three principal stress axes that best accounts for a set of shear source mechanisms and shape ratio. The homogeneous tectonic stresses are similar for both processed datasets. We have obtained maximum stress in almost vertical direction, as it is typical for sedimentary basins in the depth around two km depth, and medium and minimum stress axes in the horizontal direction. We explain that the shear dip-slip events are the result of bedding plane slip along preexisting weak bedding planes loaded by the aseismic hydraulic fracture opening. This model can explain events located along the fracture as well as the multiplets and the orientation of the observed nodal planes with respect to the stress orientation. This model agrees with a large amount of fluid containing proppant being pumped into the reservoir, which is then stored in the aseismic vertical fracture. The observed strike-slip events probably resulted from the reactivation of favorably oriented preexisting fractures or faults.

ESC2018-S32-356

SEISMICITY INDUCED BY HYDRAULIC FRACTURING IN THE CENTRAL AND EASTERN UNITED STATES

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We have investigated seismicity potentially associated with hydraulic fracturing (HF) in several areas of the Central and Eastern United States to improve our understanding of this relationship. In general, we find that HF induces M>2 seismicity more often than generally assumed and is the dominant source of seismicity in some areas. Detailed investigations of seismicity induced by HF indicate that the maturity of nearby faults plays a key role in the types of seismicity that are produced. In Oklahoma, we collected all available information on timing and location of HF to evaluate their relationship to seismicity. Utilizing an enhanced seismicity catalog generated with multi-station template matching from 2008-2016, we identified ~100 earthquake sequences that are strongly spatiotemporally correlated with HF wells. We were guided to these sequences by calculating a ? earthquake rate for each HF well based on seismicity before, during, and after, and then sorting wells to focus on those with the highest change in rate during stimulation. The cases we identify were spread across the state and included wells in the SCOOP, STACK, Ardmore, and Arkoma plays that have been the focus of recent development in the southern and western parts of the state. In some regions, >90% of the seismicity was correlated with reported HF wells, and in some cases >50% of the HF wells were correlated with seismicity. We found ~500 earthquakes with M 2.0-3.5 that are best explained by being induced by HF. These findings imply state regulations implemented in 2018 that require operators to take action if a M>2 earthquake occurs could have a significant impact on future operations. In Ohio, we used an array of local stations in Harrison County to examine seismicity since 2013, employing multistation template matching to Improve detection, waveform correlation to improve phase arrivals, and double difference relocation to improve the hypocentral characterization. Our analysis revealed 2 distinct groups: 1) deeper earthquakes in Precambrian basement, with larger magnitudes (M>2), b-values

ESC2018-S32-414

INDUCED SEISMICITY IN THE COOPER BASIN (AUSTRALIA): AFTERSHOCKS, SEISMIC EFFICIENCY, AND FLUID DIFFUSION

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Long-term fluid-injection experiments that have been conducted in geothermal fields in the Cooper Basin (Australia) have created large numbers of induced earthquakes. We have analyzed catalogs of the seismicity that has occurred within a time interval between 2003 and 2012. We investigate Relative Locations of Consecutive Earthquakes (RLCE) to establish links between location and magnitude. The RLCE show a peculiar physical effect, here called "Christmas-tree" effect, namely smaller event separations towards higher magnitudes. An attempt is provided to explain the effect by inspecting the clustering ("aftershocks") that has occurred for events with magnitudes between 1 to below 4. Seismic moment release has varied strongly during the injection history, also in function of the treatment parameters of the fluid injection, changing the "seismic efficiency". That could serve as a way to distinguish "triggered" from "induced" earthquakes. Finally, we focus on the relation between seismicity and the injected fluid volume, e.g., fluid diffusion along a planar ("2D") feature in the subsurface, a localized single fault or fracture plane as an alternative to the 3D diffusion that is often considered. The 2D front is then compared to the classical volumetric (3D) fluid diffusion, in relation also to the injection history. For the Cooper Basin, seismicity seems to be controlled by processes occurring on individual faults that become hydraulically conductive. Such a model seems to explain the observed seismicity, fracture, and aftershock extension.

ESC2018-S32-422

FAULT STRUCTURE AND DYNAMICAL CHARACTERIZATION OF THE 1982-2015 SEISMICITY OF ASWAN REGION (SOUTH EGYPT)

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The Aswan region (south Egypt) hosts the second largest reservoir in the world, the Lake Nasser. This artificial lake, with a gross capacity of 169 billion cubic meters, was created by the impounding of the Nile's waters behind the Aswan High Dam (111 m high) constructed between 1960 and 1971. On November 14, 1981, a Ms 5.3 earthquake took place south of the dam. Since 1982 a network of 13 stations was established to monitor seismicity around the lake, and intense seismic activity has been recorded. Since 2009, the Aswan seismic network has been updated and replaced by a new digital broadband network. The seismicity occurred in Aswan region from 1982 to 2015 was investigated using robust statistical methodologies in order to better characterize its time dynamics. The completeness magnitude was found to be 2.5 for the whole catalogue. A dataset consisting of 7,813 earthquakes, with a total number of 42,394 P-wave pickings and 31,776 S-wave pickings was organized. After that, the collected P- and S-wave arrivals were jointly inverted to establish a 1-D velocity model for the Aswan area and to perform a preliminary earthquake location. Furthermore, a modified Wadati diagram was computed for the complete dataset: under the assumption of a homogeneous medium, a Vp/Vs value equal to 1.73 was inferred. The obtained 1-D P- and S-wave velocity models were used to perform a probabilistic, non-linear, global-search absolute earthquake location and, subsequently, a relative location of the seismicity through the double-difference technique with the aim to better delineate the faults of the area and to study the space-time distribution of the observed seismicity. In particular, we found that deep seismicity is mainly characterized by mainshock-aftershocks sequences and occurred mostly on the Western side of Kalabsha Fault whereas shallow seismicity is mainly induced by the Lake Nasser and occurs in correspondence of the intersection of the Kalabsha Fault with other faults of the area; here oblique strike-slip motions of shallow earthquakes have been observed. The analysis of the time-clustering properties of the shallow earthquakes has revealed the presence of annual modulation that is not evident in the time dynamics of the deep earthquakes. Furthermore, the shallow events are featured by the Allan Factor scaling exponent (measuring the strength of the time-clustering in an earthquake sequence) lower than that of the deep events, indicating a tendency of the time dynamics of the shallow earthquakes to behave more regularly than the deep ones. The b-value estimated for the whole

catalogue was 1.07; anyway, subdividing it into declustered deep events and shallow events sub-catalogs, a higher b-value (1.11) of shallow seismicity with respect to the b-value (0.94) of deep seismicity has been found.

ESC2018-S32-454

SEISMICITY INDUCED BY HYDRAULIC FRACTURING IN OHIO IN 2016: CASE STUDY OF THE CONOTTON SEQUENCE IN HARRISON COUNTY

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In November of 2016, a sequence of hydraulic fracturing induced seismicity was observed in Harrison County, Ohio. The events in this sequence were ≤ M 2.7 and were spatiotemporally correlated with hydraulic pumping stages from the Conotton horizontal wells. A series of adjacent wells to the west of the Conotton wells also induced seismicity along an east-west trending basement fault system. The fault's east-west trend extended beneath the Conotton horizontals based on seismicity observed in 2015, and the seismicity from the Conotton stimulation is an extension of the same fault system. Using a 5 station seismic network, 129 earthquakes were located using Hypoinverse. Relative locations were obtained using HypoDD and demonstrate that the activity was split into two depth populations: those that were shallow and directly below the Paleozoic Utica formation in which hydraulic fracturing was happening, and those that were deeper and related to the crystalline basement fault system. In addition, cross-correlation template matching techniques were used to observe some ~1200 detections of earthquakes with M > -0.85. Interestingly, the b-value evolved from values > 1 early in the sequence to < 1 when the larger events started happening. During the sequence, the operator took mitigation actions by skipping stages and reduced volume across stages that were closer to the fault. Production data from the wells were also examined to investigate how interactions with a fault influence produced oil, gas, and brine.

ESC2018-S32-469

SOURCE MECHANISMS OF POST-BLASTING TREMORS OBSERVED IN DEEP MINE ENVIRONMENT - SYNTHETIC AND REAL DATA TESTS.

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Legnica Glogów Copper District (LGCD) located in south-western Poland is an area characterized with very high seismic activity induced by mining. Every year more than 2000 induced seismic events with M>1.5 are recorded in the district. While most of the tremors are rather weak, some of strong events cause rockbursts or rockfalls inside the underground tunnels. To minimize the rockburst hazard, several different passive and active prevention methods are used. Among others, the method based on blasting is considered as the most effective way to decrease stress accumulation in the vicinity of mining faces. The seismic activity, including weak to moderate seismic tremors, is usually increased short time after blasts. For such kind of after-blast seismicity, we can expect some common features in source mechanisms, including existence of non-double-couple (isotropic) component in the full moment tensor (MT). This knowledge can be used later to increase the effectiveness of prevention activities, e.g. rock support etc. In this work, we show the results from synthetic tests obtained for the real in-mine seismic network consisting of more than 30 sensors, located inside the tunnels. The synthetic waveforms for different types of source models with both non-double-couple and pure double-couple sources were used to test the sensitivity of different components of full MT to different number of sensors and azimuthal coverage. Real data was inverted to obtain the MT of selected seismic events. The synthetic tests were used to define the limitations of the results.

ESC2018-S32-514

IMPLEMENTING ADAPTIVE TRAFFIC LIGHT SYSTEMS FOR MANAGING INDUCED SEISMICITY: STATUS AND OUTLOOK

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Traffic light systems (TSL) are today an essential ingredient of induced seismic risk management. Their simplicity and robustness make them indispensable components of future GeoEnergy projects at risk of inducing felt earthquakes. However, classical TLS are purely reactive and inherently heuristic. They do not take into account the wealth of information available in near real-time. We are currently developing the next generation of TLS, Adaptive Traffic Light Systems (ATLS), which are data driven (i.e., updating forecasts as new data arrives), model-based (i.e., using statistical and physics-based models of the reservoir for probabilistic forecasts and scenario computations) and risk-based (i.e., integrating rate forecasts, ground motion prediction, exposure and vulnerabilities into a quantitative assessment of risk). In this presentation we review the key ingredients of ATLS, discuss the performance based on retrospective analyses and the roadmap towards real-time applications.

ESC2018-S32-518

MICROSEISMIC MONITORING IN A CAVERN FIELD NEAR HENGELO, THE NETHERLANDS

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M. den Hartogh, H.J. Leusink, R. van Steveninck, J. Wondrak, T. Schicht, N. Vollmer AkzoNobel mines Röt salt from its brinefield near the city of Enschede at depths of approximately 400 meters. The development of the brinefield Hengelo took place in 4 phases: 1. 53 wells drilled 1934-1958 from which 42 caverns are developed; 2. 225 wells drilled 1958-1975 from which 94 caverns are developed; 3. 226 wells drilled 1976-2007 from which 85 caverns are developed; 4. 53 wells drilled 2008-2017 from which 52 caverns are being developed. In the oldest part of the brinefield uncontrolled leaching took place. Most of these caverns started migrating through the overburden; some of them caused significant surface subsidence. Currently the subsidence decreases through time. AkzoNobel now proceeds to finally close this area. During production from the wells from 1958-1975 AkzoNobel gradually introduced controlled leaching methods like using a blanket, regular sonar measurement and completion adjustments. However the control measures were not implemented according to current criteria straightaway, leading to overmining. In 2004 the so-called Good Salt Mining Practice (GSMP) was developed for the Hengelo brinefield. In the GSMP two criteria are defined to prevent overmining. One is cavern stability, meaning that the roof of the cavern should have a minimum thickness of 5 meters in the salt formation. The other criteria is inherent safety, meaning that the height of the cavern is limited such that if cavern migration would occur the migration will extinguish before reaching the less consolidated soil layers. When the GSMP was applied it was found that the caverns created from the wells from 1976 onwards were in compliance with these criteria. However of the caverns from the period 1958-1975 currently 41 are potentially instable and not inherently safe. Another 11 are not inherently safe, but still stable. Currently none of these caverns is migrating. However migration of these caverns in the future could cause significant surface subsidence. In 2016 AkzoNobel reanalyzed the risks associated with these caverns. In order to reduce the risks pro-actively AkzoNobel and K-UTEC have developed a fit-for-purpose microseismic monitoring system enabling tracking cavern migration right from the onset. Until November 2017 the system comprised two seismometers at the ground surface and two hydrophones in two different caverns at a depth of approximately 350 m. Between November 2017 and January 2018 the system was extended and comprises three borehole seismometers in depths of 40 m and three hydrophones in three different caverns at depths between 350 m and 520 m. Monitoring started in January 2016 and over time K-UTEC has built up knowledge to separate noise from signal. Since the installation of the extended seismological survey several seismic events have been detected and analyzed. The recording and subsequent visualization of these events show that the installed micro-seismic monitoring system is capable of detecting very small micro-seismic events. Further steps in preventive risk reduction are backfilling caverns based on risk prioritization with solids from our brine purification, investigating additional backfilling materials and further investigation of the parameters controlling cavern migration.

ESC2018-S32-519

MICROSEISMIC MONITORING OF THE GAS STORAGE CONCESSION "MINERBIO STOCCAGGIO" (BOLOGNA, NORTHERN ITALY)

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The storage concession "Minerbio Stoccaggio" (Bologna, Northern Italy), covers a 69 km^2 area, 65% of which is located in the Minerbio municipality. In 1997, the Italian Ministry of Economic Development (MiSE-DGS-UNMIG) conferred the storage permit to Stogit S.p.A., the main Italian company dealing with natural gas storage activities. In 2016, in the framework of an operating protocol signed by MiSE, Emilia Romagna region and Stogit, concerning the concession "Minerbio Stoccaggio", the INGV (Istituto Nazionale di Geofisica e Vulcanologia) was commissioned to carry out specific investigations aiming to assess the applicability of the guidelines for monitoring of anthropic activities issued by MiSE in 2014 (MiSE-DGS-UNMIG, 2014). In this work we describe the analysis conducted by INGV during the start-up phase of the project. As a first step, the now operating microseismic network, consisting of three surface stations and one 100 m deep borehole sensor with inter-station distance of about 2.5 km, has been integrated with the regional stations of the Italian National Seismic Network (RSN). The final network configuration consists of 19 stations installed in a 80x80 km^2 area, connected in real time with the data acquisition center of INGV - Milan. Preliminary analyses of ambient seismic noise recorded within the surface projection of the storage reservoir, show average values of the acceleration power spectral density (PSD) of about -110 dB with respect to 1 (m/s^2)^2/Hz, in the frequency range 1-30 Hz. These values are comparable with the High Noise Model curve of Peterson (1993). The borehole sensor, installed in the same area, shows average values of PSD of about -120 dB. The storage reservoir, a depleted gas field exploited until 1971, is represented by a series of sandy levels of turbiditic nature belonging to the Porto Garibaldi Formation (Plio-Pleistocene) with a thickness of about 80 m, separated by clayey levels of limited thickness. The initial gas-water contact identifies a surface of 8 km^2 located at 1370 m depth. We adopt this level as a reference in order to define the crustal volumes involved in monitoring. According to the above mentioned guidelines, we define the inner domain of detection, DI (10 x 10 x 5) km^3 , within which we should ensure the highest network performance, and the extended domain of detection, DE (22 x 22 x 11) km^3. By comparing the simulated power spectral density of hypothetical seismic sources located in DE with the meanpower spectra of the ambient seismic noise observed at each station-site, detection and localization thresholds are estimated for the now operative seismic network and for the network planned by Stogit, which will be implemented in the framework of the above mentioned operating protocol. Under unfavorable noise conditions (characterized by a PSD value corresponding to the 90th percentile of the observed PDF), operative and planned seismic networks allow to locate earthquakes with ML≥1.0 and ML≥0.8 respectively, occurring at the depth of the reservoir.

ESC2018-S32-521

SYNTHETIC EARTHQUAKE CATALOGS BY 3-D HM MODELLING OF GAS PRODUCTION

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Induced seismicity due to oil and gas production is a generally observed phenomenon. It has been agreed that slip on pre-existing faults is induced by poroelastic stress changes in the reservoir / surrounding rocks (Segall and Fitzgerald, 1998) and differential reservoir compaction due to the extraction (Roest and Kuilman, 1994). Synthetic earthquake catalogs by 3D HM Modeling using a generic model of the gas field from Northern Germany are aiming to investigate the hazard from induced seismicity. In this modeling approach, the mechanical behavior of the rock formation is based on poroelastic theory and Mohr-Coulomb failure criterion. The main features of our algorithm for earthquake catalogs are applying Griffith's fracture criterion to determine whether the faulting process has stopped and Clustering algorithm DBSCAN to discover multiple seismic events in one time step. Numerical results compare fairly well to measured reservoir pressures and observed subsidence data. Synthetic earthquake catalogs have shown

plausible features in time, space and magnitude distribution, but there are some magnitude gaps between relative big and small events. This also can be found in Gutenberg- Richter relation. The onset of seismic activity postdates the commencement of production by approximately 9 years. The induced earthquakes are weak with magnitudes (Mw) up to 2.0+. The Gutenberg–Richter b-value is about 1.4.

ESC2018-S32-533

INTEGRATED SEISMIC AND GROUND SURFACE DEFORMATION MONITORING OF A GAS STORAGE ACTIVITY IN NORTHERN ITALY: THE CORNEGLIANO LAUDENSE INTEGRATED NETWORK

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A new gas storage facility is currently under construction by Ital Gas Storage S.p.A. in a depleted gas reservoir located near Cornegliano Laudense (Lodi) in Northern Italy, in the hearth of the Po Plain, some tens of km south of Milano. The natural gas reservoir was discovered in 1951 and used for gas production until 1997, up to its economic depletion. The reservoir is located at a depth of 1.4-1.6 km and covers an area of 6 km2. The storage capacity at full operability is estimated in 1.5-2.0 BSmc. The gas storage plant is expected to start its operations in the second half of 2018. The gas storage facility plan foresees the realization of monitoring activities, according to the Italian Guidelines for Monitoring hydrocarbons exploitation, re-injection and gas storage activities. Therefore "integrated" monitoring operations are being developed, by exploiting both a dense local network for seismic monitoring and Differential Synthetic Aperture Radar Interferometry (DInSAR) techniques as well as some permanent GNSS stations for ground surface deformation monitoring. Such activities are carried out by two Italian public research institutions, i.e. the OGS (National Institute of Oceanography and Geophysics) and CNR-IREA (National Council of Research-Institute for Electromagnetic Sensing of the Environment), respectively, which have been associated through a specific agreement. The seismic monitoring is carried out by OGS. The network (code RMCL) has been operating since 2017 and it has been designed to detect the micro-seismicity in a volume surrounding the underground reservoir of about 3-5 km with a high degree of detail and sensitivity, as well as the natural seismicity in a larger volume up to 10-15 km of distance from the reservoir. RMCL consists of 10 new stations deployed at increasing distance from the reservoir and equipped with borehole broadband sensors (deployed at depth of about 75 m) and surface accelerometers. All sites feature soft alluvial soil down to a depth of even some hundred meters. One permanent GNSS station is co-located with a seismic station near the network center. The ground surface deformation monitoring is carried out by CNR-IREA. It consists in the yearly analysis of DInSAR data (SENTINEL-1 satellites) with a spatial resolution of 30-100 m; the interferometric analysis is constrained by the local GNSS stations together with some other stations located in the surroundings, at a distance of some tens of km. In addition, an analysis of the previous ground deformations is being carried out for the 1992-2010 time-span, using ERS-ENVISAT data and for the 2015-2017 time-span, using SENTINEL-1 data. The monitoring plan also includes the estimation of the data baseline for the two branches. To this aim, the natural background seismicity will be assessed using seismicity data acquired by the same network configuration before the beginning of storage activities for a time period of about 18 months; similarly, the past ground deformation history will be evaluated using the already mentioned 20-year dataset. In this presentation, we will describe the infrastructure of the integrated monitoring activities that is being realized for the Cornegliano Laudense gas storage facility and we provide some details about the seismotectonic context of the area and the regulatory framework set up by the Italian Guidelines for Monitoring. We will also present some preliminary results of the analysis carried out in order to evaluate the quality of the data acquired by seismic network as well as the data baseline (i.e. historical and background instrumental seismicity and past deformation history) for the two types of monitoring.

ESC2018-S32-540

A NEW STUDY OF THE PAST SEISMICITY OF THE CENTRAL ADRIATIC OFFSHORE (ITALY): THE 1987 PORTO SAN GIORGIO SEISMIC SEQUENCE

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In recent years, triggered/induced seismicity aroused great interest, especially in areas where hydrocarbon fields are located near active fault zones, as it happens in Italy (Bertello et al., 2010). In particular, after the 2012 Emilia earthquake sequence, the seismicity triggered/induced by hydrocarbon production operations has become an important topic and several earthquakes of recent and past seismicity have been investigated about a possible relationship with industrial operations (Grigoli et al. 2017). The challenge is to discriminate induced/triggered earthquakes from natural seismicity, especially if no specific seismic monitoring networks have been installed. In this context the study of historical and past seismicity close to hydrocarbon fields allow us to infer new insight about the mechanism that could trigger/induce earthquakes (Caciagli et al., 2015). The aim of this work is to provide new study of past seismicity of the Central Adriatic offshore (Italy) providing a refined relocation of 1987 Porto San Giorgio seismic sequence using advanced earthquake location technique and studying in detail the macroseismic intensity data. On 3 July 1987 at 10.21 (UTC) a Ml 5.0 earthquake struck Porto San Giorgio area (Central Italy) and started a seismic sequence in the Adriatic offshore, nearby an hydrocarbon field. The seismic sequence was made up of 91 earthquakes with Ml ranging from 1.3 to 5.0 and thrust fault kinematics. The Porto San Giorgio mainshock produced moderate damage into the surrounding areas. Although the Porto San Giorgio seismic sequence has been studied in different works (Riguzzi et al., 1989; Console et al., 1992), some issues about the earthquake locations and the activated fault structures remain open. In particular, we have relocated the seismic sequence using first P and S arrivals data that have been carefully selected by historical catalogue following a probabilistic approach with the NonLinLoc code (Lomax et al., 2000) and exploring different velocity models. The results show that the re-located seismic sequence (about 30 events) developed in upper portion of crust (less than 15 km) activating thrust faults, similar to the main geological features that characterizes the outer Apennines thrust belt and Adriatic foreland folds. Moreover, a detailed analysis of macroseismic data has been carried out. We have calculated synthetic seismograms of the Porto San Giorgio mainshock for different hypocentre depths and synthetic, macroseismic intensity maps have been computed. In order to constrain the earthquake location, we have compared the synthetic maps with the real intensity map, derived from the real macroseismic data, finding an additional evidence for the location of the Porto San Giorgio mainshock.

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ESC2018-S32-550

ANALYSIS OF ATTENUATION AND VP/VS VARIATION IN THE VICINITY OF COSTA MOLINA (SOUTHERN ITALY) WASTEWATER INJECTION WELL

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The seismicity of the High Agri Valley (Basilicata Region, southern Italy) has both natural and anthropogenic origin (both reservoir lake as well as oil production related seismicity). This study investigates the fluid-injection induced seismicity is caused by the disposal of the wastewater that is a byproduct of the oil extraction in the valley, the site of the biggest onshore oil field in west Europe. Injection of the wastewater into the Apulian Platform formation started in June 2006 and resulted in a number of weak microearthquakes along a NE dipping fault zone. We used direct P- and S-wave arrivals registered by the nearby seismic stations of the ENI oil company to characterize the effective attenuation of the medium using the peak frequency method. For the closest station to the disposal well, we found an anomalous value of the P-wave attenuation factor QP=49, significantly lower than QP=60 found for the other stations. The S-wave attenuation for the nearest station was found to be QS=58 and in case of other relatively close station QS=52. It shows an unusual Qp/Qs ratio of the P and S attenuation factors lower than 1 for the nearest station. The attenuation anomaly is also correlated with anomalous velocities, specifically the VP/VS ratio of the investigated area. Using both origin times of the earthquakes and Wadati plots we have found that the waves arriving to the nearest station are characterized by an average velocity ratio (VP/VS=1.98) higher than that retrieved for the other more distant stations (VP/VS = 1.90). Additionally, for the nearest station, the changes of the VP/VS velocity ratio correlate with the pumping pressure of the injection, further indicating the effect of the wastewater disposal. The anomalous values of the effective Q, with the unusually low ratio of attenuation factors, and the increased VP/VS for the nearest station may be interpreted as a result of increased saturation of the seismic medium in the vicinity of the injection well. Changes of the saturation of the rocks disproportionately affect P-wave velocities and attenuation in comparison to S-waves. Nevertheless, the rays going to the nearest station spend relatively small part of its travel-time in the target layer of the injection (Apulian Platform). Therefore, it is unlikely that increased saturation in the given layer is the sole factor responsible for the anomaly. To fully explain the differences we suggest the presence of the anomaly also in the overburden rocks, with the possible existence of a local 3D structure that is not necessarily connected to the injection process.

ESC2018-S32-553

SOURCE PARAMETERS OF THE WEAK SEISMICITY OCCURRED CLOSE TO THE COLLALTO GAS STORAGE (NORTHEASTERN ITALY)

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Since 2012, OGS has been involved in monitoring and studying the microseismicity possibly induced by the gas storage activities located at Collalto, nearby the town of Treviso in Northeastern Italy – (hereinafter RSC). In this context, a reliable estimate of the moment magnitude (Mw) associated with other source parameters for local events, even the smaller ones, becomes essential for better understanding the dynamic of the monitored faults and the discrimination between induced and natural earthquakes. To this purpose, we apply the procedure developed by Zollo et al. (2014, JGR doi:10.1002/2013JB010116), a parametric inversion approach for the estimation of seismic source parameters which exploits both signals recorded on the horizontal components for the S waves and, separately, the vertical ones for the P waves. In particular, the adopted approach exploits standard seismological models to separate the source spectrum from the contributions due to the propagation effects (inelastic attenuation and geometrical spreading) and site effects. The inversion analysis consists of an initial iterative multi-steps procedure during which different values for the attenuation and the parameter that controls the decay of the source

spectra at high frequencies for all source-receiver pairs are tested. In the following step, once the attenuation and site effects are removed from the experimental spectra, the inversion goal is to retrieve for each seismic event the seismic moment and the corner frequency, which in turn are used to calculate the source radius and the static stress drop according to a selected dynamic source model, as well as the radiated seismic energy. Finally, from the estimated source parameters, the apparent stress drop and the seismic efficiency, which can be a proxy for the radiated seismic energy connected to the stress released by the earthquake, are derived. This procedure is applied to 30 earthquakes occurred in the period 2012-2016 spanning in the local magnitude range 1

ESC2018-S32-555

SEISMICITY INDUCED BY DEPLETION: PROBABILISTIC MOMENT TENSOR INVERSION FOR EVENTS OCCURRING IN THE GRONINGEN GAS FIELD, NETHERLANDS

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The Groningen gas field is one of the largest natural gas fields in the world, producing since 1963. Since the early 1990's, induced seismicity started to arise in its vicinity. Of the over 190 exploited gas fields in the Netherlands, only 15% experienced induced seismicity and only in three of those fields (Groningen, Bergermeer and Roswinkel), events with magnitudes ML > 3 have occurred. In the Groningen gas field, events were recognized as induced by the gas production, originating from the declining gas pressure followed by compaction of reservoir rocks, resulting in subsidence at the surface and stress changes on the many faults existing in the reservoir. The fault structure at reservoir level is well known and seismicity mainly occurs in regions of high fault density, although it is difficult to relate events to individual faults. Until early of 2018, more than 1500 events were detected, with more than 520 event magnitudes equal or larger than ML 1.5. The strongest event recorded so far (ML = 3.6) occurred on 16th August 2012 near the village of Huizinge, raising a huge number of damage claims as well as public concerns. Due to the soft soil conditions and the shallow hypocentres (approx. 3 km depth), damage to structures was caused despite the relatively low magnitudes. In 1995 a geophone monitoring network consisting of eight borehole stations was installed and operated by KNMI. This network has been extended several times, providing a detection threshold of M=1.5 since 1995. Due to limited resolution, event depths have been fixed at 3 km depth in the location procedure. Since 2015, the network has been expanded extensively, now comprising more than 70 borehole stations. Each of the stations is equipped with an accelerometer at the surface and an array of four 4.5 Hz 3-C geophones with a vertical spacing of 50 m. Data of all stations is publicly available for research purposes. With the new network in place, the Groningen gas field offers the best instrumentation worldwide to study induced seismicity caused by a depleting gas reservoir and the associated seismic hazard. We employ our newly developed probabilistic moment tensor inversion tool "Grond" to analyse source mechanisms of events recorded on the new network. "Grond" adapts an optimization scheme using elements of simulated annealing and the bootstrap technique. Rather than optimizing a single objective function, it tries to find volumes in parameter space that satisfy low misfit values over an ensemble of N variations of the objective function. The search parameter can be varied extensively by the user, allowing to deal with the inherent trade-off between number of tested models and ability to find the global minimum without getting trapped in local minima. Due to the inherent capabilities of probabilistic methods, we are able to analyse trade-offs between inversion parameters and to assess uncertainties. We analyzed all events of M>1.5 in the period 2016-2018 and even smaller magnitude events for several event clusters. For each inversion, data from stations up to 8 km distance from the source were used, ensuring the data to travel through a known velocity model. For each region within the Groningen field a mean 1D P-and S- velocity model was derived from a detailed 3D velocity model developed by the mining company (NAM). Apart from solving for a deviatoric mechanism, we also explored the

potential of source mechanisms featuring isotropic parts.

ESC2018-S32-577

EFFECTIVE STRESS DROP AND ASEISMIC DEFORMATION

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The concept of effective stress drop of a seismic sequence is based on the cumulative seismic moment and area activated by seismic ruptures. The analysis of end-member cases of clustered seismicity shows that the estimated effective stress drop of a cluster is only in agreement with the stress drop of a single event rupturing the same area if no aseismic deformation takes place and rerupturing of asperities occurs during the sequence. The evolution of the cumulative seismic moment release as function of the cluster radius can be used to discriminate different processes: the exponent of seismic moment scaling with radius indicates if the ruptured area is uniformly loaded or whether external loading takes place. Our analysis of 13 sequences ranging from injection-induced activity to natural swarm and aftershock activity shows standard cubic scaling of the total seismic moment in most cases. Slightly higher exponents in the case of injection-induced sequences are indicative of the ongoing local forcing related to the massive fluid injections during the cluster evolution, while lower exponents down to 1 in the case of creeping events might be related to a decreasing/fractal asperity density. Three seismicity groups can be distinguished: a normal-stress-drop group of geothermal injections, swarms and mainshock-aftershock sequences, a low-stress-drop group of shale and gas fracking, and the very low-stress-drop case of creeping events. The small effective stress drop can be interpreted by small shear modulus of the rocks, or alternatively, by a large portion of creep in the total slip. Then the seismic events with normal static stress drop would account only for a small portion of deformation. This is probably the case of hydraulic fracturing. Considering the rigidity of sands and shales is of the same order as of other types of rocks, it appears that during hydraulic fracturing of these formations a high portion of strain is released aseismically.

ESC2018-S32-586

THE NOVEMBER 15, 2017, POHANG EARTHQUAKE: A POTENTIAL ANTHROPOGENIC EVENT OF MW 5.5 IN SOUTH KOREA

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On 15 November 2017 a Mw 5.5 earthquake struck the southeast part of the Republic of Korea (South Korea), injuring many people and causing extensive damage in and around the city of Pohang. This event was preceded by the September 2016 Mw 5.5 Gyeonju earthquake, occurred ≈30 km farther south on one of the largest fault of the region, the Yangsan Fault. These two earthquake were the largest earthquake ever recorded since the last century in Korea. The November 2017 earthquake has triggered intense public debate in South Korea about its potential link with geothermal stimulation operations at a nearby EGS site. The proximity of this industrial facility with the epicentre of the earthquake has raised public concerns in South Korea, reflected by the sharp increase of web searches using the keywords “geothermal” and “geothermal power plant” in Korea in the days following the Pohang earthquake. In the absence of data from a local seismic network, we use advanced full-waveform seismological techniques, applied to regional and teleseismic network data, to locate the Pohang earthquake sequence and determine the source parameters of the largest events. We also use geodetic data to quantify the coseismic deformation and obtain an independent estimate of the mainshock source parameters. Seismicity and geodetic results are in agreement regarding location, depth and fault geometry. The main findings of our work are: 1) hypocentral depths are shallower than the characteristic background seismicity of the area and mainly in the range 3-7 km, similar to the depth of injection (≈4 km); 2) The mainshock and most of the aftershocks

occurred within 2 km of the EGS site 2) The mainshock occurred within 1.5 km from a Ml 3,1 induced event occurred in April 2017, during hydraulic stimulation operations. 3) Our seismological and geodetic analysis rules out a re-activation of the Yangsan fault, but we found that the earthquake transferred static stress to its northern branch, potentially increasing the seismic hazard in the area. 4) Our full-waveform techniques (using regional and teleseismic data publicly available) demonstrates the extent to which a suspected case of induced seismicity can be investigated without local data from site operators. Finally, according to our analysis it seems plausible that the occurrence of this earthquake was influenced by these industrial activities. This work has been supported in part by European Commission Horizon2020 project 691728 DESTRESS.

ESC2018-S32-649

GAS PRODUCTION AND INDUCED SEISMICITY IN THE GRONINGEN GAS FIELD

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The Groningen gas field in the north of the Netherlands is one of the largest gas fields in the world. The field was discovered in 1964 and production from the field commenced in 1968. In 1991 the first seismic event in the field, with a local magnitude of Ml = 2.4, was recorded. Between 1991 and 2003 the seismicity rate in the field was fairly constant. Between 2003 and 2014 an increasing activity rate with time was observed (Muntendam-Bos and de Waal, 2013; Bourne et al, 2014; Nepveu et al, 2016). Concurrently, the largest magnitude observed increased, culminating in a Mw = 3.6 event at the town of Huizinge in 2012. The link between the occurrence of the seismicity and the pressure depletion in the field due to the production of the gas was firmly established (Roest & Kuilman, 1994, Mulders, 2003) . In addition, indications of the influence of the significant summer/winter swing in production rates on the occurrence of seismicity were derived by simple cross-correlation (Nepveu et al, 2016). By using a methodology called the "shift-and-add" or "co-adding" technique, which is well-established in astronomical imaging techniques (cf. Harpsøe et al, 2012), we derive that the signal of the depletion rate at the locations of the earthquakes was statistically significantly different from the signal at alternative, random locations in the field. We conclude that a local increase in depletion rate leads to an increased earthquake likelihood at a location where earthquakes are likely to be generated such as a fault or fracture. The assessment of the hazard posed by the field changed significantly when in 2013 the prediction for the maximum expected magnitude was found invalid (Muntendam-Bos and de Waal, 2013). Subsequently, the production offtake from the Groningen gas field has been decreased from 54 bcm/yr in 2013 to 21.6 bcm/yr in 7 consecutive steps. In addition, in 2015 the seasonal (summer/winter) swing was reduced significantly. We have systematically analysed the (regional) behaviour of the induced seismicity rate in the Groningen gas field during these changes in gas production rates. Our analysis shows that an initial statistically significant response of the seismicity rate, correlating in time and space with the changes in production rate, is observed. However, these changes, especially the decreases in seismicity, seem to be of a temporary nature only. While low regional production levels are maintained we observe the appearance of clusters of events. Re-analysis using the "co-adding" methodology showed that despite the minimization of field wide seasonal fluctuations, the signal at the earthquake locations still contain a statistically significant increase in depletion rate at the location of and just prior to an earthquake occurring. Close analysis of the depletion and depletion rate at the locations of the clusters indeed shows a temporal correlation between the onset of the cluster formation and an increase in depletion rate. However, not every increase in depletion rate coincides with the occurrence of seismicity nor does every cluster correlate to an obvious increase in depletion rate. We postulate that the ongoing depletion due to the gas production continuously loads the faults and fractures in the gas field rendering them critically stressed at some point in time. Only on these critically stressed faults and fractures a local increase in depletion rate can trigger an event. Due to the stress transfer induced by the event, this event can be the onset of a cluster of events or act as a preamble for a larger magnitude event.

Following the cluster of events, a certain amount of depletion is required in a region before a new cluster of events can occur.

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ESC2018-S32-663

LOCAL SEISMOLOGICAL MONITORING AT THE VERKHNEKAMSKOYE POTASH DEPOSIT

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Today seismological monitoring at the Verkhnekamskoye potash deposit is one of the most effective instruments for the geodynamic situation control. Seismic monitoring systems cover all 5 operating mines. Each of them has 7 to 12 seismic stations. Data in a near real-time mode are transmitting to the information-processing center. The parameters of seismic events are determined automatically with the subsequent control by the operator. The minimal representatively recorded magnitude is in the range from ML=-1.2 to ML=-0.5. Annually, monitoring systems record up to 1500 seismic events associated with the destruction of rocks near mine openings. Identification of seismically active zones and their ranking according to the degree of danger is based on an analysis of the spatial distribution of epicenters and their temporal dynamics. These data on a par with the results of other types of monitoring are used to adjust plans of mine works and backfilling. Very high efficiency seismological observations have been demonstrated in monitoring of emergencies associated with the breakthrough of water into the mine workings. The first experience of such observations was obtained in 2006, when the BKPRU-1 mine began to flood. The monitoring system, developed for few months, made it possible to delineate the boundaries of the expected collapse zone with high accuracy. An analysis of the dynamics of microseismic activity within this zone showed that its intense bursts began to be recorded two weeks before the formation of a sinkhole on the earth's surface. During the next year, when there was an active growth of the sinkhole, seismic monitoring data allowed to successfully predict the direction and dynamics of its development. In the following years, when the mine was flooded, new collapses began to form on the earth's surface above the minefield. For the period from 2010 to 2017 at a distance of 700 to 1300 m from the first main sinkhole 5 new collapses appeared. Their plan dimensions are from 5 to 140 m, and the depth can exceed 100 m. For 4 of them the monitoring system recorded an increase in seismic activity, which began 1 to 3 months before they appeared on the earth's surface. Since such objects have small linear dimensions, seismic monitoring is the most effective method that allows directly predicting their occurrence and monitoring the dynamics of their development. Seismological monitoring showed the same high efficiency in observation of the development of the emergency at the SKRU-2 mine. The sensors of the mine monitoring network registered a sharp increase in microseismic activity in one of the parts of the mine field in September 2014. After this, an operatively deployed local monitoring system allowed to precisely localize the boundaries of the anomalous zone and to watch in detail the dynamics of seismic activity within it. It should be noted that other monitoring methods (seismic survey, leveling) in this area have not registered any anomalies. The seismic network recorded two

bursts of seismic activity. The first had a duration of about one month (from September 8 to October 10, 2014), after which the intensity of seismic processes decreased to almost zero. The second one began on November 15, it had a very high intensity and was finished by the formation of a sinkhole on the earth's surface on November 18, 2014. Currently, real-time seismic monitoring systems are installed at all emergency or potentially hazardous areas of the Verkhnekamskoye potash deposit.

ESC2018-S32-670

THE JOINT USE OF GPS AND MULTI-TEMPORAL DINSAR TECHNIQUES TO MONITOR SUBSIDENCE ALONG ON-SHORE HYDROCARBON RESERVOIRS

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Focusing on subsidence processes associated with anthropogenic activities, the Italian Ministry of Economic Development (MISE) has defined some general guidelines to monitor hydrocarbon activities in areas with high seismic and hydrogeological risk. One of the main goals of these guidelines was to establish the main procedures to analyze the spatial and temporal evolution of environmental parameters, as well as their possible correlations with underground anthropogenic activities. In this study, we tested the “geodetic protocols and guidelines” to study ground deformations along on-shore hydrocarbon reservoirs along the Ravenna coastline and the southeastern Sicily. These protocols include the joint use of Global Positioning System (GPS) and multi-temporal Differential Interferometric Synthetic Aperture Radar (DInSAR) techniques. They consist on three steps: 1- data collection and processing; 2- data integration and comparison; 3- data analysis and interpretation. The main objectives of this study are: a) monitoring land subsidence phenomena along selected areas; b) analyzing possible relationships between hydrocarbon exploitation and anomalous deformation patterns; c) evaluating the limits and advantages of the proposed approach, to provide feedbacks for improving MISE guidelines. Experimental results on target regions show wide areas affected by subsidence mainly related to natural and anthropogenic processes. Ground deformations retrieved through multi-temporal DInSAR time series exhibit low sensitivity as well as poor spatial and temporal correlation with hydrocarbon exploitation activities. However, some limits must be taken into account, e.g., the presence of dismissed reservoirs, the poor spatial/temporal availability of production data, the different sample rate of SAR retrievals and hydrocarbon exploitation data. We finally evaluate the advantages and limitations of proposed protocols, suggesting to improve techniques and security standards established by MISE for monitoring hydrocarbon reservoirs. The present work is supported and funded by the Italian Ministry of Economic Development (MISE) under the MISE-DGRME research project (ID 0752.010).

ESC2018-S32-676

WAS THE MW 5.5, NOVEMBER 15, 2017, POHANG, SOUTH KOREA, EARTHQUAKE RELATED TO ANTHROPOGENIC ACTIVITIES: A PHYSICS-BASED STUDY ON TRIGGER PROBABILITIES

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On 15 November 2017 a Mw 5.5 earthquake occurred in South Korea. The hypocenter was close to an Enhanced Geothermal Systems site, where high pressure hydraulic injections had been performed during the previous two years and only two month before the event. Therefore, first studies of the earthquake indicate that the event was possibly triggered or induced by hydraulic stimulations. We adapt a probabilistic discrimination method for the problem of multiple hydraulic stimulation experiments. The method combines physics based seismicity models with hydro-geo-mechanical modeling of porous stress changes during and after fluid injections. Uncertainties of the geo-mechanical models and of seismological parameters are considered in a Bayesian approach. The applications to the Korea earthquake in Pohang aims to clarify the possible contribution of different injection, bleed-off and shut-in phases for the triggering probability of the

Mw 5.5 earthquake. It is used as a first demonstration of the assessment method, which can be used in future experiments for a better risk study prior injection. H.H. has been supported by European Commission Horizon2020 project691728 DESTRESS

ESC2018-S32-703

MINE COLLAPSES AS FACTOR OF SEISMIC HAZARD

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That part of seismic events that is result of falling large rock masses (the collapses of the arches of caves, roof in mines, development of sinkholes) from the point of view of their influence on seismic hazard are investigated poorly and often are not considered as serious threat to human activity. On the one hand falls and collapses have rather small magnitudes (usually less than 5) that are not comparable with magnitudes of the tectonic earthquakes. On the other hand the strongest and large-scale rock fall accidents are rather rare events though the area of their possible appearance can be quite wide. Often collapses happened at territories where there are conditions of appearing and development of underground cavities (caves, mines), which gradually increase in their sizes and lead to loss of stability of their roof. If to consider purely natural phenomena, one may note they are widespread everywhere in karst provinces. The near-surface layer of well solved rocks is usually most active therefore appearing most collapses are not too big to render any seismic effect that may be sensed at wide territories. Large-scale collapses happen only in deep caves, and often such phenomena are very exotic. Most often the last result from artificial factors, such as underground mining that may be reasons of loss of roof stability. In mines of soluble ores collapses usually appears after inflow of low-mineralized water from the surface. Almost uncontrollable dissolution of salt and washout promote rapid growth of the cavities which gradually reach the surface and therefore the sinkhole is appeared. In insoluble or poor-soluble ores (coal, copper ore and carbonates) collapses happen as result of roof shift along the systems of the existing faults or new ruptures appeared during mining. Such collapses may be accompanied by sinkhole appearing and considerable subsidence of the surface as well. In our investigation these phenomena like large-scale collapses and rock falls are considered as strong seismic sources which can matter in areas with weak or moderate natural (tectonic) seismicity. The importance of considering such phenomena is caused by two major factors:

- the magnitude of collapses can reach the maximum limits set for tectonic earthquakes (up to 5.5);
- the depth of the hypocenters is small (usually less than 1 km) that makes them dangerous for the settlements close to the mined territory or even over it.

The problem of correct seismic hazard assessment due to collapses rises because their other nature (non-tectonic) does not allow applying to them the standard models. It concerns the model of the sources zones used for structuring seismicity in space and time and for the description of its recurrence. Techniques of assessment of maximum magnitude as main measure defining seismic effect on a surface are not developed. The model of seismic effect propagation for shallow sources may also differ from the one used for the tectonic events located rather deeper. After investigating well-known collapses occurred in many mines of the world we have considered all aspects mentioned above. First of all the model of seismogenerating zone where collapses are possible is developed. For this zone the following parameters are determined:

- maximum source depth, Hmax;
- maximum magnitude of possible events, Mmax;
- spatial distribution of sources;
- number-to-magnitude distribution;
- time limits of zone existence (T1 – the year of the beginning, T2 – the year of the end).

The model of seismic effect propagation for superficial sources radiating mainly surface waves fading with distance more slowly than body waves is also specified. This set of models is enough to define long-term seismic hazard which is caused by existence of not backfilled underground space or a possibility of their emergence when mining.

ESC2018-S32-718

SPACE-TIME VARIATION OF LOW MAGNITUDE SEISMIC EVENTS OCCURRED IN THE NORTH-WESTERN PART OF ROMANIA AS REVEALED BY

WAVEFORMS CROSS-CORRELATION AND SPECTRAL ANALYSIS

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Seismicity in Romania is dominated by the intermediate-depth earthquakes occurred beneath the South Eastern Carpathian Bend Zone. The crustal seismicity developed in several regions is characterized by a mixture of sporadic isolated events with cluster of earthquake sequences, located mostly in the upper crust. Recently, due to continuously developments of the Romanian Seismic Network (RSN) and additional deployments of a temporary seismic array (within South Carpathian Project) we were able to detect several clusters of shallow seismic events in the north-western part of the country, near the Dragan seismic station (DRGR). This area was not characterized as seismically active up to the last decade, therefore are not any documented indications for these events to have tectonic origin. The aim of the present study is to determine the similarity degree among these events using cross-correlation technique on the waveforms recorded by the DRGR station. The relocation of these events based on double differences relative location approach and cross-correlation analysis reveal a migration of these events, on E-W direction. At the same time for the events characterized by high similarities we verify the sources colocations, by comparing the sources dimensions derived from spectral analysis with the inter-event distances assessed through cross-correlation analysis. These observations outline new aspects related to seismicity space-time patterns with important consequence on discriminating tectonic from man-made events and on characterizing the seismic activity in the study area.

ESC2018-S32-719

INDUCED SEISMICITY AT OPEN PIT AND UNDERGROUND MINING IN KUZBASS

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In the Kuznetsk Basin (Kuzbass), coal is being actively extracted, currently there are 124 enterprises, half of the enterprises work in the open way, and the other half in an underground way. Together with companies leading the development of coal, a monitoring system has been created, which includes 17 stationary seismic stations. It is established that induced seismicity near open pits and underground mines dominates over the natural in Kuzbass. The Bachat earthquake with ML = 6.1 in 2013 destroyed buildings in nearby villages and caused a powerful aftershock process. Spatially earthquakes are confined to the development of the Bachatsky open pit and occur from the bed to a depth of 4 km. Another kind of activation is observed in the area of the Kaltan open pit coal mine. A number of events with a magnitude of up to 4 occurred in the formation zone of the dump. Underground coal mines in Polysaevo. Monitoring of induced seismicity near underground excavations has established that events occur below the workings to a depth of up to 1 km and move with the advancement of the coalface in space. A strong influence of vibrations on the development of seismicity near the longwall is established.

ESC2018-S32-730

TEMPORAL RELATIONSHIP BETWEEN INJECTION RATES AND INDUCED SEISMICITY

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Fluid injections into rock formation are known to induce seismicity. It follows that increased rates of injected volume are causing increased rates of seismicity and decreased rates of injected volume are causing decreased rates of seismicity. Therefore, the cross-correlation of injection and seismicity rates (with their means removed) is high if the seismicity is induced by an injection. The high values of the normalized cross-correlation imply that the seismicity is induced, while the time delay of the peak of cross-correlation function represents the delay of seismic response to injection characterizing the medium. Monitoring of induced or triggered

seismicity is used to understand the effectiveness of hydraulic stimulation and to prevent large felt seismic events that can cause nuisance or even damage. Davis and Frohlich (1993) developed criteria for differentiation between natural and triggered seismicity, which became very widely used. One of these criteria is temporal correlation of injection and seismicity. However, the verbally formulated criterion of temporal correlation is interpreted in many ways. Opršal and Eisner (2014) developed a cross-correlation methodology to objectively measure temporal correlation of injection and seismicity rates. They point out that well-known cases of induced seismicity have significantly high normalized peaks of cross-correlation function when applied between mean-removed seismicity and injection rates. They also point out that the delay of seismicity after injection measured by the delay of the peak of the cross-correlation function in all studied cases is relatively small and suggest a delay of less than 24 h. In this study we tested mentioned methodology on three different data sets - two of them were acquired during short-term hydraulic stimulation of shale gas to study temporal relationship between seismicity and the injection. Third data set is the induced seismicity related to changes of the water level in a dam. In our study a new observation is made; we show that seismicity induced by hydraulic fracturing and measured by the normalized cross-correlation can have very positive to even short negative delay after the injection. We explain this observation by rapid decline of induced seismicity after decrease of injection. On the contrary, we show that the seismicity triggered by water impounding in a dam is characterized by longer delays due to much greater distance between lake and the induced seismicity. We show how it is possible to measure the delay by the cross-correlation methodology despite periodicity of the signals.

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ESC2018-S32-732

FEASIBILITY STUDY ON THE USE OF 4D SEISMIC TOMOGRAPHY FOR MONITORING OFF-SHORE HYDROCARBON EXPLOITATION

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Seismic monitoring in areas of geo-resources exploitation is a very important topic. In Italy the guidelines issued by the Italian Ministry of Economic Development (MiSe), which are written with particular reference to the anthropic activities of on-shore cultivation, re-injection and storage of hydrocarbons, indicated that the monitoring must be done before and during the period of exploitation activity. Seismic monitoring has a dual aim of allowing the detection and location of seismicity in a volume surrounding the anthropogenic activities, and discriminating the natural from induced seismicity. Furthermore, the monitoring enables tracking the space-time-magnitude evolution of seismicity, which whenever necessary allows promptly to reschedule or to suspend the activities. Fluids involved in the geo-resources exploitation through extraction or reinjection processes may create new fractures and/or alter the frictional condition on existing faults, and thus trigger new failures. For this reason, the monitoring of induced seismicity is strongly connected with the fluids involved in field operations. In Italy, many gas and oil fields are located off-shore. This characteristic makes the monitoring more difficult if no specific seismic network has been installed. Here we present a feasibility study of 4D seismic tomography aimed at the offshore reservoir monitoring and at the image the space and time evolution of the fluid storage and migration processes. The 4D seismic tomography consists in the reconstruction of three-dimensional elastic properties images of the subsoil in different consecutive time windows. In this study, we evaluate the capability of the tomographic method to provide high resolved images such as to detect and tracking the fluids presence and migration into the investigated volume. The feasibility study was performed by using numerical simulations of an active seismic survey investigating the exploitation volume during a waste-water injection repeated in several time

epochs. The first step was the layout set up: a seismic network deployed over a surface of 30x30 km2 and centred at the injection well was considered; then, the station density and the shot number and geometry were fixed by assuming the dimension and depth of target volume. The second step consisted in the construction of medium models varying with time. Starting from a layered velocity model, we constructed the velocity models perturbed as consequence of injected fluid. The propagation of the injected fluid from the well bottom into the underground formation was simulated by using the diffusivity law (S Shapiro et al 2003). The fluid front extension simulated at successive time periods defined the area where the seismic velocity was perturbed (i.e., the perturbation was calculated by Gassmann equation). The P- and S-phase catalogues obtained through forward modelling (i.e. accurate ray tracing using the velocity models obtained during steps one and two) are the input of the third step. To make more realistic the catalogues, we assigned an error on arrival times and performed a selection of the total number of phases based on the signal-to-noise ratio. This latter quantity was evaluated by considering geometrical and anelastic attenuation, as well as the characteristic noise level at each station laying at the sea-bottom. In the fourth step, we inverted the simulated data-sets obtaining a 3D tomographic velocity image for each time epoch. To identify the high-resolution and low-smearing model regions, we computed the derivative weight sum, the resolution matrix and checkerboard tests. Finally, the last step consisted in a comparative analysis of 3D tomographic images to infer the space and time changes of elastic properties that can be, in turn, related to fluid presence and diffusion within the target volume. The results are evaluated based on images resolution, minimum velocity amplitude resolved and variation on travel times due to fluid migration.

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ESC2018-S32-750

FLUID DRIVEN FAULT SLIP OF EXPERIMENTAL FAULTS SUBJECTED TO FLUID PRESSURE STIMULATION: CARBONATES VS. SHALES

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Fluid overpressure is one of the primary mechanisms for triggering tectonic fault slip and human-induced seismicity. This mechanism is appealing because fluids lubricate the fault and reduce the effective normal stress that holds the fault in place. However, models of earthquake nucleation predict that a reduction in normal stress, as expected for fluid overpressure, should stabilize fault slip. We conducted laboratory experiments in the double direct shear configuration in a true-triaxial machine on carbonates and shale fault gouges. In particular, we: 1) evaluate frictional strength and permeability, 2) characterize the rate- and statefriction parameters and 3) study fault slip evolution during fluid pressure stimulations. With increasing fluid pressure, when shear and effective normal stresses reach the failure condition, in calcite gouges, characterized by slightly velocity strengthening behaviour and high permeability, we observe an acceleration of slip that spontaneously evolves into dynamic failure. For shale gouges, with a strong rate-strengthening behaviour and very low permeability, we document complex fault slip behavior characterized by periodic accelerations and decelerations with slip velocity that remains slow (i.e. vmax~200 µm/s), never approaching dynamic slip rates for the maximum displacement achieved in these experiments. Our data suggest that fluid overpressure can accelerate aseismic creep with the development of local frictional instability and dynamic rupture even for faults that are characterized by a velocity strengthening behavior, which indeed should favor aseismic creep. We show that fault rheology and fault stability change with fluid pressure, which suggests that a comprehensive characterization of these parameters is important for better assessing the role of fluid pressure in natural and human induced earthquakes.

ESC2018-S32-762

SEISMIC NETWORKS LAYOUT OPTIMIZATION FOR A HIGH RESOLUTION MONITORING OF INDUCED MICRO-SEISMICITY

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It is well known that the seismicity monitoring is a crucial task during hydrocarbon exploitation or water fluid injection/extraction for energy development (Ellsworth et al., 2013; Davies et al., 2013). Seismic monitoring is aimed at characterizing the seismicity in the sub-surface volume where industrial exploitation activities take place, with the purpose to discriminate the natural from man-induced seismicity. The target is to track the space-time-magnitude evolution of the seismicity with the aim, if needed, to re-modulate, interrupt (in the foreseen cases) or restart industrial activities. Therefore, is essential to develop a high sensitivity seismic observing system, which is capable to detect and locate extremely low magnitude events whose occurrence and spatial distribution could be related to fluid migration and consequent pore pressure changes. The detection/location threshold of a seismic network and its accuracy in the determination of earthquake source parameters depends on station density and the network areal coverage as well as on the use of advanced location techniques. In this work, we present an optimization study for seismic networks aimed at monitoring micro-seismicity induced by energy development operations as in offshore areas of hydrocarbons exploitation, re-injection and storage). The performance of different networks configuration has been evaluated considering the "Guidelines for monitoring the seismicity in industrial activities" of the Italian Ministry of Economic Development (MiSE,http://unmig.sviluppoeconomico.gov.it/unmig/agenda/upload/85_238.pdf); whereas, the target of a monitoring system in areas with exploitation of underground resources is the detection of all the earthquakes characterized by a magnitude value of at least Ml 0.5 and highly accurate locations (i.e. location errors within a few hundred meters). In detail, we considered different network layouts, in terms of seismic station density and geometry (surficial deployment and borehole stations), covering an area of about 30 km by 30 km around a wastewater re-injection well. For each seismic network configuration, we evaluated its performances in terms of detection/location magnitude threshold and events location errors by simulating for different depths (i.e., 3 km and 8 km) sets of seismic sources distributed in space and with varying magnitude values. These analyses were performed by using a method that allows calculating the signal-to-noise ratio for each source-stations couple and taking into account the propagation of seismic waves in an anelastic stratified medium (Stabile et al., 2013). In order to improve the network resolution, we considered a seismic network which integrates a constellation of small size seismic arrays (i.e., maximum array aperture less than 500-1000 m). In order to take advantage of this integration, different standard and array location techniques were considered with the aim to improve the network performances in detecting and locating seismic events. The results show that a network designed according to MiSE guidelines, that is integrated by seismic arrays, allow to achieve a magnitude detection threshold of M=0 for earthquakes located down to 8 km depth. The expected location errors are of the order of a few hundreds of meters. The obtained results confirm that the station density represent a crucial parameter for the seismic network performances and show that the integration of the standard network with a constellation of seismic arrays allow us to obtain better network performances in terms of detection capability and location accuracy.

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ESC2018-S32-778

RESULTS FROM HIGH-RESOLUTION OBSERVATION OF SEISMIC ACTIVITY IN THE

REGION OF NORTHERN GERMAN GAS FIELDS NEAR ROTENBURG

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The Institute for Geophysics, University of Stuttgart, performed a high-resolution monitoring campaign of seismic activity in northern Germany from 2014-2017. Region of interest was the central part of the northern German gas-fields which are in production since the 1960s. Here the 2004 ML 4.5 Rotenburg earthquake was the strongest event ever observed in the Rotliegend gas fields of the Netherlands and Germany. Combining network and array approaches with enhanced visual screening and automated detection, we achieved an ML 0.5 sensitivity despite strong influence of anthropogenic noise. Gas fields showed very different behaviour reaching from no induced events at all (within the limits of sensitivity), to singular ML 2 earthquakes without aftershocks, and to clustered seismicity of b value close to 1. We investigate on different geological setting, and changes in production rate. Beside induced seismicity close to reservoir depth we could observe additional, deep crustal earthquakes in the same region. They match deep (> 25 km) northern German earthquakes outside the gas fields, and will be discussed related to post-glacial isostatic adjustment (GIA) processes.

ESC2018-S32-779

DETECTION OF WEAK SEISMIC SEQUENCES BASED ON ARRIVAL TIME COHERENCE AND EMPIRIC NETWORK DETECTABILITY: AN APPLICATION AT A NEAR FAULT OBSERVATORY.

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Monitoring microseismicity is the primary tool to understand and to observe the progress of mechanical processes occurring in an active rock fracture system. In geothermal or hydrocarbon field or along a seismogenic fault system, the observation of microseismicity gives the possibility to determine the geometry of the fractures and to investigate the interaction between fluids and rocks, in response of the stress field perturbation. The seismic monitoring aims to detect and characterize the seismic sources for discriminating them from several noise sources, related to ambient conditions or human activity that usually affects the seismic recordings. A variety of fast and automated methods have been recently proposed to detect and locate microseismicity using large and dense seismic networks. In this work, the microseimic data recorded along the Irpinia fault zone (Southern Apennines, Italy) are analysed and natural earthquakes are detected using an automated, migration-based, method. The detection of weak signals is typically achieved at the cost of increasing the number of false detections. We propose a new criterion for the automatic discrimination of real against false detections including empirical data and information about the detectability of the seismic network. Taking into account this information, we improve the performance of earthquake detection without the visual inspection of the seismic signals, minimizing operator actions. We demonstrate that a threshold criteria based on the coherence value of the seismic signals is not an appropriate choice to discriminate real/false detections and to identify small earthquakes that are recorded by only few seismic stations. The proposed methodology is automatic, self-updating and can be tuned at different success rates (calculated as the percentage of real detections), deciding to be more/less conservative about the possible false detections. Our results show a 96.8%, 92.1% and 83.3% of level of success with a success rate greater than 0.8, 0.5 and 0.3, respectively.

ESC2018-S32-862

SEISMIC RESPONSE AND FRACTURE GROWTH DUE TO FLUID INJECTION

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Hydraulic fracturing involves high-pressure injection of fluid into a well in order to create new cracks and open permeability paths to exploit the trapped gas, oil or geothermal energy. Fluid pressure is high enough to fracture the rock mass, inducing microseismicity in the sourrounding area. An increase of the mentioned pressure results in the reduction of the frictional resistance of pre-

existing faults to sliding, which consequently can lead to release of the accumulated stress in seismic events (Langenbruch and Zoback, 2016). SHale gas Exploration and Exploitation Risks project (SHEER, www.sheerproject.eu) aims at assessing short and long-term risks associated with groundwater contamination, air pollution and induced seismicity, in connection to shale gas exploration and exploitation. An important part of SHEER is devoted to monitoring and understanding how far this enhanced permeability pattern will develop both in space and time. We propose an approach to identify pathways for gas and fluid migration due to fracking processes by modelling the fracture growth. The data used for this purpose comes from the northwestern part of The Geysers (California, USA). The selected seismic cluster is sufficiently isolated from the rest of seismic activity in the broader area of The Geysers geothermal field. In addition, a high quality seismic catalog is available for this specified cluster (Martínez-Garzón et al. (2014) and Kwiatek et al. (2015)). The approach combines the distances of 1254 seismic events from the Prati-9 injection well with two additional parameters. The first one, deflection angle, is the angle between Maximum Horizontal Stress (SHmax) direction and a well-earthquake azimuth. The second one, rotation angle, is the angle by which one double-couple (DC) earthquake source is turned into another arbitrary DC (Kagan, 2007). Metrics of mentioned parameters are different, hence a solution based on the concept of probabilistic equivalence of earthquake parameters was proposed. Therefore, earthquakes clustering was studied in an equivalent dimensions space, where the equivalent dimension of a parameter is its cumulative distribution function (Lasocki, 2014). Hierarchical clustering, based on the Ward linkage distances between rotation angles, deflection angles and events distances, allowed for distinguishing 13 fractures families. Afterwards, we analyzed the characteristics of each cluster defining the criteria for possible fractures linkage with the potential for gas migration. Clusters' features such as the number of fractures intersections, seismic potential or fracture growth rate were taken into consideration thus identifying the fracture networks.

ESC2018-S32-864

INSIGHT INTO HYDRAULIC-FRACTURING INDUCED RUPTURE PROCESSES BASED ON AUTOMATED CLASSIFICATIONS OF WAVEFORM ATTRIBUTES AND SIMILARITIES

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In-situ, multi-stage hydraulic fracturing (HF) experiments were performed at the Äspö Hard Rock Laboratory (Sweden) at a depth of 410 m to study hydraulic fracturing growth and induced seismicity under controlled conditions for different fluid-injection schemes (continuous, progressive, pulse injection). Acoustic emission (AE) activity was recorded with a near field network of 11 piezoelectric sensors covering a volume of 30x30x30m around a horizontal, 28m long injection borehole. Sensors are most sensitive in the frequency range of 1 to 100 kHz, but sampling rates were extended to 1 MHz. In order to gain insight into the rupturing processes induced by the stimulation with water we set up an automated waveform based classification procedure to extract and characterize a massive number of high-frequency AEs from the continuous recordings. This includes the detection of events using a stack-and-delay approach and a first classification of these detections based on waveform attributes. These attributes are used to train a stochastic classifier, here Hidden Markov Models, which is able to identify false detections and further event classes. An automated full waveform location algorithm relying on the stacking of waveforms and coherence analysis is applied to the resulting AE catalog. A second classifier exploits waveform similarities by calculating network-based event cross-correlations to identify clusters of events with regard to their location and underlying rupture processes. The procedure was successfully tuned and tested based on one of the experiments (HF2). Compared to a preceding manual classification the automated event classifier was able to correctly classify 96% of the AEs. Hypocenters are spatially clustered in a planar region, revealing the geometry of the main fracture plane. We found highly correlated but also highly anti-correlated signals. We interpret the latter as reverse rupture processes at similar locations induced by the

stimulation. The procedure reaching from detection to event characterization is consequently applied to further experiments including different injection schemes and rock types. This does not only provide insights into the rupturing processes but also into the stimulation parameters controlling the induced seismicity.

ESC2018-S32-875

ANOMALOUS DIFFUSION OF SEISMICITY ASSOCIATED WITH OPERATIONAL PARAMETERS DURING STIMULATION OF THE GEOTHERMAL SYSTEM BELOW BASEL

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Enhanced Geothermal Systems (EGS) provide an alternative energy source that exploits geothermal energy stored into deep "hot" rock formations. Typically, the development of an EGS requires stimulation (permeability enhancement), which is achieved by massive fluid-injections under high pressure into the deep rock formation. Such fluid-injections can induce several small to larger magnitude earthquakes, posing a risk to nearby communities and infrastructures, as well as to the sustainability of the project. A characteristic example is the development of an EGS below the city of Basel (Switzerland). In December 2006 approximately 11,500 m3 of water were injected at high pressures into the well in order to enhance permeability in the reservoir and exploit geothermal energy. The water injection under high pressures into the impermeable crystalline basement induced more than 10,000 earthquakes during the 6-days injection phase, which reached magnitudes that required the reduction of the injection flow rates, the eventual well shut-in and the abandonment of the project. The spatiotemporal properties of the induced seismicity indicate the migration of the seismic front away from the borehole cashing shoe, which is more likely associated with pore-pressure diffusion into the fracture network. During the first three days of the injection phase, seismicity diffuses away from the cashing show at slow diffusion rates, which can be described by a slow subdiffusive process. The diffusion process changes dramatically following the increase of the injection flow rates and the wellhead pressure, where a fast migration of seismicity and superdiffusion is observed, culminating in the larger magnitude events. After the reduction of the injection rates and the eventual well bled-off, the induced seismicity rates decreased drastically and the earthquake diffusion process turned back to slow subdiffusion, which persisted for a 100-days period. In addition, the observed scaling properties of the induced earthquake sequence show broad probability distributions that indicate correlations in the seismicity evolution, in contradiction to the Poissonian assumption, where earthquakes occur randomly in space and time. The efficient spatiotemporal modelling of such induced earthquake sequences in EGS is thus of primary importance in order to monitor operations, quantify the associated seismic hazard and gain information regarding the geometry of the stimulated reservoir.

Acknowledgements
G. Michas acknowledges financial support from an AXA Research Fund postdoctoral grant.

ESC2018-S32-904

CAPTURING RELATIONSHIPS BETWEEN FLUID-INDUCED SEISMICITY RATES AND FLUID INJECTIONS: AN EXAMPLE RELATED TO FRACTURE STIMULATIONS IN ENHANCED GEOTHERMAL SYSTEMS

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We present a model for describing relationships between fluid-induced seismicity and operational parameters of fluid injections. The analyses are performed considering (1) the injection phases (i.e., time periods in which fluid injections are performed) and (2) the free-response phases (i.e., the post-injection periods). The implemented models are tested using the data from two cases of reservoir stimulations in enhanced geothermal systems (Cooper Basin, Australia, and The Geysers, US). For modeling the seismic sequences occurring during sustained fluid injection operations we present a novel covariate approach in which a probability distribution is defined as a basic template function for modeling the inter-event times (IET), and the possible dependencies on operational parameters are modeled writing the parameters of the probabilistic model in terms of deterministic functions of explanatory

covariates that are drawn from the operational data. Our results suggest a possible power-law relationship between the ? parameter of a exponential distribution of IET and the injection rate. The exponent of the power law varies between -1.22 and -0.73 in the Cooper Basin case, and between -1.04 and -0.78 in The Geysers case. On the other hand, we model the seismicity recorded in the post-injection periods using the modified Omori law (MOL). We analyze the seismicity during three free-response periods after three fracture initiation tests in Cooper Basin, finding a p-value that varies in the range $1.6<p<2.7$. These p-values are in general higher than the p-values usually found for natural seismicity, meaning that these fluid-induced seismic sequences tend to have a shorter duration than what is usually observed in natural aftershock sequences. Finally, for the inference of model parameter values, we propose the implementation of Bayesian methods for model parameter estimation, which provide a valid framework for evaluating the stability of the solutions and to assess the uncertainties in the model parameter values.

ESC2018-S32-907

MODELING INDUCED SEISMICITY WITH A STOCHASTIC-GEOMECHANICAL SIMULATOR

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The risk of inducing seismic events does nowadays call for the full development of new forms of exploitation of the geo-resources. Understanding the physical mechanisms is pivotal to the development of numerical tools to forecast induced seismicity and to elaborate mitigation strategies. Modeling tools constitute the base of the so-called Adaptive Traffic Light System, which could provide a real-time evaluation of the GeoEnergy system performance in the future. In this work, we summarize recent results of a numerical approach coupling a fluid flow simulator with a geomechanical-stochastic formulation to simulate injection induced seismicity. We present the main features of the developed approach, which includes non-linear pressure evolution as well as static stress transfer. The proposed approach is then applied to evaluate the relevance of induced seismicity related to a possible gas phase and to the system conditions. Based on some synthetic modeling, we finally focus on assessing the efficiency of the reservoir creation. Furthermore, we assess the seismic hazard associated with the fluid injection, estimating the probability of exceeding a certain magnitude event during and after stimulation. Both these factors (improved efficiency and lower seismic hazard) are then combined in a unique tool to evaluate injection strategies.

ESC2018-S32-910

SEISMIC MONITORING OF SEVERAL HYDRAULIC STIMULATIONS IN CENTRAL EUROPE

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Since 2005 several hydraulic stimulations were seismically monitored in Central Europe applying the method of Nanoseismic Monitoring. Nanoseismic Monitoring has to be seen as an approach between classical seismic networks consisting of a few single 3c-stations and the idea of passive seismics where an area of interest is densely covered with hundreds (or even thousands) of single seismometer stations. The method is based on the use of several seismic small arrays, each consisting of one 3c-central station and three 1c-satellite stations arranged as a tripartite small array. Applying Nanoseismic Monitoring and the adjusted software NanoseismicSuite which allows the detection and location of seismic signals with a SNR down to 1, detection thresholds below Ml 0.0 for seismic events can usually be achieved. Since 2005 several hydraulic stimulations in different oil and gas reservoirs in Northern Germany and Poland and the EGS project in Basel in 2006 were monitored applying Nanoseismic Monitoring. Depending on the local noise conditions, the achieved detection thresholds for seismic events vary between Ml = -1.5 in 5 km distance and Ml = -0.4 in 3 km distance for the different studies. With these thresholds we were able to detect, identify and locate seismic events which are related to the respective stimulation, in space and time of occurrence. We will present several case studies performed in

Central Europe were Nanoseismic Monitoring has been sucessfully used for seismic monitoring of induced seismicity caused by hydraulic stimulations. All aspects influencing the monitoring results will be presented and discussed: seismic network design/station layout, noise analysis, data analysis for event detection and the software tools used for event location.

ESC2018-S32-942

MONITORING OF INDUSTRIAL SEISMICITY ON THE TERRITORY OF KAZAKHSTAN

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Starting from 1994, a monitoring network of the RSE IGR consisting mainly of sensitive seismic arrays of different configuration has been operating on the territory of Kazakhstan. Monitoring of Kazakhstan seismicity has revealed some earthquakes occurred at regions that traditionally were considered as aseismic. A range of earthquakes was related to the places of active industrial effect, mainly on the territory near quarries that conduct regularly powerful explosions, and at oil fields. The report shows information about events of industrial and induced nature occurred on the territory of Kazakhstan. The industrial earthquakes at hard rock deposits (Zhezkazgan deposit and Zhomart quarry in Central Kazakhstan, gold ore quarries of Northern Kazakhstan), at raw hydrocarbon deposits (Tengiz oil field, Zhanazhol gas condensate field), at former Semipalatinsk Test Site were investigated, as well as natural-industrial (induced) earthquakes (in Central and West Kazakhstan). The nature of such earthquakes appearance can be different: at hard rocks deposits it is dynamic manifestation of rock pressure that results in rock collapse, rock bursts. At oil and gas fields the industrial earthquakes are, as rule, due to decrease of formation pressure in oil strata, and at the regions of underground nuclear explosions conducting (UNE) – with cavities collapse formed after explosions. Also, near large active quarries there could appear natural-industrial earthquakes with origins related to active faults (region of iron ore production, Rudniy town, region of coal quarries, Karaganda town, etc.). Despite large amount of industrial events recorded by the IGR network, these do not reflect the whole pattern of geodynamic activity at the regions of intensive industrial effect, as in general the reference magnitude mpva for the whole Kazakhstan territory by the permanent network of seismic observations is 3.0 – 3.5. It is necessary to conduct permanent monitoring by special networks of seismic observations at regions of large hard rock deposits, oil and gas fields, and the STS, as large earthquakes at such regions are dangerous not only by huge number of victims, destructions and economic loss, but by probably serious ecologic consequences.

ESC2018-S32-945

SOME SEISMICITY CHARACTERISTICS IN THE AREAS OF LARGE RESERVOIRS AND GREATEST WATERFALLS

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We have been studying some seismicity data in the areas of four artificial reservoirs (Kariba (Zambia, Zimbabwe), Koina (India), Nurek (Tadjikistan), Dworshak (USA)), natural one (Sarez lake (Tadjikistan)) and three waterfalls (Victoria (Zambia, Zimbabwe), Khone (Laos), Niagara (USA, Canada)). We have estimated an occasional realization probability for strong earthquakes (M>6.0) at depth of ~110-125 km near Sarez lake. It was established that in some cases induced seismicity reveals by reservoirs filling at enough big depths in the lower crust and even uppermost mantle. Negative correlation of biggest magnitudes of earthquakes (Mmax) occurred near reservoirs and waterfalls with water discharge in these structures (Vd) is established. The biggest Mmax values were observed for earthquakes occurred near Sarez lake (Tadjikistan, 2015, Mw 7.2) and Koina reservoir (India, 1967, Mw 6.6) with the lowest Vd values. The smallest Mmax values correspond to events near Khone and Niagara waterfalls, where large artificial reservoirs are absent, but great water discharge takes place. The data obtained indicate that permanent vibration by water fall from the big height leads to the seismicity level decay. Large induced earthquakes can be expected near big artificial reservoirs with relatively low water discharge in the corresponding dams.

ESC2018-S32-946

RELATIONSHIP BETWEEN INJECTED VOLUME OF WATER AND MAXIMUM EXPECTED MAGNITUDE, DURING THE PUERTO GAITAN (COLOMBIA) EARTHQUAKE SEQUENCE FROM 2013 TO 2015

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The 4,7 earthquake of November 2015 is the largest event recorded to date in the municipality of Puerto Gaitán. It happened in one of the most geologically stable regions of Colombia and within the largest heavy oil producing field in the country. More than 1000 events have been recorded since 2013, of which fourteen are Moment Magnitude greater than 4,0 +. Like most documented studies of induced seismicity, the case of Puerto Gaitán seems to be associated to the deep injection of co-produced wastewater from oil and gas extraction. The evidence suggests a close relationship in space and time between injection operations and seismicity. However, there is still no certainty if the seismicity is associated with the activation of an unmapped fault or if, on the contrary, it takes place in a complex geological system of multiple faults. An analysis of temporality between water injection and seismicity allowed us to identify a time lag between both events, which are common in wastewater injection sites. Furthermore, the sequence of events in Puerto Gaitán may not fit into a well-known correlation between the volume of fluid injected and the maximum expected magnitude. The expected size of the events should be the highest among those reported in the literature, however they are located well below the linear correlation. Taking into account the considerations to date studied with induced earthquakes, the evidence in Puerto Gaitán proposes new scenarios in the analysis of human-related earthquakes. The slopes of the seismicity and water injection curves represent the input and output power of the system. It contributes to characterize reservoir's mechanical behavior. We suggest a wide band of possible solutions to study the correlation between injected volume and Maximum Magnitude expected in Puerto Gaitán.

ESC2018-S32-952

SEISMIC DISCRIMINATION BETWEEN EARTHQUAKES AND QUARRY BLASTS IN IRELAND

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The vast majority of local seismic events detected in Ireland by the Irish National Seismic Network (INSN) each year are quarry blasts. In addition, several small (ML < 1.5) earthquakes are detected around Ireland and its near offshore regions. To avoid contamination of earthquake catalogs by man-made seismic events such as quarry and mining blasts, a robust discriminant or set of discriminants is necessary. To date, discrimination of events recorded at the INSN has been done using time and location. The most common technique for discrimination between seismic signals involves comparing the relative amplitude of the P and S phases of the signal. Another technique, the spectral ratio, involves comparing the ratio of the low-frequency to high-frequency regions of the signal amplitude spectrum, usually applied to S-waves. Successful discrimination at local distances has been achieved with both of these techniques in various regions worldwide. We investigate the performance of these discriminants on 1500 local seismic events recorded during the time period 2010-2016, taking advantage of the unprecedented seismic network coverage of Ireland during this period. Our study shows significant overlap at local distances between earthquakes and quarry blasts using the P/S amplitude ratio discriminant, whereas a much higher level of discrimination is achieved by applying the spectral ratio discriminant to S-waves.

ESC2018-S32-978

ANALYSIS OF THE SOURCE PARAMETERS BEHAVIOUR DURING THE VAL D'AGRI TEST-INJECTION (ITALY)

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Recent advances in understanding induced earthquake mechanics are due to the new and

high-quality observations from seismic signals, natural faults and laboratory experiments. The synergy of different approaches allows the acquisition of useful observations to understand the earthquake source process. In this study we investigate the source parameters behaviour of induced earthquakes recorded during daily injection tests in a wastewater disposal well in Val D'Agri (VDA, Italy). We choose this area because of its complexity and particularity. VDA is a Quaternary extensional basin located in the Southern Apennines characterized by a complex tectonic evolution, high seismic hazard and significant hydrocarbon exploitation. The basin hosts the largest onshore oilfield in Europe that produces oil and associated gas from low-porosity, fractured Cretaceous limestone. Wastewater associated to hydrocarbon production is reinjected into the Costa Molina 2 high-rate well (CM2) into an unproductive marginal portion of the carbonate reservoir at 2890-3096 m depth (b.s.l.). Initial injection tests were performed from 2 to 12 June 2006 with variable duration (from 4 to 32 hr) and hourly injection rate of 38 m3/hr. During the tests a maximum well-head pressure of 101 bar was measured. These tests induced a swarm microseismicity (69 events, ML comprised by 0.3 and 1.8) recorded by a high-performance local network run by INGV (Mc 0.4, 23 stations) that constitutes our testing data-set. We investigate the full moment tensors decomposing them in Double-Couple (DC), Isotropic (ISO) and Compensated Linear Vector Dipole (CLVD) components by using HybridMT technique. We obtain significant contribution of %ISO and %CLVD components that tend to increase with time. Also, we compute the moment magnitudes (that we compare with ML) and the static stress drops (by spectral analysis). Finally, we discuss each analysed source parameter as a function of the injection pressure curve in the geological/tectonic contest.

ESC2018-S32-1049

A HYBRID-EMPIRICAL GREEN'S FUNCTION TECHNIQUE FOR PREDICTING GROUND MOTION FROM INDUCED SEISMICITY: APPLICATION TO THE BASEL ENHANCED GEOTHERMAL SYSTEM

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A method is demonstrated for the prediction of site-specific surface ground-motion due to induced earthquakes occurring in predictable and well-defined source zones. The method is based on Empirical Green's Functions (EGFs), determined using micro-earthquakes at sites where seismicity is being induced (e.g., hydraulic fracturing and wastewater injection during shale oil and gas extraction, CO2 sequestration, conventional and enhanced geothermal injection). Using the EGF approach a ground motion field (e.g., an intensity map) can be calculated for a potentially felt induced event originating within the seismic zone. The approach allows siteand path-specific effects to be mapped into the ground motion field, providing a local ground-motion model that accounts for wave-propagation effects without requirement of 3D velocity models or extensive computational resources. As a test case, the ground motion field for the mainshock (ML = 3.4, M = 3.2) resulting from the Basel Enhanced Geothermal System was simulated using only seismicity recorded prior to the event. The performance of the method was significantly better than a previously developed generic ground motion prediction equation (GMPE) for induced earthquakes and showed improved performance through intrinsic inclusion of site-specific effects relative to predictions for a local GMPE. Both median motions, and the site-to-site ground-motion variability was captured, leading to significantly reduced misfit relative to the generic GMPE. It was shown, however, that extrapolation beyond a couple of magnitude units leads to significant uncertainty.

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SESSION 33

ESC2018-S33-122

USING HORIZONTAL TO VERTICAL SPECTRAL RATIOS TO EVALUATE SUBSURFACE SEISMIC PROPERTIES IN THE NETHERLANDS

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Site characterisation is key for seismic hazard analysis and risk mitigation but the properties in the subsurface are often a challenge to obtain. Over the last decades, increasing numbers of induced seismic events caused by gas production triggered the research on lower magnitude earthquakes and site response in the Netherlands. Although the magnitudes of the earthquakes are relatively small (max. recorded magnitude is 3.6), the damage on houses is significant. Due to the dense monitoring network, the Groningen gas field is an excellent laboratory for induced seismicity and near-surface wave amplifications.

ESC2018-S33-131

THE SEISMIC BEDROCK MAP OF THE PO PLAIN (ITALY)

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The seismological and earthquake-engineering communities are used to consider the seismic bedrock as the rock, or rock-like geological formation having a shear-wave velocity, Vs, greater than some target value that is usually inferred from the definition of some specific ground type in anti-seismic codes. Following the current Italian and European provisions, the boundary between softer soil deposits and the underlying base rock (i.e., seismic bedrock depth) can be associated with a shear-wave velocity greater than 800 m/s, as it corresponds to the lower bound VS,30 of the rock ground type (i.e., soil category A; European Committee for Standardization, 2004; Ministero delle Instrastrutture e dei Trasporti, 2008). The aim of this study is to map the seismic bedrock depth in the Po Plain area (Norther Italy), one of the largest alluvial basins worldwide, with an area of about 50.000 km2 and a thickness of Plio-Quaternary sediments that varies from few hundreds of meters up to about 8 km (Pieri and Groppi, 1981). This study relies on an extensive collection of both existing and newly acquired single-station, and array microtremor measurements, with the aim of defining the soil resonance frequencies and the shear-wave velocity gradients within the soft sediments above the seismic bedrock. The single-station measurements were analyzed by means of the horizontal-to-vertical (H/V) spectral ratio technique (Nakamura, 1989) while the microtremor array were analyzed by applying both frequency wavenumber (Lacoss et al., 1969) and spatial autocorrelation (Bettig et al. 2001) methods. The shear-wave velocity profiles were obtained through a joint inversion of the Rayleigh wave dispersion and ellipticity curves. When microtremor array data were not available, the inversion of the horizontal-to-vertical (H/V) spectral ratio was performed, modelling the full wave field under the diffuse field assumption (Sánchez-Sesma et al., 2011; García-Jerez et al., 2016). The similarity analysis on the smoothed shape of the H/V curves allowed recognizing different macroareas inside the basin: i) the Alps and Apennine foothills zones, where the soft sediments above seismic bedrock do not show significant amplifications at frequencies <1 Hz; ii)the central area of the basin, where the impedance contrast characterizing the soft to stiff soildiscontinuity is responsible for broad H/V peaks, in the range 0.5-0.7 Hz; iii) the Eastern areas, toward the Adriatic Sea, where the soft sediments above seismic bedrock show decreasing amplified frequencies, down to 0.3 Hz. Based on the collected data, an empirical regression model (Ibs-von Seht andWohlenberg, 1999) that relates the thickness of the soil deposits above the seismic bedrock to their resonant frequency wasdefined and applied to map theseismic bedrock depthin the Po Plain. The uncertainties on the estimate of sediments thickness were evaluated with 95% confidence limits following D'Amico et al., 2004.The resultant seismic bedrock map shows quite stable values around 150-200 m of depth in the central part of the plain and increasing depths toward to the Adriatic Sea, up to about 400 m in correspondence

to the Adriatic coast. A particular case is represented by the anticline zones, where due to an important tectonic uplift of the base rock formation, the H/V curves indicate pronounced amplifications at higher frequencies (i.e. 0.7-1 Hz), with the seismic bedrock depth ranging from a few tens of meters (i.e. anticlines with surface expression) to about 130 m (Laurenzano et al., 2013; 2017). The anticline zones are at basin scale the only case where the geologic and the seismic bedrock tend to overlap in correspondence of the base of continental Quaternary sediments. In the other part of the basin the seismic bedrock depth can be associated to different stratigraphic discontinuities well recognized inside the continental Quaternary succession: the R-Surface (e.g., Scardia et al., 2012) to the west and southeast of the basin, besides the Y-Surface and the AES6 subsynthem base (e.g., Scardia et al., 2012; Martelli et al., 2017) in the central plain. The proposed seismic bedrock map may be a useful tool for both scientific and applied purpose. In particular, this study may serve as benchmark for future site response assessments, numerical modelling of seismic-wave propagation, dynamic ground-response analyses, and soil hazard assessments at the basin scale.

ESC2018-S33-136

SHEAR-WAVE VELOCITY MEASUREMENTS TO OVER 2 KM DEPTH IN THE SEATTLE BASIN, WASHINGTON STATE, USA, AS CHARACTERIZED WITH THE KRSPAC MICROTREMOR ARRAY METHOD

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We acquired microtremor Rayleigh-wave array data at 11 sites in the Seattle basin, Washington State, USA, and applied the wavenumber-normalized SPatial Auto-Correlation method (krSPAC) to obtain shear wave velocity (Vs) to over 2000 m depth. In the krSPAC approach, we transform observed coherency-versus-frequency spectra to coherency-versus-kr (where k and r describe wavenumber and nominal station separation, respectively) prior to Vs modeling. The requirement for array symmetry is eased through this transformation, permitting flexibility in array deployments at challenging sites such as in urban areas. We deployed seven-sensor nested asymmetric triangular arrays, with nominal interstation separations that varied from approximately 300 m to 2000 m. We model Vs to 3300 m depth at one site, with an average modeled depth of 1200 m among all sites. Comparison of krSPAC Vs results to a previous interpretation from ambient noise tomography suggests a broadly comparable Vs structure in the 250 to 1000 m depth range and improved resolution at depths between 0 and 250 m. Whereas noise tomography methods commonly require months of recording time, the krSPAC approach in this study required less than six hours of recording time per site. At each site, we resolve a geologic boundary where Vs increases above 900 m/s, which is interpreted as the base of the unconsolidated (Quaternary) deposits in the Seattle basin. Using this boundary as the reference horizon for linear-elastic transfer function calculations, we estimate ground motion amplifications of a factor of up to 2 from the overlying Quaternary sediments between 0.3 and 7 Hz. Our amplification estimates are consistent with previously-published simple spectral ratio amplification spectra from earthquakes recorded in the basin.

ESC2018-S33-138

ANISOTROPY AND STRUCTURAL COMPLEXITY OF THE CRUST AND UPPER MANTLE OF THE ST. LAWRENCE CORRIDOR, EASTERN CANADA

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The St. Lawrence corridor in eastern Canada is a highly populated region with significant critical infrastructure. The region encompasses three active seismic zones (Western Quebec, Charlevoix and Lower St. Lawrence) separated by regions of very low seismicity. Whether the variations in seismicity are temporal or physical has implications for seismic hazard assessment. Despite being far from a plate boundary, the region is tectonically complex with the St. Lawrence River marking the boundary between the Canadian Shield to the north and the Appalachian Orogeny to the south. Teleseismic receiver function models, using a Neighborhood

Algorithm inversion, were developed for seismograph stations along the St. Lawrence to better define the structural complexities and to compare seismic and aseismic regions. Gaps in the broadband coverage of the Canadian National Seismograph Network were supplemented by deploying temporary stations and by taking advantage of the additional coverage provided by the US Transportable Array. The inversion was performed for individual earthquakes and again for multiple events stacked over narrow azimuthal ranges. Several pervasive features including a 5-10 km thick high velocity lid, a low-velocity mid-crustal layer and Moho at 35-40 km are observed. There are no structural differences between the active and less active area. By correlating the layers seen in the 1D models beneath each station, a pseudo-3D model was developed for the region from the Charlevoix Seismic Zone southwest to Montreal. A preliminary model has been developed for the region from Charlevoix northeast to the mouth of the St. Lawrence River where the temporary stations are still in operation. The crustal velocities in the Charlevoix-Montreal zone have an apparent azimuthal dependence which can be explained by the uppermost layer dipping toward the north or northeast but a contribution from anisotropy cannot be completely ruled out. Evidence for anisotropy at greater depths is obtained via SKS splitting. Fast-polarization directions are subparallel to the strike of the St. Lawrence valley in the east and parallel to the valley further west, with a slight rotation of fast orientation from west to east. Delay times for single measurements vary from 0.4 to 1.6 seconds, averaging ~1 second. This delay time requires an upper-mantle component, likely a combination of contributions from "fossil" lithospheric anisotropy and mineral alignments due to present-day sublithospheric mantle flow.

ESC2018-S33-219

A 6-COMPONENT SEISMIC SENSOR ROTAPHONE: NEW DESIGN, TESTING AND FIELD DEPLOYMENT

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A new six-degrees-of-freedom mechanical seismic sensor called Rotaphone has been developed and tested, both in a laboratory and in field experiments. It is primarily designed for collocated measurements of three translational and three rotational ground motion velocity components by one instrument. The device consists of a rigid frame and sensitive low-frequency geophones attached to it, arranged in parallel pairs to detect spatial gradients. Optionally, the instrument can be extended to a nine-component sensor by adding laser dilatometers measuring strain components. Rotaphone operates in a high-frequency range (above 2 Hz). Its theoretical (noise-free) sensitivity limit in this range is 10?9 m/s in ground velocity and 10?9 rad/s in rotation rate. Relatively small size and weight, and easy installation and maintenance make the instrument useful for local-earthquake recording and seismic prospecting. The first local network composed of seven Rotaphones has been built around Litomerice (Central Bohemia, Czech Republic) in the scope of geothermal project RINGEN. Examples of 6-component records of local seismic events are shown.

ESC2018-S33-267

SITE EFFECTS ANALYSIS OF SHALLOW SUBSURFACE STRUCTURES AT MASHIKI TOWN, KUMAMOTO, BASED ON MICROTREMOR HORIZONTAL-TO-VERTICAL SPECTRAL RATIOS

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The 2016 Kumamoto earthquake sequence included the main-shock with the magnitude of 7.3 on April 16, 2016. According to field survey results of Kawase et al. (2017), there's a Damage Concentrated Area (DCA) in Mashiki Town along the prefectural route No.28. We want to know why it appeared DCA in Mashiki town. Recently, a new research method of the diffuse field concept (DFC) to Earthquake Horizontal-to-Vertical spectra ratios (EHVRs) has been proposed by Kawase et al. (2011). However, as it is difficult to get enough earthquake waves at one area, Kawase et al. (2018) proposed the empirical ratio (EMR) between EHVR and Microtremor HVR (MHVR), which can be used to transform MHVR to EHVR. The transformed EHVR is called pseudo-Earthquake HVR (pEHVR). Here, we also want to verify the application of EMR method in Mashiki

town. Based on the inversion method for EHVR developed by Nagashima et al. (2014) we can invert S-wave velocity structure from pEHVR using only microtremor records. In this research, we performed microtremor survey around DCA in Mashiki Town, Kumamoto, Japan by the single station method. We obtained microtremor data at 62 sites in the area of 500 m by 800 m. Then, we calculated MHVR of every site and obtained 48 reliable MHVR curves (the rest are too noisy or unstable). After deciding peak frequency of every MHVR curves, we made a fundamental peak frequency map of Mashiki Town. After that, we transformed MHVR to pseudo-EHVR (pEHVR) with Kawase's EMR method. To verify the applicability of EMR method in Mashiki town, Kumamoto, we used earthquake waves recorded by two strong ground motion stations at Mashiki town: KMMH16 (from NIED) and KMMP58 (from Kumamoto Prefecture). We worked out EHVR of these two sites and compared them with pEHVRs for nearest microtremor sites. We found that pEHVRs are closer to EHVRs than MHVRs so we used pEHVRs in our research to obtain velocity structures below 48 microtremor sites. We identified 1D S-wave velocity structures of Mashiki Town, by using Nagashima's inversion method (Nagashima et al., 2014). Next, we analyzed dynamic 1-D soil responses of all the sites by Yoshida's equivalent linear code based on the inverted velocity structures. Finally, we analyzed both linear and nonlinear (=equivalent linear) cases for comparison and we estimated peak ground velocities (PGVs) and peak ground accelerations (PGAs) of all the sites. The input ground motion at the bedrock was calculated by the new method of diffuse field concept (Nagashima et al., 2018) through the assumption of linear 1-D soil response for the vertical component. We made PGV and PGA distribution maps of linear and nonlinear cases of Mashiki town. Based on the research results, we have four major findings: First, the subsurface layers in the northeastern side are harder and shallower than those in the southwestern side. Second, the EMR method is suitable for Mashiki town, Kumamoto, because pEHVRs are closer to the observed EHVR than MHVRs. Third, the total thickness of layers would be less than 25m with S-wave velocity less than 200m/s. Lastly and most importantly, we found that distribution maps of PGA and PGV are not similar to building damage survey results at DCA during the Kumamoto earthquake.

ESC2018-S33-280

ESTIMATE OF RAYLEIGH WAVE DISPERSION CURVE BY MEANS OF TWO SENSORS APPLYING THE SPAC ZERO CROSSING METHOD

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In the last few years, the use of ambient vibration measurements to estimate the VS profile is significantly increased, especially for Seismic Microzonation studies. In this framework, the multiple-station techniques (seismic arrays) are definitely attractive due to their relative cheapness and feasibility in urban contexts. Nevertheless, due to the lack of free space in most of European historical centers, even these techniques can present practical limitations hampering their application. The aim of this work is to verify the capability and the reliability of the SPAC zero crossing method (Ekstrom et al., 2009) in obtaining the estimation of the Rayleigh wave dispersion curve at the urban scale by using pairs of GPS synchronized sensors. If effective, this technique would allow to reduce soil occupancy by also reducing preparation time, allowing a more extensive use of the multiple station technique in the study area. Moreover, if used in tomographic configurations, this method would allow the identification of possible geological heterogeneity within the study area when several sensors are deployed (e.g., Pilz et al., 2012). SPAC zero crossing directly derives from SPAC technique proposed by Aki (1957): in this case, the azimuthal average of the correlation coefficient obtained for different directions is replaced by the correlation coefficient value obtained from a single pair of stations. This use is justified assuming the presence of a sufficiently isotropic ambient vibration wavefield. Applying this formulation and displaying the correlation coefficient values with respect to the frequency, it is possible to note that this trend resembles the Bessel function of zero order (J0) but the peak amplitudes may not decrease monotonically with increasing frequency. This behavior depends on the background disturbance and non-linear effects of the data processing as well as the azimuthally non-uniform power of the ambient vibration (Ekstrom et al., 2009). In view of this, it is useful to focus the attention only on the frequencies corresponding to the zeroes of the correlation function, assuming

that these points should be less affected by variations in the spectral power of the background disturbance. In particular, if ω_n denotes the frequency of the nth observed zero crossing and z_n denotes the nth zero of J0 (namely the argument value that makes null the J0 value), it is possible to determine the corresponding phase velocity $c(\omega_n)$ as: $c(\omega_n) = (\omega_n r)/z_n$. (1) The association of a given zero of the correlation spectrum observed with the corresponding value of z_n could be difficult because the background disturbance can make the first annulment of the correlation unreadable even allowing the identification of successive zeros. To take into account this possibility, different correspondences between the experimentally obtained zeros and the sequence of z_n values are assumed. This leads to the definition of a certain number of possible dispersion curves, as many as the possible zero crossing taken into account. To express this multiplicity, the different estimates of phase velocity $c_m(\omega_n)$ are associated to the number m of "lost" or "added" zeros compared to that one corresponding observed. This situation is expressed by this relationship:

$c_m(\omega_n) = (\omega_n r)/(z_n+2m)$. (2)

where m takes the values 0, ±1, ±2, etc..

To face the problem of the identification of the site representative dispersion curve between those ones calculated using Eq. 2, the SPAC zero crossing method was applied in different geological contexts using arrays with two or three vertical sensors. The results are compared with the Rayleigh wave dispersion curve obtained by "classical" seismic arrays with 16 or more geophones analyzed with ESAC technique (Ohori et al., 2002). The outcomes of these study cases demonstrate that the Rayleigh wave dispersion curve representative of the site is that one associated to the maximum value of m which shows a decreasing trend with increasing frequency.

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ESC2018-S33-302

STUDYING THE SHALLOW SUBSURFACE OF MARS BY AMBIENT VIBRATION RAYLEIGH WAVE ELLIPTICITY - SIMULATIONS AND FIELD TESTS IN PREPARATION FOR INSIGHT

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NASA's InSight mission will for the first time deploy a very sensitive three-component seismometer package, SEIS (Seismic Experiment for Internal Structure), directly on the surface of Mars in November 2018. Although the properties of the regolith are not the main focus of InSight, propagation through this low-velocity near-surface layer will influence the signals recorded by SEIS, as demonstrated by the Apollo seismograms measured on the Moon. In addition to quantifying this influence, the physical properties of the regolith are of interest in themselves, e.g. for future landing site selection and rover missions, as well as for the study of rock degradation and geomorphology at the landing site. Therefore, a number of investigations are planned to study these properties using the data of InSight's single seismic station. One of them is the inversion of Rayleigh wave ellipticity curves derived from ambient vibrations. To test this method for application to InSight, we develop a plausible model for the uppermost 50 m of the subsurface at the landing site, based on laboratory measurements, analysis of orbital data, fragmentation theory, and field data from an analogue site. We calculate a synthetic random wavefield within this model, for a surface-wave

based simulation on the one hand and synthetics explicitly considering body waves on the other hand, and do not observe any striking differences in the measured H/V and Rayleigh wave ellipticity curves. We consider two different single-station methods to extract the Rayleigh wave ellipticity from the wavefield and find that one of them, H/V using time-frequency analysis (HVTFA), allows identifying also the first higher mode, which can provide useful additional constraints during the inversion. By scaling the synthetics with the help of high-frequency seismic signals generated by a terrestrial dust devil, we find that the atmospheric background wavefield, considered to be the major source of seismic noise on Mars at short periods, should be above the self-noise of SEIS's short period sensors, even if the signals are not produced within 100–200 m of the station. We use model ranking based on the corrected Akaike's information criterion to select a preferred model parameterization when inverting the ellipticity curves and show that they can distinguish between different velocity-depth functions in the shallowest layer. We investigate how well the subsurface model can be recovered, based on available prior constraints, e.g. from lab measurements of seismic velocities or the analysis of seismic signals generated by InSight's heat flow probe HP3 (Heat flow and Physical Properties Package), including the importance of prior assumptions on density. Using reasonable a priori constraints on the regolith velocities can help to obtain useful information on sub-regolith properties and the minimum depth to the bedrock. The minimum velocity and thickness of the sub-regolith layer are better constrained than the maximum values, and Q does not have any influence on the ellipticity curves, while it effects the amplitudes of the standard H/V curves. Inversion results show a low sensitivity to setting the density of the layers to wrong, fixed values. However, assumptions on the velocity range in the upper-most layer have a strong influence on the results also at larger depth. Wrong assumptions can lead to results far from the true model in this case. Additional information on the general shape of the curve, i.e. single or dual peak, could help to mitigate this effect. We also consider the effect of instrumentation resonances caused by the deployment conditions specific to InSight, i.e. SEIS will be located within one to a few meters distance of the lander feet, and on a mechanical leveling system that provides coupling to the ground and a level placement of the sensors. Both the leveling system resonances and wind-driven lander flexible modes occur at significantly higher frequencies, above 35 Hz and 20 Hz, respectively, than the structural response of about 5 m of regolith, as expected at the landing site. While the lander and solar panel resonances might be too weak in amplitude to be recorded by SEIS, the leveling system resonances will show up clearly in horizontal spectra, the H/V and ellipticity curves. They are not removed by trying to extract only Rayleigh-wave dominated parts of the data. However, they can be distinguished from any subsurface response by their exceptionally low damping ratios of 1% or less as determined by random decrement analysis.

ESC2018-S33-307

CHARACTERIZATION OF SWISS STRONG MOTION SITES BY INVERTING HVR CURVES FROM EARTHQUAKE RECORDINGS

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Based on the diffuse field theory proposed by Kawase et al. (2011), Nagashima et al. (2014) developed a new inversion technique using a hybrid heuristic search, a combination of a genetic algorithm and simulated annealing inversion methods. With the assumption that the wave field after the shear wave arrivals is diffusive, the Horizontal to Vertical spectral Ratio (HVR) of this wave field is calculated and inverted in order to reconstruct the velocity profiles of the underground. We tested and applied Nagashima's method to strong motion sites in Switzerland, where seismicity is lower than in Japan. To perform this analysis, we selected and picked regional earthquakes with local magnitude between 2.5 and 4.6. The HVR curves are computed for each event using a 40 seconds long window and averaged over different events. We inverted these data for shear-wave velocity profiles down to large depth. The investigated sites are part of the Swiss Strong Motion network. For all of them, site characterization measurements are systematically performed, mainly using ambient vibrations recorded with passive seismic arrays. These velocity profiles are

used as starting models for the inversion of the HVR curves and to constrain the upper part of the velocity structure. Additional layers are added for the deepest portion of the subsurface. The preliminary results show a good fit between synthetic and computed HVR curves for all tested sites. We compare the obtained velocity profiles with the 3D geological information of the region of interest. Such information was compiled in the project Geomol with a geological 3D model of the Swiss Plateau. Moreover, available information from deep boreholes were used for comparison. The same procedure will be systematically applied to other sites of seismic station in Switzerland and the resulting velocity profiles will be updated using future earthquakes recordings.

ESC2018-S33-328

LITHOSPHERE-ASTHENOSPHERE BOUNDARY BENEATH CENTRAL MYANMAR FROM S-RECEIVER FUNCTION CONSTRAINTS

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The Cenozoic tectonic evolution of Myanmar involves a complex interplay with the eastward subduction of the Indian plate along the Indo-Burmese arc, and has still been heatedly debate. Lithosphere-Asthenosphere Boundary (LAB), as a global seismic discontinuity, is crucial to investigate the dynamic processes for deep-material movement. However, due to the sparse seismic data coverage in the Indo-Burman block, detailed variation of the LAB depth beneath this region is poorly understood. From June 2016 to January 2018, 38 portable broadband seismic stations with dense spacing of ~10-15km were deployed across the main geological units of central Myanmar, i.e., the Indo-Burman Ranges, the Central Basin and the Shan Plateau along ~22°N. Each station was equipped with a Güralp CMG-3ESP or a Nanometrics Trillium 120PA seismometer and a Reftek 130 data acquisition system. Based on the seismic data collected by this new array, detailed images of the LAB deep variation beneath the Shan plateau have been derived from S- receiver function poststack migration. Teleseismic S- receiver functions are perfectly suited for LAB observations, for they are free from the interference with multiples from Moho or shallow structures. With a total of 668 S-receiver functions calculated by the maximum entropy deconvolution method [1], we performed 2-D wave equation-based poststack deep migration for receiver function imaging [2]. In the S- receiver function images, a coherent negative signal appeals at ~110-130 km beneath the Shan Plateau, which is believed to be the Sp phase of the LAB. This depth range is in good agreement with previous seismic observations in the adjacent SW Yunnan, China. Our preliminary results indicate that the Shan plateau in Central Myanmar may share the similar tectonic setting with SW Yunnan under the influence of the eastward subducted Indian plate. This study is supported by the National Natural Science Foundation of China (grants 41490612-41474040). [1] Wu, Q., Li, Y., Zhang, R., et al. 2007. Receiver Functions from Autoregressive Deconvolution. Pure Appl. Geophys., 164(11), 2175-2192. [2] Chen, L., L. Wen, and T. Zheng. 2005. A wave equation migration method for receiver function imaging: 1. Theory, J. Geophys. Res., 110, B11309.

ESC2018-S33-338

INVESTIGATING THE CONTRIBUTION OF BODY, SURFACE, OR DIFFUSE WAVES FROM JOINT INVERSION OF AMBIENT NOISE DATA

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Knowledge of site conditions is important to predict damage induced due to earthquakes, particularly within an urban environment. One of the important steps in this process is to test the soil strength at any site. The soil strength is directly related to shear modulus, which can be obtained from shear wave velocity (Vs). The two common methods used in earthquake site characterization for Vs estimation using ambient noise data are Rayleigh wave dispersion curve and horizontal-to-vertical spectral ratios (HVSRs) inversion. Usually the Vs profiles are generated by using the Rayleigh wave dispersion curves and HVSRs are used to get the peak frequency and amplification of a site to estimate the seismic hazard. Peak frequency in HVSRs is an indicator of depth of the soil/bedrock interface, which is often not possible to obtain from the dispersion curve

inversion due to the lack of resolution at lower frequencies in dispersion curves. Therefore, joint inversion of dispersion curves and HVSRs gives us more reliable and deeper Vs depth profiles. This study also examines the contribution of different wave types to the HVSR curve. Ambient noise data from different sites with varying HVSR curves is utilized. Geotechnical data for all these sites exist for validation. Usually the amplification functions are either based on SH transfer function or ellipticity function, ignoring the contribution of the other wave types. We will use an advanced technique for joint inversion that allows us to compute the contributions from all wave types (surface and body) in theoretical amplification functions and can jointly invert for both dispersion curves and HVSRs. It is based on the theory of diffuse field assumption (DFA) and believes that a diffusion-like field is generated when random seismic sources in an elastic, inhomogeneous and anisotropic medium generate ambient vibrations. In DFA, HVSR is given in terms of imaginary part of Green's function that is proportional to the averaged cross-correlations of recorded signals from diffused and equipartitioned fields within the medium. The HVSRs obtained for our study area have low peak frequencies (~ 2 Hz) information and hence are used to estimate Vs variations at shallower depth intervals and hence in constraining the subsurface velocity model. The results obtained from just the dispersion curve inversion estimate the shallow velocity structure quite well when compared with the geotechnical data but fail to identify the deeper velocity variations and the soil/bedrock interface due to the loss of sensitivity at deeper depth intervals. The thin layers in the shallow subsurface are easier to identify but the deeper thin layers in the Vs profile are not being identified by dispersion curve due to the loss of resolution. The joint inversion of dispersion curve and HVSRs is better able to retrieve the shallow velocity structure and soil/bedrock interface similar to the geotechnical data as well as an estimate of the bedrock Vs. The current study contributes to estimating a well-constrained subsurface Vs model with less uncertainties and in understanding the involvement of different wave types for varying site conditions.

ESC2018-S33-385

WAVEFIELD GRADIOMETRY: COMPARING CONVENTIONAL F-K TECHNIQUES TO LOCAL SPATIAL GRADIOMETRY FOR SITE CHARACTERIZATION

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Estimating the site-effects at locations of seismic stations and performing microzonation for seismic hazard assessment requires knowledge of the shallow shear-wave velocity profile. Conventionally, this information can be obtained using large and dense arrays of sensors and processing techniques such as the spatial autocorrelation method (SPAC), frequency-wavenumber (f-k) analysis, multichannel analysis of surface waves (MASW) and seismic refraction tomography (SRT). However, at sites with limited access, for example in urban areas, on mountain slopes, at the ocean or lake bottom and at extraterrestrial sites, the requirements for the optimum array used for these techniques cannot always be fulfilled, either because of spatial constraints or due to high transportation and installation costs. Estimating the local spatial gradient of the wavefield allows retrieving the local apparent velocity by using significantly smaller arrays. At the Earth's free surface, the seismic wavefield gradient corresponds to the rotational component of the wavefield. Therefore, a rotational sensor in combination with a conventional translational three-component (3C) seismometer could replace the remaining array to one single 6C station. Besides reducing the amount of required stations, such sensors would also minimize the influence of lateral heterogeneities at the receiver location. We performed a conventional seismic site characterization at a potential site for a seismic borehole station in Valais, Switzerland, and compared the resulting dispersion curves from conventional methods to local velocities retrieved by gradiometry, using both active and passive data. Active data was acquired using 4.5 Hz 3C geophones and multi-component sledgehammer sources, whereas passive data was recorded using 5 s 3C seismometers. The array for measuring

spatial gradients had a diameter of only 10 meters. Results from f-k analyses and gradiometry are generally in agreement. We demonstrate the principles of gradiometry and discuss potential reasons for the remaining deviations between the different techniques. Finally, we give an outlook for future investigations at that site, including the use of rotational sensors.

ESC2018-S33-438

AMBIENT VIBRATIONS MEASUREMENTS TO STUDY ROCK SLOPE INSTABILITY IN THE ETNA AREA

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We show the results of an integrated study of geologic surveys and seismic site response in the southern segment of the Acireale fault (eastern flank of Mt.Etna), where creep phenomena and landslides play an important role. We performed ambient noise measurements using the Horizontal to Vertical Spectral Ratio (HVSR) technique, in order to infer the occurrence of directional amplification effects in the fault zone.The fractures surveyed in this study take place along a fault segment belonging to a wider NNW-SSE system, locally known as Timpe, which displaces a large part of the Etna eastern flank. Along this part of the fault system, stickslip motion, producing seismic sequences of low magnitude (M<4.9) earthquakes, and aseismic displacements take place. Literature data about creep rates, obtained from analysis of historical records and field surveys, indicate significant movements varying from 0.5 to 2.3 cm/year. HVSR analysis was performed on ambient noise recorded in 30 sites, using a 3-component seismometer (Tromino). Time series of ambient noise were recorded with a sampling rate of 128 Hz,divided in different time windows of 20 s, following the guidelines suggested by the SESAME project (2004). Spectra of each window were smoothed and then HVSRs were calculated in the frequency range 0.5-20.0 Hz. Experimental spectral ratios were also calculated after rotating the horizontal components of motion by steps of 10 degrees starting from 0° (north) to 180° (south). This approach has been used for ambient noise signals by several authors to identify site response directivity in the presence of faults. In the present study we also applied the time-frequency (TF) polarization analysis described by Burjánek et al. (2012 and reference therein). This technique provides quite robust results, overcoming the bias that could be introduced by the denominator spectrum in the HVSR calculation. Polarization parameters obtained all over the time series analysed are then cumulated and represented using polar plots, together with ellipticity vs. frequency diagrams.The HVSR measurements were performed near the cliff edge, where the fractures are more evident, and moving towards its inner parts. The results point out a clear seismic site effect very marked in the neighbourhood of the fractures, in the eastern part of the studied area, and a decrement moving towards West. In particular, the HVSRs show a tendency to increase the amplitude, in the frequency range 1.5-4.0 Hz, with a clear “eye shape” (Castellaro and Mulargia, 2009) in the FFT. The presence such a characteristic allowed us to exclude anthropic disturbances on HVSR results. The rotated spectral ratios show a broadband frequency effect with several adjacent peaks pointing out a preferential direction with angles of about 80°-90°. Furthermore, the TF results set into evidence the presence of a significant horizontal polarization at the measurement sites along and across the investigated faults. The ambient noise is sharply polarized in a narrow frequency band (1.0-4.0 Hz), following a roughly east-west trend that is almost perpendicular to the fault strike. The results of ambient noise measurements performed along the studied fault segment therefore pointed out the presence of directional amplifications, also confirmed by the results of the time–frequency analysis, with the largest amplification occurring at high angle to the fault strike. The nature of the observed site effects is highly complex as a number of different mechanisms, such as near-surface structures and slow gravitational deformations, contribute. Consequently, the shear wave velocities could be lower with respect to the values typical of lava formations. Measurements performed some hundreds meters away from the fault zone show a reduction of the observed directional effects that may be ascribed to the fault fabric. We relate the polarization effects to compliance anisotropy in the fault zone, where the presence of predominantly oriented fractures makes the normal component of ground

motion larger than the transversal one. Such findings corroborate the hypothesis that the observed landslide movements can be related to creep movements along the investigated fault.

ESC2018-S33-452

ARRAY DESIGN FOR SITE CHARACTERIZATION MEASUREMENTS IN THE SWISS STRONG MOTION NETWORK RENEWAL PROJECT

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The most important parameter to understand amplification effects at a given site is the shear-wave velocity profile of the underground, which can be obtained by performing site characterization measurements. There is a large variety of tools which can be used for this purpose. Many of them are analyzing ambient seismic noise, which has the advantage that the signals do not have to be generated artificially, but are present at all times. In contrast to active seismic experiments, we cannot control the sources of the signal to be analyzed. Therefore, the different seismic wave types which are present in the signal, mainly surface waves, have to be separated by appropriate methods. Using arrays of seismic sensors, we can observe the propagation of the different wave types across the array and deduce their velocity, i.e. the dispersion curves. The design of a seismic array is not a trivial issue and needs to be adapted to the techniques which are supposed to be used for the analysis. There are other issues to be considered. The available space in urban areas is very limited compared to measurements in agricultural landscapes. Lateral variations and varying geology also influence the array response. Furthermore, costs for the instruments, the manpower and the necessary workforce to analyze the data should be taken into account. The Swiss Seismological Service started to renew and extend its strong motion network (SSMNet) in 2009. The project is ongoing and is scheduled to be finished in 2020 with the installation of the 100th new station. For all of these stations, site characterization measurements are systematically carried out. The measurement techniques vary from site to site. At most of the sites, array measurements of ambient seismic vibrations are performed. The data are analyzed using different techniques such as SPAC, 3-component high-resolution FK and WaveDec (wavefield decomposition). We optimize our arrays for these measurements to be able to measure dispersion curves of Love and Rayleigh waves in a wide frequency range in a limited time with a limited number of participants. Additional constraints are that the planning of the arrays and their implementation in the field should be easy. The optimization of an array of seismic sensors is a nontrivial issue. Maranò et al. (2014) optimized array designs by minimizing the side-lobes of the array response in a given wavenumber range. The resulting arrays depend on the number of sensors used, but most of them have a design which can be mainly described by a three-fold rotational symmetry. Another approach is to optimize the array for the use with SPAC. The original SPAC method (Aki, 1957) is based on seismic stations installed on a circle. It can be shown that a limited number of stations on the circle are sufficient for a good measurement, but the number has to be odd. Three or five stations are sufficient. Other frequency ranges can be covered by adding rings with larger or smaller radius. Even if advanced SPAC techniques such as M-SPAC do not necessarily require a strict station positioning on rings, it is still advantageous to plan the array with such a configuration. For our measurements, we generally use 16 sensors connected to 12 dataloggers and set them in five rings with three stations each around a central station, increasing the radii of the rings from about 8 m to over 200 m. In this way, dispersion curves can be measured over a wide frequency range with only one array. We will present which steps we take to plan such an array for a given site, compare the array response of different array designs and analyze which radii and rotation angles between the different rings give the best array response.

ESC2018-S33-462

SEISMIC WAVE-FIELD ANALYSIS FROM DENSE SEISMIC ARRAYS AND IMPLICATIONS FOR SITE EFFECTS IN CEPHALONIA, GREECE

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Site-specific characteristics of the observed ground motions are considered important for the

estimation of seismic design parameters in engineering applications. Seismological observations have indicated that effects of surface geology and geometry (e.g. sedimentary valleys, topography) significantly contribute to ground-motion amplification and variability. These effects are generally associated with a substantial proportion of surface waves in the seismic wave field, largely caused by lateral variation of material properties of the site. Among them, the surface waves diffracted by the basin edges contribute significantly to ground-motion amplification and variability. Understanding of the seismic wave field crossing the site, hence, is the key aspect to characterize and quantify these effects. However, this task remains technically challenging due to the complexity of such effects as well as the limitations of geophysical investigations, especially in case of small-size sedimentary valleys. Studies investigating the properties of the wave field have shown that seismic arrays are very useful to characterize the fine-scale structure of Earth's interior and the variations of the material properties. A single seismometer is unable to determine both velocity and direction of the incident seismic waves while arrays of seismic sensors enable us to study the phase delays that normally cannot be identified in seismograms of single stations. Yet, a one-dimensional (1D) seismic array can only determine the component of the wave vector, which lies in the array direction. Therefore, two-dimensional (2D) arrays are needed to retrieve the back-azimuth and velocity of the incoming waves. This study presents the results obtained from the analysis of the seismic wavefield composition of two 2D dense seismic arrays, deployed during the seismological experiment held at the small-size, shallow alluvial valley of Koutavos-Argostoli in the Cephalonia Island of Greece, under the framework of 2010-2014 FP7 EU-NERA (Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation) project (Imtiaz, 2015; Imtiaz et al., 2017). The principal dense array was positioned close to the center of the valley and consisted of 21 velocimeters in concentric circles with radii of 5 m, 15 m, 40 m and 80 m around the reference station. Another smaller array (Array B) was deployed near the one edge and consisted of 10 velocimeters with interstation distances ranging from 5 to 60 meters. A set of 46 earthquakes, with magnitude 2 to 5 and epicentral distance up to 200 km was analyzed. Among the various available array techniques, the MUSIQUE algorithm (Hobiger et al., 2012) was used to analyze the selected events. It combines the MUSIC (MUltiple SIgnal Characterization) (Schmidt, 1986) and quaternion-MUSIC (Miron et al., 2006) algorithms and offers an advanced three-component (3C) seismic array processing technique. In addition to the estimation of the apparent velocity and direction of the dominant incoming waves, MUSIQUE allows identification of Love and Rayleigh waves, and estimation of the polarization parameters (i.e., ellipticity and sense of rotation) of the Rayleigh wave particle motion.
The results clearly indicate a predominance of scattered surface waves (40-60% of total energy), mainly from the closest edges, beyond the fundamental frequency (~1.5 Hz) of the valley. Love waves dominate the low-frequency wave field (1.5 - 3 Hz) while Rayleigh waves strongly dominate only in relatively narrow bands at higher frequencies. Within particular frequency bands, an excellent consistency was observed among the dominance of the identified surface wave type, group velocities estimated from the ground velocity structure, and site amplification in terms of the Standard Spectral Ratio. For both arrays, amplification observed between 1 and 2.5 Hz, 3 and 6 Hz frequencies could be associated, respectively, with the diffracted Love and Rayleigh waves. The findings provide an exciting opportunity to advance our knowledge in understanding the physical causes lying behind the spatial variation of earthquake ground motion and multi-dimensional site effects.

ESC2018-S33-465

THE CONTRIBUTION OF RAYLEIGH WAVE ELLIPTICITY CURVE TO CHARACTERIZE SOIL PROFILE

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During the last decades the use of ambient vibrations on seismic site characterization has largely increased. Taking advantage of the large wavelength range of these signals, the subsurface structure can be investigated in a broad depth range from few meters to several hundreds of meters. The use of non-invasive techniques is very

important on urban sites and even with a single-station measurement it is possible estimate the physical properties of the shallower layers. This knowledge is very important to estimate the soil seismic behaviour and it will allow the achievement of a proper microzoning in urbanized areas. On the other hand, an adequate urban microzoning will help decision-makers on the definition and implementation of earthquake mitigation measures. Ambient vibrations single-station measurements and the application of Nakamura (1989) methodology, through the determination of the H/V curves, allow the estimation of the ellipticity curves on the assumption that seismic noise is mainly composed by Rayleigh waves propagation. The inversion of these ellipticity curves will also give information on subsoil properties. In general, the inversion of these curves is performed together with the dispersion curves obtained by other independent surface-waves methods (for instance ReMi, MASW or SASW). However, it is important to investigate to what extend the inversion of this curve will give information on the subsoil structure. In this communication we will present some sensitivity tests to investigate the accuracy of the Rayleigh wave ellipticity inversion on the subsoil structure estimation (thickness and depth of the different layers). We start with a simple theoretical model of a soil layer over an half-space, testing for different impedance contrasts. To compute the theoretical ellipticity curve in a stratified linear elastic medium it is necessary to know the characterization of each layer through four parameters: the velocity of propagation of P-waves (VP), the shear wave velocity (VS), the density and the layer thickness (h). The VS is clearly the most influent parameter, but VP has a non-negligible influence on Rayleigh wave ellipticity curve. Due to this reason we maintained a fixed value for the Poisson's ratio equal to 0.35.
We compute theoretical ellipticity curves for low (2), medium (3) and high (5) impedance contrasts between the soil layer and the half-space. For each impedance contrast four layer thicknesses were tested (h = 2m, 5m, 10m and 20m). The ellipticity curves were inverted assuming that VP, VS, and h were known with 5% or larger incertitude. We performed a statistical analysis of the results to investigate the error associated to VS1, VS2 and h estimations as a function of the uncertainties introduced in the initial model. The results will be tested with data from real sites obtained with seismic linear array methods using passive and active sources. This communication is supported by FCT- project UID/GEO/50019/2013 - IDL.

ESC2018-S33-466

SPLITTING FUZZY SEISMIC WAVEFIELD FROM TIEN SHAN GEODYNAMIC POLYGON

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Modern geodynamic processes cause changes in structural and textural characteristics of rocks which are expressed both in reversible processes (closing and opening of cracks) and irreversible process related to crack formation processes. For monitoring this processes our group made annual research of geoelectrical and magneto-telluric situation in Geodynamic polygon in Tien Shan. We have 3 stationary monitoring points. The purpose of this investigation is to solve the fundamental problem of the Earth studies – the problem of studying modern geodynamic processes in a wide range of phenomena changes of prestressed media. Such disasters as earthquakes etc. These processes become apparent in different physical fields and physical parameters including electromagnetic fields and electromagnetic parameters of lithosphere. We need to find the difference of tangent components of electromagnetic field recorded at daylight surface. For implementation of this algorithm, we developed the MTS data processing program to single out the sources of endogenous electromagnetic field (Batalev et al., 2017). The main task is to find the very transformation of the acoustic and electromagnetic emissions that would allow enunciating an inverse problem on the detection of the location of the field generation and activity of their sources. Here we consider some assumptions and theoretic wave propagation approximations from endogenic crack forming source. The main problem is instability of source existence, inharmonic and nonstationary wavefield character. It means that contemporary fuzzy seismic signals are formed. These spread-spectrum signals of endogenous

nature observed during the field geophysical research are certain physical phenomena (Sobolev, 1993) that require appropriate theoretical description. Phased array techniques for single-component sensors and vectorial analysis of three-component recordings are common for evaluation the relative contributions of different wavetypes (P, SV, SH) and can provide estimates of the azimuth and slowness of seismic phases. The cross-correlation method has to be applied for sensors check. This scheme has many of the limitations of the wavefield classification scheme if we discuss seismic activity in 10-100 Hz range. This process requires a physical model of direct upward seismic waves from near-surface moving small structure (as fracture or crack). Which of equation parameters need to be analyzed to divide P-, SV- from SH-wave contributions to the seismogram before signal processing. Such mathematical justification could facilitate signal detection. For comparison results from small seismic array we expect to make simultaneous registration by available geophysical equipment and observe its correlation. As an example in 2017 the we performed some field experiments.

ESC2018-S33-499

FUNDAMENTAL FREQUENCIES MAPPING IN OUED-FODDA, ALGERIA, USING AMBIENT VIBRATIONS DATA

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We used ambient vibration data and the Horizontal-to-Vertical Spectral Ratio method (HVSR) to estimate Fundamental frequencies (f0) and the corresponding amplitudes (A0) in the city of Oued-Fodda located in north-central Algeria, in the Middle-Chellif basin. This region has suffered several destructive earthquakes, the strongest was the 1980 El-Asnam earthquake (Ms7.3). The causative fault of this earthquake is located about 1 Km north of the city of Oued-Fodda. The ambient vibrations measurement campaign includes a set of 80 points inside and outside the city with a minimum interstation distance of 200 m. For clear and reliable results, the measurements were made following the recommendations of previous similar worldwide studies. The first results show fundamental frequencies that vary from 1 to 4 Hz in the northwestern part of the city and from 4 to 7 Hz in its southern part. The corresponding amplification factors vary from 2 to 6. The maximum amplification factor is observed northeast of the city. The results also show flat HVSR curves at several sites in the center of the city which may correspond to the presence of Paleozoic substratum as suggested by previous geological studies in the region. Near future measurement campaigns are planned to better constrain our results.

ESC2018-S33-542

VS30 MAPS AND FUNDAMENTAL PERIODS IN GUADALAJARA, JALISCO, MEXICO, OBTAINED FROM SEISMIC NOISE ANALYSIS

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Guadalajara is the second largest city in Mexico with an estimate of 4.5 million inhabitants. It is located on the Colima-Jalisco region, where the occurrence of large magnitude subduction earthquakes is well documented. The largest event in this region occurred on June 3, 1932 (Ms 8.2). Moreover, the north part of the Jalisco block is just 20 km away from Guadalajara City, and even though it causes only small to moderate earthquakes, the ground accelerations can be even 8 times bigger as those produced from subduction events. This is why it is important to improve the geotechnical classification and to analyze the seismic response in the urban area of Guadalajara. In order to complete the geothechnical soil classification, we recorded seismic noise along profiles on 30 locations within the urban area of Guadalajara. Using MASW and ReMi methods, we obtain velocity profiles that we further consider to obtainVs30 values. Moreover, using strong ground motion records of the Mw 8.0 1995 event and H/V spectral ratios, we obtain

fundamental periods for some of the measurement points. For those locations with no strong ground motion records, we obtain the fundamental period considering the predicted rock depth from the estimated velocity profiles. With these results, we generate Vs30 maps as well as isoperiod maps, using and comparing different algorithms. The results are in good agreement with the existent geological information. Though our results cover the west part of Guadalajara (which had not been considered in previous studies) it is urgent to consider new measurement campaigns to improve and complete the obtained maps, in order to assess the possible damages in case of the occurrence of a large magnitude subduction event or even a moderate event from the northern Jalisco block.

ESC2018-S33-559

WAVEDEC CODE: AN APPLICATION TO THE JOINT ESTIMATION OF SHEAR MODULUS AND DISSIPATIVE PROPERTIES OF THE NEAR-SURFACE FROM MULTI-COMPONENT, ACTIVE SURFACE-WAVE SURVEYS

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The reconstruction of the geophysical properties of the subsurface at instrumented sites is a key effort for engineering seismology. In fact, the knowledge of the geo-mechanical parameters of the subsoil, ideally from the most surficial soil cover to the seismological bedrock, enables modelling the local site response, thus allowing the interpretation of the recorded earthquake waveforms separating the source and path terms, on one hand, from the site term. Site characterization improves therefore the robustness of magnitude and seismic attenuation estimation of collected events, and helps understanding the seismic behavior of various soil types. For the purposes of subsurface imaging, several approaches and techniques have been proposed and used, with different outcomes in terms of costs, easiness of execution and interpretation, resolution and reliability of characterization. Indeed, invasive prospecting techniques such as downhole surveys offer the advantages of a direct investigation of the subsoil; on the other hand, they are time-consuming and expensive, therefore hardly sustainable for the characterization of tens or hundreds of sites, as many strong motion networks consist of nowadays. Non-invasive, indirect geophysical surveys – in particular surface wave analysis - are understandably more cost- and time-effective, and they are currently believed to provide a reconstruction of the subsurface properties with resolution and reliability comparable with those of an invasive test. This has been achieved through the refinement of acquisition, processing and inversion techniques, with particular attention to the integration of all available types of information in the solution of a single inverse problem. Going forward in this direction, we illustrate the use of an approach for surface wave surveys we have developed, which is incorporated in a processing code, named WaveDec, publicly available. This approach is based on the maximum likelihood estimation of the parameters describing surface wave propagation: phase velocity, ellipticity (for Rayleigh waves), and attenuation coefficients. Originally developed for the processing of array-recorded microtremor data, the code has been adapted to handle active data; in this work we focus on this latter application. The technique we apply identifies the frequency-dependent parameters of surface wave propagation minimizing the difference between measured and simulated wavefield; the subsoil is modeled as a 1D stack of horizontal layers with anelastic behavior. All recorded traces (from all sensors and components) are jointly considered. The search for the best-fitting combination of propagation parameters is sped up with the use of factor-graph technique. The possible presence of multiple modes of Rayleigh wave propagation in the collected traces is taken into account; the code progressively decomposes the acquired wavefield (hence its name WaveDec), identifying the (minimum) optimal number of waves explaining it, following a Bayeasian information criterion. The processing output of WaveDec is therefore a set of (multimodal, if more than one mode was identified) frequency-dependent phase velocities, ellipticity values, and attenuation coefficients. The joint inversion of these experimental curves allows reconstructing not only the shear modulus profile of the investigated subsurface, but also its shear damping ratio model. It is worth remarking that the retrieval of this latter piece of information is often neglected in the application of invasive or

non-invasive geophysical techniques. The application of WaveDec to active or passive surface wave data, allowing for an elastic soil behavior, has been already presented; the further contribution of this work is the joint modelling of all recorded components in the anelastic simulation of the synthetic wavefield. We present the validation of WaveDec approach through the processing of a synthetic dataset; we also present an application to a field case, drawn from a MASW dataset acquired at an alpine-valley site to verify the likelihood of liquefaction. In the latter case, the dispersion and attenuation curves estimated with WaveDec have been compared with those obtained with established f-k and amplitude regression techniques. We show that the joint use of all components of the acquired wavefeld and the combined estimation of Rayleigh wave propagation parameters improves the robustness of their estimation. Further developments of our work are related to adapting WaveDec code to the processing of Love waves, as well as its systematic application to a statistically significant number of sites for the estimation of both shear velocity and damping ratio profiles. In a longer term perspective, the study of the attenuation properties of surface waves acquired in a passive fashion is also envisaged.

ESC2018-S33-584

VS PROFILE DERIVED FROM SURFACE-WAVE AND DOWN-HOLE METHODS: COMPARISON AT SOME CASE STUDIES IN CENTRAL ITALY

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Site characterization is a basic step in any study involving the estimation of local seismic amplifications. A main product of a site characterization analysis is the shear-wave velocity (Vs) profile, which is often obtained in the one-dimensional (1D) case through geophysical methods integrated to geological information. Among geophysical methods, surface-wave techniques based on passive seismic data are increasing of popularity and are usually employed within the seismological and engineering community to derive shallow 1D Vs profiles. In this study we used surface-wave passive techniques to characterize four Italian sites situated in different geological context. At each target site, a down-hole survey was also executed by other researcher groups (Cnr-Igag, Università degli Studi di Firenze and Università La Sapienza di Roma) providing the subsurface Vs profile for a maximum depth of investigation of about 50 m. Because the passive non-invasive seismic experiments were conducted before and independently from the down-hole results, we had the opportunity to compare the 1D velocity models obtained with the two methods (i.e. passive seismic data and down-hole tests) in a blind way. The four sites have been selected in the framework of two projects: i) three sites were investigated during the microzoning activity of the Amatrice area (OCDPC n. 394 of September 19, 2016) after the 2016 seismic sequence of the Central Italy (Amatrice downtown, and the nearby villages Sommati and Sant'Angelo where the main geological formation is the Laga Flysch); ii) one site (ROM9.IV in Rome) was investigated for a characterization analysis regarding the Italian seismic network following an agreement between Department of Civil Protection (DPC) and Istituto Nazionale di Geofisica e Vulcanologia (INGV) (DPC-INGV 2012-2021, Allegato B2-Obiettivo1, Task B).
We used arrays of three-components seismic stations arranged in 2D configuration and we recorded, at each target site, some hours of ambient vibrations (i.e. seismic noise). The array geometry was defined according to the logistic, and, when possible, two geometries with a progressive larger aperture were used at a same site to increase the frequency band of analysis. The maximum aperture of the 2D arrays varied approximately from 100 to 200 meters using 12 seismic stations. The 2D arrays measured the dispersion curve using frequency-wavenumber and spatial auto-correlation methods. The resonance frequency (f0) was also computed by the horizontal-to-vertical (HV) noise spectral curves. A joint inversion of f0 and dispersion curves in terms of surface waves has provided the local Vs profile and the consequent soil class category, based on the mean value of the best Vs model in the uppermost 30 m of the subsurface (Vs30 as prescribed by the national Italian seismic design code). Additionally, a joint inversion under the diffuse field assumption was also tentatively tested to derive the subsurface velocity structure. Our blind test between 2D array and down-hole methods shows some discrepancies between Vs

profiles derived at the same site: forward computations of theoretical dispersion and ellipticity models, using the Vs profile resulting from array and down-hole surveys, show an overlapping only in a narrow frequency band, highlighting the different resolution of the two methods. In particular, we observe a general agreement in the main trend of the velocity-depth profile (Vs discrepancies are within 20% range) at soft sites, but thin layers with different elastic properties documented by the down-hole surveys cannot be reproduced by array methods. Moreover, the resonance frequency of the HV curves in the low frequency range (i.e. < 2 Hz) is not reproduced by forward ellipticity-model computation assuming the Vs profile from down-hole data; this is expected because the down-hole surveys have smaller investigation depth (<50 m) and cannot reveal deeper seismic contrast responsible of the low-frequency resonance. However, the main differences for Vs are observed at IV.ROM9 where borehole data show at the shallow (approximately at a depth of 20 m)the presence of a strong velocity reversal, which is related to a stiffer volcanic deposit overlaying asoft sedimentary layer. To conclude, the comparison at our case studies from borehole and array methods provides some differences in terms of Vs profile. This can be partially explained considering that a borehole test is a punctual survey whereas array experiment is an areal survey influenced by the average elastic properties of the investigated subsurface. A secondary factor to consider is the different resolution provided by the two methods. We believe that, for the assessment of the Vs profile to compute the local seismic response, it is likely a good compromise to combine the results derived from boreholeand 2D array for the shallowest and deeper part, respectively.

ESC2018-S33-630

DIFFERENT APPROACHES IN USING SURFACE WAVES DATA TO IMAGE MUD VOLCANOES STRUCTURE ON THE EXAMPLE OF TAMAN PENINSULA SHELF

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Taman peninsula is a densely populated area that is why active mud volcanoes can be dangerous. Among a large number of volcanoes in that region, there are submarine ones, which have not been studied in detail until now. This paper contains results of geophysical surveys made in 2015 on the active mud volcanoes Golubitsky and Gorely. The use of modern methods based on measurements of surface waves formed by ambient noise [1] or active impact [2] made it possible to construct a vertical geophysical section and to image the deep structure of mud volcanoes. Mud volcano Golubitsky is located on the Azov sea shelf near the Kerch bridge under construction. The main goal of the fieldwork was to obtain reliable surface wave data in marine conditions. Novel equipment where used when performing underwater measurements, including specialized broadband bottom seismometers and recorders placed in the buoys. The technology of underwater mud volcanoes depth study included profile seismoacoustic measurements of the noise field with the output for analysis of the spectral amplitudes of surface waves at various points of the passed profile. Marine experiments have confirmed that the developed technology allows one to study structure characteristics of the volcano feeding system and surrounding areas of the bottom. Within the framework of another geophysical experiment, the velocity structure of the upper part of the Gorely volcano was studied. The method of work is based on the measurement of the Rayleigh wave dispersion curve, in our case it is carrying information about the layered structure of the medium up to several tens of meters of depth. These unique scientific results are of great practical importance from the ecological safety of the region point of view. The reported study was partially supported by RFBR, research project No. 18-35-00541. References:

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ESC2018-S33-644

RAYLEIGH THREE-COMPONENT BEAMFORMING: SIGNED ELLIPTICITY ASSESSMENT FROM HIGH RESOLUTION FREQUENCY-WAVE NUMBER PROCESSING OF AMBIENT VIBRATION ARRAYS

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For site characterization, temporary ambient vibration arrays (up to a few hours) have demonstrated their efficiency and their reliability compared to classical techniques based on borehole measurements. Most of them are acquired with three-component sensors. However only the vertical components are often processed with frequency-wavenumber (FK) or spatial autocorrelation (SPAC). Vertical components mostly contain Rayleigh waves and they can be processed without any particular assumption other than planar wave fronts. Horizontal components contain variable portions of Rayleigh and Love waves which require more sophisticated methods for a proper separation. The simplest method that considers the three components of an array is the computation of H/V spectral ratios used to retrieve the resonance frequency of the site and to assess the 1D-ness of the site, i.e. a constant H/V peak frequency observed over the whole array is a necessary condition for moderate lateral variations of the structure properties. A more advanced step is to measure the Rayleigh ellipticity versus frequency. Various methods have been proposed so far to extract the polarization from ambient vibrations recorded on a single three-component station (e.g. FTAN and Raydec methods). Some improvements were achieved by integrating polarization assessment with a high resolution FK technique (Poggi et al. 2010). If only the absolute value of the ellipticity was then available, new array based techniques were recently proposed with enhanced efficiencies providing also the ellipticity sign (Marano et al. 2017). With array processing, higher-order modes are often detected even in the ellipticity domain. In this work we develop an alternative three-component technique based on a high resolution beamforming where radial and vertical components are integrated at a low level. If N is the number of three-component sensors, cross-spectral density matrices of dimension 2N are calculated for all presumed directions of propagation. They are built with N radial and N vertical channels. As a first approach, steering vectors are designed to fit with Rayleigh wave properties: the phase shift between radial and vertical components is either $-\pi/2$ or $\pi/2$. We show that neglecting the ellipticity tilt due to attenuation has only minor effects on the results. Additionally, we prove analytically that it is possible to retrieve the ellipticity value from the usual maximization of the high resolution beam power. The method is tested on synthetic data sets and on experimental data. Both are reference sites already analyzed by several authors. A detailed comparison with previous results on these cases is provided. We outline the ability of our method to correctly retrieve dispersion estimates in terms of phase velocity and signed ellipticity for both fundamental and higher modes within a wider frequency range than classical FK approach.

ESC2018-S33-687

ACTIVE MASW METHOD FOR NEAR-SURFACE SITE CHARACTERIZATION IN THE SKOPJE URBAN AREA. GENERATING DISPERSION IMAGES OF OPTIMAL RESOLUTION

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During the last decades, the Multichannel Analysis of Surface Waves (MASW) method has been one of the most popular geophysical methods for site characterization, particularly for urban areas with relatively high ambient noise. The method is based on analysis of the dispersive characteristics of surface waves. It consists of the following steps: (1) array design and acquisition of Rayleigh waves; (2) extraction of dispersion curve; (3) inversion and estimation of the shear wave velocity (Vs) vs. depth model. The first step is probably the most important as it contributes to a more accurate extraction of dispersion curves and to the enhancement of the resolution of the Vs model. Seismic surveys using the active MASW method were carried out at characteristic locations within the Skopje urban area. 2D surveys in “roll-along” mode were conducted at each of the surveyed sites using a SoilSpy Rosina 17 channel digital seismograph (MoHo - Science & Technology,

Italy). The seismic energy was generated by vertical blows with a 8 kg sledgehammer on an aluminum plate and recorded with 4.5 Hz vertical geophones. Attention was paid to optimize the field acquisition parameters, such as the offset of the seismic array, the receiver spacing and the length of the record. To this end, the surveys were performed varying the acquisition parameters one-by-one in order to determine their respective influence on the dispersion image resolution. Preliminary 1D MASW surveys were first conducted at one of the investigated sites. The Rayleigh wave data, for the preliminary surveys, was acquired with a fixed receiver spacing of 2.5m for a variety of minimum offsets: 5, 10 and 15m and recording lengths between 0.5 and 2s. Pre-processing of the raw data was conducted using the SoilSpy Rosina software. The consecutive analyses and interpretation were carried out applying the SurfSeis 3.06 software (Kansas Geological Survey, USA). The dispersion images were generated using the "wavefield transformation" method according to Park et al. (1998), whereas the inversion of the extracted dispersion curves was performed with the iterative process proposed by Xia et al. (1999). For comparative purposes and to validate the interpretations conventional seismic refraction and reflection surveys were carried out as well. In some cases, 2D MASW "roll-along" survey data were applied for seismic reflection analyses. The dispersion images were generated for each source-receivers configuration. The effective dispersion curves were extracted from the dispersion images as a combination of the fundamental and higher modes of the Rayleigh waves. As a result of the preliminary 1D surveys, longer recording length (2s) and minimum offsets (10 and 15m) provided better resolution dispersion images at the site with low background noise. For the high background noise sites, where most of the 2D MASW surveys were conducted, data collected with shorter recording lengths (0.5 seconds) provided a better quality dispersion images. As well, the dispersion images of shorter minimum offset seismic arrays (5m) were generally of good quality. Longer recording lengths (2s) in this cases contributed to higher noise in the signals. Although it was expected that the recording length should not directly influence the quality of the dispersion image, it was inferred from this result that the dispersion images resulting from longer recording length contains more inappropriate information, i.e., noise. On the other hand, in some cases, the dispersion images for longer recording length contained more information at the lower frequency range, important for estimation of the shear-wave velocity (Vs) in the deeper layers. The final outputs of the 2D MASW surveys, were 2D Vs models along each of the surveyed transects. The generated models clearly show the variation of the Vs value along a depth of 15-30m whether it is the case with a steady increase of Vs with depth or the case of low velocity layers trapped between higher velocity layers. The joint acquisition of 2D MASW and seismic reflection data applied at some of the sites, proved very cost effective in terms of time and effort engaged for field acquisition, and favorable for subsurface investigations in complex geologic conditions. The main conclusion drawn from the obtained active MASW results is that there is no widely accepted configuration of the seismic array and data acquisition protocol. Site-specific acquisition parameters have to be developed for each investigated location and calibrated during the preliminary MASW measurements.

ESC2018-S33-690

AMBIENT VIBRATION INTEGRATED ONLINE SERVICE (AVIOS): TOWARDS A MORE AUTOMATIC WAY OF PROCESSING AMBIENT VIBRATION ARRAY RECORDINGS.

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Ambient vibrations array techniques are gaining success and have reached over the years enough maturity to compete with traditional approaches for site characterization. Geopsy is a popular tool set to process ambient vibrations and invert shear wave velocity profiles (Vs). It has run on all desktop PC and MacOSX with a lot of freedom and manual steps left to the user since 2005. Born some 15 years ago with a research project (SESAME 2001-2004), the concepts and the methods require a complete renewal especially towards standardization and automation to face new challenges with the multiplication massive data sets. Ambient Vibration Integrated Online Service (AVIOS in short) is a recent effort to pipe

all array methods into a single robust process from measured ambient vibration signals to Vs profiles. Recorded data are first sorted, organized and geo-localized with a desktop tool (geopsy) before being submitted to AVIOS service (currently at https://avios.geopsy.org). No specific parameter is to be selected or chosen from the user expertise. Computations are run on dedicated clusters and results are provided back to the user after a certain time. After a high resolution three-component frequency-wavenumber processing, the obtained curves are post-processed in a smart way (Rayleigh and Love dispersion curves and ellipticity curves) and they are inverted to provide Vs profiles with a series of predefined parameterizations. Higher modes are automatically identified even in the presence of osculation points. A PDF document is produced summarizing all results for a fast user review. During the test phase all intermediate files are also available for download. Publication mechanisms of the results are still under discussions (manual user selection, peer reviewing, expert users 'likes', automatic criteria,...). The service is proposed for free if the data owner accepts an open access to the results, eventually after a grace time. The results will be then accessible through a QuakeML format to any user, registered or not. For users who wants to keep their full control over their results, payment will be required before using the service. The exact terms and rules are currently under discussions.

ESC2018-S33-739

GROUP-VELOCITY DISPERSION CURVE ANALYSIS OF 2017 AYVACIK EARTHQUAKES IN ÇANAKKALE, TURKEY

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In February 2017 several earthquakes occurred in Ayvacik (SW Çanakkale city, Turkey) with magnitude range 5.3 > Mw > 5.0. Three-component strong ground motion records of the earthquakes were recorded by nationwide seismic network of Prime Ministry Disaster and Emergency Management Authority, Republic of Turkey (AFAD). In this study, Ayvacik earthquakes used to study the characteristic of surface wave propagation between earthquake sources and stations. Surface wave group velocity dispersion curves obtained by multiple-filter method for the ground motion of the 2017 Ayvacik earthquakes were used to determine the horizontal 1D velocity structures for deep sediment and upper part of the crust from focal layer to the engineering bedrock beneath the stations in the different azimuthal directions.

ESC2018-S33-799

APPLICATION OF GLOBAL-PHASE SEISMIC INTERFEROMETRY TO EASI

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A number of seismic methods exist to image the lithosphere below a collection of receivers, using distant earthquakes. In the current practice, especially mode-conversions in teleseismic phases are utilized. Instead, body-wave seismic interferometry can be used. With seismic interferometry, reflections are extracted from the coda of distant seismicity. This allows the creation of reflection responses as if there were large seismic sources at receiver locations. These reflections can be further processed into sharp reflectivity images of the entire lithosphere (e.g., Abe et al. 2007; Ruigrok et al. 2012). This study makes use of data collected by the Eastern Alpine Seismic Investigation (EASI), a passive seismological project that aims unraveling the structures of the Earth's upper layers. 55 stations were deployed along a N-S oriented profile, and have been recording in the field for over a year (2014/2015). The EASI transect is 550 km long and developed between the Adriatic Sea and the internal Bohemian Massif. The geometry of station location within the transect has been studied in order to maximize the deep illumination coverage along the profile, with 10 km spacing (along N-S direction) and 15 km spacing (oblique), leading to a uniform ray coverage at depth considering that the majority of the seismic events are incoming from North and East directions (e.g. Japan, and Pacific Ocean) and few are arriving from South and West directions (Africa and Atlantic Ocean). EASI uniquely samples varying lithospheric terrains and has sufficient aperture such that source-side effects can be eliminated

from the estimated reflection responses. Hence, we expect to deliver a sharp reflectivity image that can help towards understanding the tectonic evolution of the Alpine and Variscan orogenies.

ESC2018-S33-836

CO-SEISMIC TEMPORAL CHANGES OF SHALLOW MATERIAL DURING STRONG GROUND MOTION

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Temporal changes of Vs generated at the subsurface by the Mw 9 2011 Tohoku earthquake in Japan are analyzed using interferometry and autocorrelation of waveforms recorded by surface and borehole sensors at the KiK-net station IBRH16. Spectral ratios and interferometry of data recorded in moving time windows at the surface and a depth of 300 m exhibit clear time delays and reduction of the predominant frequency during the strong ground motion, followed by partial recovery in the waveform coda. Converting the time delay evolution to velocity changes implies about 30% velocity reduction in the structure between the two sensors. Calculating temporal evolution with autocorrelation of data at the surface sensor in moving time window indicates about 50% velocity reduction, reflecting changes of shallower material below the station. Computing autocorrelations of data recorded by the surface sensor with the Stockwell transform allows monitoring temporal changes with higher resolution that approaches the sampling rate of the waveforms. Using this technique we estimate about 60% drop of seismic velocity below the surface sensor during the strong ground motion, followed again by partial recovery in the coda. These in-situ results provide fundamental information on in-situ dynamic properties of soils and damaged shallow rocks that complement laboratory measurements, with important implications for constitutive equations of material degradation and healing and nonlinear site effects.

ESC2018-S33-849

SPATIAL VARIATIONS OF SITE-EFFECTS RECOVERED FROM A 3D VS-MODEL BASED ON THE JOINT INVERSION OF MASW AND AMBIENT DATA, AND THEIR CORRELATION WITH DAMAGE FROM STRONG EARTHQUAKES: THE CASE OF THE VRISA SETTLEMENT AND THE 2017 M=6.3 LESVOS EARTHQUAKE

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A strong earthquake with magnitude M6.3 struck on June 12, 2017 the island of Lesvos and the surrounding area, situated at the north-east part of the Aegean Sea. While the mainshock epicenter was estimated to be ~15 km off the southern coast of Lesvos island with a focal depth to 12 Km, relatively limited damage was reported along the coastal Lesvos area. An exception was the historical settlement of Vrisa, where extensive damage (including a large number of collapsed masonry houses) was observed, mainly in the northwestern part of the village, which was located on recent (Holocene) sediments. On the contrary, for the remaining part of the village, founded on stiffer Neogene deposits, limited damage was reported. Moreover, the earthquake affected mainly the historical, masonry buildings of the village, with a negligible Impact on the (fewer) reinforced concrete modern constructions. Since the previous pattern is indicative for the presence of strong site-effect phenomena, we have employed a large number of surface geophysical measurements, recording mainly surface waves from both active and passive sources, in order to study the shallow geophysical structure and examine the spatial distribution of the expected site effects on seismic motions for the Vrisa area. To determine the 1-D shear-wave velocity structure, a circular Noise-Array was realized in the northern (Holocene) Vrisa area (with a radius of 10, 40 and 100 m for the inner, the middle and the outer circle radius, respectively). Moreover, 23 lines of MASW were realized with the use of 4.5 Hz vertical geophones. This dataset was complemented by the performance of nearly 70 single station ambient

noise measurements, which were conducted with the use of broad-band seismometers (CMG-6TD or CMG-40T-60 sec with Reftek 130 digitizers). Horizontal-to-Vertical Spectral Ratio (HVSR) curves were calculated for all noise recording sites, while dispersion curves were determined with the use of the f-k method, both for the MASW and the Noise-Array data. For the final 1-D shear-wave velocity model determination we employed a joint inversion of Rayleigh wave dispersion curve and Rayleigh ellipticity information. For this reason, Rayleigh wave ellipticity was extracted from the noise recordings using the approach of Hobiger et al. (2009). Ellipticity was jointly inverted with the reconstructed Rayleigh dispersion curves, in order to increase the Vs-model penetration depth, as well as to reduce the non-uniqueness of the model inversion. The joint inversion was performed with the use of a Monte-Carlo approach, namely the neighborhood algorithm, as adapted by Wathelet et al. (2008) and realized through the Geopsy software tools (http://www/geopsy.org). The final Vs models show the presence of a very soft layer (Vs700-800m/sec), which outcrops in the Vrisa southeastern section, corresponding to the Neogene formations. The transition from Neogene to Holocene formations is rather abrupt, suggesting the presence of a NE-SW normal fault that creates the local basin, which is filled with Holocene formations. Preliminary 1D site response analysis in the frequency domain for the final geophysical model of the Vrisa area confirms the presence of strong amplification of seismic motions in the northwestern Vrisa area, in good agreement with the damage pattern of the June 12, 2017 M6.3 earthquake.

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ESC2018-S33-906

RELATIVE SITE AMPLIFICATION AND PREDOMINANT FREQUENCY ESTIMATION AT 5 STATIONS IN THE BODRUM PENINSULA

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The Bodrum Peninsula is surrounded by the Gulf of Güllük to the north, the dodecanese islands (Greece) to the west and the Gulf of Gokova to the south. This region with a population over one and half million in summer season is one of the most populated touristic centers in the Aegean coast of Turkey. There are numerous active seismic entities which pose a great threat to settlements in and around of this region. Considering the high seismic risk and population of the peninsula, a strong ground motion network was deployed in June 2015 in order to investigate ground motion characteristics as well as behavior of shallow site profiles at such seismically active urban regions. This network has recorded the main and the aftershocks of the July 20th, 2017 Bodrum-Kos earthquake. In this study, a dataset included 4.0<Mw<6.6 earthquakes was selected for site effect calculation. Predominant frequencies and amplification values of shallow soil layers under the stations were estimated through Horizontal to Vertical Spectral Ratio and Standard Spectral Ratios. Then, sediments thicknesses beneath the stations were empirically calculated by using predominant frequencies. In addition, the damage distribution of the Bodrum-Kos earthquake was discussed with its relation to the estimated predominant frequencies and relative amplifications. The research for this paper is supported by Boğaziçi University Research Fund Grant Number 10260.

ESC2018-S33-916

PULLING SEISMIC EVENTS OUT OF THE NOISE TO CHARACTERIZE THE SUBSURFACE

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The match filter technique has proven to be a unique tool to massively detect small seismic events close to the level of the noise. Typically it requires a template to start the search. However, automatic methods have been developed with arrays by beamforming to possible source regions to find high energy events, and then searching for

repeats of those events and growing a catalog. Those possible events that did not have repeats are eliminated. The sources that are found need to be similar, but not exact as in searches for repeating earthquakes. The search is for source regions that produce similar events, but are not necessarily exactly the same earthquake. The technique has allowed for the detection of millions of sources, an order of magnitude above the standard match filter technique. Here we present the next step, single station detection. The power of pulling the source out of the noise comes from multiple detections in space across many stations. We instead look for many detections in time from a single station. This is done by stepping through the time series and cross correlating 100 second windows with the rest of the time series. Templates are derived from within the time series at points that have many high correlation coefficients. We use the sum of the correlation coefficients, like the spatial detection method, to find repeated events. We use the stack of the repeats as a template to search for more events. We have verified the technique with a temporary seismic array in southern Mexico. Thousands of M1.5 - M4.5 earthquakes were found that were previously not in the Mexican National Seismological Service catalog. Their locations depict the subduction interface, the deeper plate plunging more than 50 km below the surface, the magma chamber of 2 volcanoes, and an active fault region within the crust. The detection technique should prove powerful for places like Jupiter's moon Europa, where NASA is considering sending a lander with a seismometer. The bandwidth to send data back to the Earth will most likely be a large constraint. Ice sources of seismic events on the Earth greatly repeat, more than from rock sources. In addition, the strong tidal forces that Europa experiences from Jupiter and the other Galilean moons should provide a strong and repeating strain source. The technique will be able to generate a catalog of seismic events on Europa and develop those templates which can be sent back to the Earth for further analysis. Comparing these templates to the modeled seismic sources will help to constrain the depth of ice and oceanic layers. As a first step to proving the technique on Earth, we apply it to seismometers installed on floating ice in the Arctic where both ice cracking and earthquakes from the spreading ridge below are measured.

ESC2018-S33-924

INVERSION OF AMBIENT SURFACE WAVE DISPERSION FOR SUBSURFACE CHARACTERISATION: THE CASE OF A THICK BURIED CLAY LAYER

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The Maltese archipelago is composed of Tertiary sedimentary rocks laid down between the Chattian (late Oligocene) and the Messinian (late Miocene). They consist of four principal formations of limestones, clays and marls. The sedimentary sequence has been intensely faulted and vertically displaced by tectonic faults active since the early Miocene. In the western half of the archipelago, the full sedimentary sequence is mostly conserved, consisting of an outcropping layer of competent Upper Coralline Limestone (UCL), overlying an up to 75 m thick layer of clays and marls (the Blue Clay, BC). This is in turn underlain by a thick layer of fine-grained Globigerina Limestone (GL). The existence of the Blue Clay layer (absent from the eastern half of the archipelago) has been the subject of intensive investigation in recent years, particularly in the context of site response and site amplification. Seismically, the clay layer represents a shear-wave velocity inversion. Here we present the results of geophysical investigations to extract shear-wave velocity profiles in this type of geology, using geophone arrays and three-component velocimeters. Site frequency analysis was carried out through H/V analysis of ambient noise at a large number of characteristic outcrops. The buried clay layer produces a uniformly consistent peak in the 1.0 – 2.0 Hz range in the H/V spectral ratio. L-shaped geophone arrays were set up at 27 appropriate sites, and ambient Rayleigh wave dispersion curves were extracted and jointly inverted with the H/V curves using a genetic model based algorithm to yield the S-wave velocity profiles. The velocity structure, in particular the velocity inversion, was well-resolved in all cases down to the GL layer, and helped to constrain the previously unknown values of the seismic velocities in the UCL and BC. A wide variation in the S-wave velocity of the UCL was observed, which correlated with the state of macro-fracturing in the rock, whereas the

corresponding velocities in the BC were more uniform, but depended on the thickness of overburden on top of the clay layer. The velocity profiles were then used to simulate site-specific frequency response curves in response to selected seismic inputs, using the equivalent-linear approach SHAKE2000. The site amplifications are discussed in relation to the standard EC8 guidelines using the normal site classes, which are shown not to be appropriate in several cases within the local context. This study is part of an overall investigation into the seismic hazard and seismic risk of the Maltese islands, and was partially supported by the Interreg Italia-Malta funded project SIMIT.

ESC2018-S33-960

CHARACTERIZATION OF SITE CONDITIONS FOR THE ROMANIAN REAL-TIME SEISMIC STATIONS

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Local site conditions can influence the frequency content, amplitude and duration of the ground motion recorded at a seismic station. A good knowledge of site effects is therefore highly important for the understanding and interpretation of seismological data acquired by the seismic networks and for their use in hazard and earthquake engineering studies. The earthquake activity in Romania is high compared to other European countries and it's dominated by the intermediate-depth earthquakes occurring in Vrancea region, although weak to moderate crustal earthquakes are recurrent in different areas of the country. To monitor this activity, the National Institute for Earth Physics (NIEP) has developed one of the largest real-time seismic networks in Eastern Europe. The Romanian Seismic Network (RSN) consists of 134 stations installed in different geologic/tectonic environments continuously recording the ground motion and sending real-time data to the Romanian National Data Center (RoNDC). In the framework of a national project, NIEP has started a comprehensive campaign to characterize the site conditions for all the stations that constitute the RSN. In this study, we present the results obtained since the beginning of the project. In order to derive the site conditions we applied different techniques that are using various types of data, such as seismic noise, earthquake and active seismic data. We employed the seismic noise in order to characterize the noise level at the stations and to investigate the noise variations at high (1 - 10 Hz) and low (0.1 - 1 Hz) frequencies, as well as to estimate the resonance frequencies of the sites and their azimuthal variations. The site amplification was estimated from local earthquake data (more than 50 earthquakes with Mw >= 4.0) using two complementary methods: the Horizontal-to-Vertical Spectral Ratio (HVSR) and the Generalized Inversion Technique (GIM). We performed active and passive seismic measurements to extract the shallow Vs velocity profile and estimate the corresponding Vs30 parameter. The measurements consisted in recording surface waves (Rayleigh and Love waves) using both a 3-C velocity sensor and a chain of 24 geophones (vertical and horizontal). The dataset acquired using 24 sensors was analysed using MASW and ReMi methods, while the surface waves recorded by the single 3C sensor were analysed using a relatively new approach (Holisurface - Dal Moro 2014). Our findings show a good consistency between the local conditions and the results obtained from different types of investigations. As expected, the noise levels and the noise variations at high frequencies are significantly increased for the stations located closer to important anthropogenic noise sources (e.g. cities). The computed H/V ratios show clear resonant peaks at different frequencies which correlate relatively well with the thickness of the sedimentary package beneath the stations. Furthermore, the polarization analysis of the H/V ratios indicates a strong directivity of the resonance peak for the stations located on topographic irregularities. At the same time, the spectral ratios obtained from earthquake data confirm to some extent the findings from the noise data in case of the stations with strong site effects and, on the other hand, they show no amplifications for stations located on hard rock or show low amplifications, around two, on wide frequency bands, for stations located on deep Tertiary sediments. Finally, we classified each site where active and passive seismic experiments were performed in terms of EC8 classes, comparing the geological and lithological

characteristics and the derived Vs30 with the EC8 categories.

ESC2018-S33-965

GEOPHYSICAL CHARACTERIZATION OF SEISMOGRAPH STATION SITES IN CALIFORNIA USING A COST-EFFECTIVE, FLEXIBLE, MULTI-METHOD APPROACH

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Between 2016 and 2018, thirty (30) State of California strong motion instrument program (SMIP) seismograph station sites were characterized using a cost-effective, flexible, multi-method field approach. The purpose of the geophysical investigation was to obtain shear-wave velocity (VS) profiles to a depth of 40 m, or greater, and the time-averaged VS of the upper 30 meters (VS30) at each site. The seismograph station sites are primarily located in urban to suburban settings, whereby there were restrictions on where geophysical testing could be conducted. Geologic conditions at the seismograph station sites ranged from deep Quaternary sediments to shallow Mesozoic bedrock. In the past, attempts have been made to characterize seismograph station sites using a single method such as seismic refraction, refraction microtremor, multi-channel analysis of surface waves (MASW), or spectral analysis of surface waves (SASW). Although such an approach can be effective, we have found that single geophysical techniques are not successful for all geologic environments or all ambient vibration conditions. To reduce the risks of using a single method approach, it was required that the microtremor horizontal-to-vertical spectral ratio (MHVSR), Rayleigh wave based multi-channel analysis of surface waves (MASRW), and array microtremor (2D array) methods be utilized at every site. State and Federal agencies generally require that multiple bids be received to make a contract award with cost often playing a significant role in the award. For this reason, most submitted cost estimates will be based on the minimum outlined scope. However, we have found that Love wave techniques are more effective than Rayleigh wave techniques at about 20% of the 225+ California seismograph station sites that we have investigated over the past seven years. In other geographic regions, such as the Central and Eastern US, we have found that Love wave techniques can be more effective than Rayleigh wave techniques at over 50% of the sites, albeit with a much smaller sample size. We have also found that some sites can only be characterized using P- and S-wave seismic refraction techniques. To ensure successful site characterization, we have adopted a flexible field approach where site characterization begins with MHVSR and MASRW testing, and when ambient vibration conditions are sufficient, array microtremor (Rayleigh wave) testing. Field data is briefly reviewed during acquisition with P- and S-wave refraction and Love wave MASW (MASLW) techniques added when deemed necessary. A two-person field crew can characterize a site in a field day, or less, using such an approach. Data reduction and modeling approaches also have a significant impact on cost. Therefore, we optimize the data modeling approach based on velocity structure and complexity of reduced surface wave dispersion data. Sites with a gradual increase in VS with depth can be adequately characterized using a local-search inversion routine to develop a single VS model fitting the fundamental mode Rayleigh wave. More complex velocity structure (e.g. velocity inversions, abrupt increase in velocity at top of rock, high velocity layers) will at a minimum require that multiple models be generated to quantify non-uniqueness using either multiple runs of a local-search inversion routine or, preferably, a global inversion routine. In some cases, complex velocity structure may require multi-mode or effective mode inversion, joint Rayleigh and Love wave inversion, or joint Rayleigh/Love wave and MHVSR inversion to model subsurface VS, which adds significant cost to data analysis. Examples are presented demonstrating the variety of geologic and site conditions encountered and the importance of using a flexible, multi-method field approach when utilizing seismic methods for characterizing seismograph station sites.

ESC2018-S33-1018

GENERATING A 3D VS MODEL FOR THE CENTRAL PART OF THE THESSALONIKI METROPOLITAN AREA FROM THE JOINT INVERSION OF DISPERSION CURVES AND RAYLEIGH WAVE

ELLIPTICITY INFORMATION EXTRACTED FROM AMBIENT NOISE DATA

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In the present work we examine the application of the joint tomographic inversion of group velocity dispersion curves and ellipticity of Rayleigh waves extracted from ambient noise records. The main study area is the broader Aristotle University campus, located in the center of the city of Thessaloniki (N.Greece), where a small-scale array consisting of 34 broad band sensors was deployed for one month, in an area with a diameter of ~1km. Vertical component cross-correlations were employed for the extraction of the Rayleigh wave group velocity travel times in the study area, between ~1 and ~15Hz. This dataset was inverted through a 2D tomographic approach, also taking into account approximate Fresnel volumes and inter-frequency smoothing constrains. As a result, we obtained the spatial distribution of Rayleigh wave group slowness for several frequencies in the range of interest (1-15Hz) in the study area. The corresponding group slowness variations for all frequencies allowed us to reconstruct the local group slowness dispersion curves for every node of the employed tomographic grid. We also extracted the Rayleigh wave ellipticity from ambient noise records of each station as a function of frequency, using the RAYDEC algorithm (Hobiger et al., 2009). Finally, the extracted ellipticity curves of all stations were spatially interpolated along the same dispersion curve tomographic grid. The final Rayleigh wave group slowness dispersion and ellipticity curves for each node were jointly inverted using an adapted neighborhood algorithm (Wathelet, 2008), in order to define a 1-D shear-wave velocity model for each node. For the inversion we employed the external module tools of the Geopsy software (http://www/geopsy.org), which allowed us to appropriate modify the weighting scheme of the penalty (misfit) function. Instead for velocities, the optimization was performed for the depth of the various geological interfaces, while allowing minimal inter-layer velocity variations, in an attempt to stabilize the solution. The final 1D Vs models from all nodes were superimposed, in order to create a pseudo-3D Vs model of the broader study area. The investigation of different model parameterizations, as well as of different misfit functions, allowed us to illustrate different model features, and quantify their robustness. Optimal results were obtained for a model with 4 main sedimentary layers, overlying a bedrock formation that has a top weathered layer, quite similar to the original larger scale model of Anastasiadis et al. (2001). The final 3D Vs model exhibits several similarities but also significant differences with the models previously presented for the area. For all model parameterizations, a dominant 2D geometry is recognized, with the discontinuity of sediments with the seismic bedrock (Vs=800m/s) being the most robust geological interface. On the contrary, the inter-bedrock transition from weathered to more competent bedrock is rather poorly resolved. The joint inversion of both dispersion curves and ellipticity information provides more realistic models for deeper layers (e.g. seismic bedrock), in better agreement with previous large-scale models and localized active-source data, in comparison to inversions based exclusively on dispersion curves. The same applies for the shallower sedimentary layers, where joint inversions stabilize the artifacts introduced from the lack of high-frequencies (>15Hz) in the dispersion curves. In general, the joint inversion approach appears to lead to both more realistic and more robust results, independent of the details of the model parameterization and inversion scheme employed.

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ESC2018-S33-1027

SITE CHARACTERIZATION USING HORIZONTAL-TO-VERTICAL SPECTRAL RATIOS OF EARTHQUAKES AND AMBIENT SEISMIC NOISE OBSERVED AT DENSE BROADBAND SEISMIC NETWORK

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A dense broadband seismic network named DANA was installed in the frame of the FaultLab project in collaboration with the University of Leeds, the Kandilli Observatory and Earthquake Research Institue (KOERI) and Sakarya University. The DANA array is deployed for 18 months, recording continuously at 50 sps with a dense station spacing of 7 km (https://www.fdsn.org/networks/detail/YH_2012/). The network crossing the source rupture area of the 1999 Izmit earthquake in the vicinity of Sapanca Lake extends northward and southward towards Kaynarca and Golpazari, respectively. Although the aim of the DANA deployment is studying scattered wave images of the lower crust beneath the North Anatolian Fault zone the stations being distributed across basin and hill areas and being located on different site conditions provide excellent data sets to study engineering problems as well. The DANA network recorded tens of earthquakes within 300 km epicentral distances which are used to estimate the horizontal-to-vertical spectral ratios. We used the Obspy seismological library routines to extract the waveform windows from the IRIS data center and for data processing. The origin times and the location parameters of the earthquakes are utilized to estimate the P-wave and S-wave arrivals which in turn are used to determine the noise and ground motion windows (the signals). The waveforms are filtered using 4th order Butterworth bandpass filter (0.4Hz-40Hz). The signal-to-noise ratio (SNR) less than 3 are eliminated from the data set. The PGA, PGV and PSA are calculated for the ground motions with SNR larger than 3. Spectral accelerations are estimated for the period ranges between 0.01 and 2.0 seconds. Then, the geometric means of the PSA values at the horizontal components are divided with the PSA estimated at the vertical component to get the horizontal-to-spectral ratio (HVR) for each earthquake. The HVRs obtained at each broadband station for each earthquake are stacked. Similarly, HVR functions are obtained for the same broadband stations using microtremor data. One hour long window length recorded midnight was selected for data analysis to get rid of the daytime industrial noise effects. The one-hour-long waveform data was dived into 100 sub-windows for which 3-component FFT estimates are done and HVR are estimated. Konno Ohmachi smoothing technique is applied for the individual FFTs. The 100 HVRs are stacked to get the average microtremor HVR for each station along with its standart deviation. The HVRs functions obtained from the earthquakes and the microtremors are to be compared for similarity and differences. Also, classifications of the HVRs with respect to the stations sites are to explored with an aim to utilize the HVRs functions as a tool for site characterization.

ESC2018-S33-1032

SEISMIC MONITORING OF BONIFACIO CLIFFS

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We present results from a seismic monitoring study of a fractured rock mass at the coastal cliffs of Bonifacio (South of Corsica). Two semi-permanent seismological stations (Lennartz 5 sec triaxial seismometers) were installed in October 2016 recording continuously during 6 months. Data analysis reveals a number of interesting features such as several spectral peaks in the frequency band between 0.5 Hz and 20 Hz that may indicate instable areas. Several spectral ratios techniques are applied to enhance differential ground motion between both stations, particularly a strong vertical motion amplification is observed from the analysis of both ambient noise and local earthquake data. The effect of the highly variable meteorological conditions, specially wind velocity, is particularly highlighted and discussed. In addition, a temporary linear array of 100 m length has been deployed in October 2016 perpendicular to the coastal cliff and gives a new comprehension of the mechanical

behavior of the area. Operational modal analysis of such dataset imposes additional constraints on the dynamic response of the site.

36thGA
ESC
MALTA
2018

SESSION 34

ESC2018-S34-321

OPPORTUNITIES FROM UNEXPECTED SOURCES OF STRONG MOTION MEASUREMENTS

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Strong motion instrumentation is critical for capturing on-scale recordings of rare large earthquakes and is essential to developing a better understanding of earthquake rupture processes and the response of the built environment to strong ground shaking. For many decades, strong motion seismic deployments typically took the same form: several-to-tens of strong-motion seismic sensors as part of regional seismic networks or installations in tall buildings within urban centers. These traditional strong motion deployments are generally still in use today and continue to provide important datasets. However, recent advancements in technology have expanded the sources of strong motion seismic data. I survey several new and unexpected sources of strong motion measurements and provide a comparison of: (1) required resources (instrumentation and deployment costs), (2) ease of instrument deployment, (3) data volumes collected, and (4) data quality. To aid in the comparison, I describe several new strong motion instrumentation types as well as the scientific products and the potential contributions of these datasets. I focus on the growing number and types of Micro-Electro-Mechanical Systems (MEMS) accelerometer arrays and track their progress over the last decade since the initiation of the Quake Catcher Network to today's explosion of MEMS-based sensor networks deployed for both research and commercial purposes.

ESC2018-S34-349

STRONG MOTION OBSERVATION AND SITE CHARACTERIZATION IN TAIWAN - THE PAST AND ONGOING EVENTS

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A dense strong motion network noted as TSMIP has been installed in Taiwan by the CWB since 1992 and then the Mw7.6 Chi-Chi Earthquake were recorded in time. As earlier in 1970s, the Strong Motion Accelerographic Network (SMA) consisted of nearly 200 analog accelerographs were installed throughout Taiwan. Most of the stations were placed in the basement of civil structures and in buildings and were used mainly for studying earthquake source, structure response, attenuation of ground motions and risk analysis. In 1980, the UC Berkeley has cooperated with the Institute of Earth Sciences, Academia Sinica to build up a dense digital array of strong-motion seismographs at Lotung Town, northeastern of Taiwan. This array was called the Strong Motion Array in Taiwan, phase I, i.e., SMART1. An additional seismic test array of accelerometers at downhole, surface, and structures, i.e. LLSST, were also installed within the SMART1 Array. The SMART1 was designed to record near field ground motions for a possible devastating earthquake (M>8) and to attain a high probability of recording detailed strong motions for damaging earthquakes (M>6.5). The second phase observation, i.e. SMART2 Array, was installed on a firm-soil site in the Hualien area by the IES from 1990, as well as the HLSST, which also includes downhole, surface, and structural arrays. The 1986 Mw6.8 Hualien offshore earthquakes caused several buildings collapse in the Taipei Basin and thus the IES installed Strong Motion Downhole Array at 12 sites in the Taipei Basin since 1992 and Broadband Seismic Array in 7 sites. The current seismic design code in Taiwan was initially constructed based on earlier observed strong motion recordings and then was modified several times according to further observations and experiences we learnt. Recently, the CWB has installed more than 55 surface-downhole stations to improve earthquake monitoring, earthquake location determination, and early warning capabilities. The network is expected to has 70 real-time stations in the near future. Otherwise, NCREE has installed a real time seismic array includes 37 stations in Taiwan called SANTA since 2012. The network is designed to support the researches on both seismology and earthquake engineering, so the network has a strong motion accelerometer and a broadband seismometer at each station. A low-cost earthquake early warning (EEW) system (P-alert) is in operation for the purpose of EEW and for providing near-real-time shake maps by Prof. Y.M. Wu at NTU. The P-alert network has more than 500 stations and the real-

time data stream of SANTA is also sent to the EEW system to product a more detail near-real-time shake map. The CWB, NCREE, and NTU are supposed to expand the numbers of the real-time strong motion stations in the following years. Since TSMIP has recorded lots of strong motion records, NCREE and CWB therefore cooperated to carried out a multiyear investigation project to understand near-surface profiles at the strong motion stations after the Chi-Chi earthquake. Vs30 and site classification at most stations were obtained by suspension PS-logging measurements and the results was announced in 2012. Recently, NCREE is implementing a PSHA project in Taiwan, so a strong motion database and a site database based on the free-field TSMIP stations has been developed. The comprehensive site parameters consist of Vs30, Z1.0, and Kappa, which were kindly provided by different experts in Taiwan individually, were provided in this site database. The S-wave velocity profiles at those stations are derived by both invasive and noninvasive approaches, as well as from a multi-proxy based model for Vs30. Microtremor array method and receiver function method were helpful to obtain the Z1.0 parameter at strong motion stations in Taiwan. The strong ground motion and site databases will be a robust foundation for next PSHA analysis of whole Taiwan, and then may lead to a new generation of seismic building code in Taiwan.

ESC2018-S34-367

S-WAVE AND P-WAVE VELOCITY STRUCTURE IDENTIFICATION BASED ON HORIZONTAL TO VERTICAL SPECTRAL RATIO AND SURFACE TO BOREHOLE SPECTRAL RATIO OF EARTHQUAKE

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The site amplification factor has been investigated in these several decades because the factor has a large impact to the ground motion. The factor depends on the local (shallow) subsurface structure and the regional basin structure, and the spatial variation of the factor would be quite large. It is important for the quantitative strong motion estimation to know the actual site amplification factor at the target site, and it is also important to identify the subsurface structure which can explain the observed ground motion characteristics. We applied the diffuse filed concept of earthquake (Kawase et al., 2011) to many earthquake observation sites in Japan and identified the subsurface structures based on Horizontal to Vertical spectral Ratio of Earthquake (EHVR). National Research Institute for Earth Science and Disaster Resilience deployed the strong-motion seismograph network, KiK-net, where two seismometers are installed at all KiK-net sites; one at the surface and another one at the bottom of the borehole. We carried out the identification of the S-wave velocity structures using only EHVR as well as the joint identification using both EHVR and Surface to Borehole spectral Ratio (SBR) at several KiK-net sites. We report here the results in detail at IBRH13. First we calculated the average EHVR and SBR of small acceleration events to obtain the elastic characteristics of the ground motion. According to the diffuse field concept of earthquake, EHVR is proportional to the horizontal to vertical ratio of the transfer functions of S- and P-waves between the ground surface and the seismic bedrock. EHVR of the surface site has a large peak around 3.0 Hz and some amplification in the high frequency range. EHVR of the borehole site has a small peak at a frequency higher than 10 Hz. The horizontal SBR also has a first peak at around 3.0 Hz and the vertical SBR has a small peak at 3.0 Hz and a broad peak at a frequency higher than 5.0 Hz. The both EHVRs and the horizontal SBR have no notable amplification in the frequency range lower than 1.0Hz. These facts implies that the site amplification factor of this site has no significant amplification in the lower frequency range and the subsurface structure deeper than the borehole site may not have a large impedance contrast interface at depth related to that frequency range. We then identified the subsurface structure based on diffuse field concept. We searched a model which minimized the residual between the observed EHVR and the theoretical EHVR by Hybrid Heuristic Searching method (Yamanaka, 2007). We resampled the spectra at frequencies with equal intervals in the logarithmic scale and we calculated the misfit in the logarithmic scale. We also identified the subsurface structure to minimize the total misfit of both EHVR and SBR. The identified variable were S-wave velocity (Vs), thickness, and P-wave velocity (Vp) of each layer. In the case of the joint identification for EHVR and SBR, one damping common in all layers was also identified between 0% to 10%. The identified

structure for only EHVR reproduced the observed EHVR and the first peak of SBR well, but did not fit well to the higher peaks of the observed SBR. The observed EHVR at IBRH13 does not show a notable peak in the higher frequency range, so EHVR can not constrain the results in that frequency range. The identified structure for EHVR and SBR explained both of the observed EHVR and SBR well in wide frequency range, therefore the result indicated that the structure reproduced the observed ground motion characteristics more than the identification result for only EHVR. The damping identified by the joint identification was reasonable value. The identification by using EHVR gives us the outlines of Vs and Vp structures which explain the whole of EHVR by the whole structures down to the seismic bedrock, and the identification by using SBR constrains well the structure between the surface site and the borehole site but cannot identify the structure deeper than the borehole site. By using the joint identification of EHVR and SBR, we take advantage of the both identification and we can obtain the subsurface structure down to seismic bedrock which is constrained by the observed ground motion characteristics well.

ESC2018-S34-428

ORFEUS PRODUCTS AND SERVICES FOR STRONG-MOTION SEISMOLOGY

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ORFEUS (Observatories & Research Facilities for European Seismology) is a European collaborative effort to promote seismology in Europe through the collection, archival and distribution of high-quality digital seismic waveform data and metadata. Intense work has been conducted in the past five years within ORFEUS to apply the advanced level of standardization reached by the broadband seismological community to strong-motion data and metadata, that are typically used in the fields of engineering seismology, geotechnical and earthquake engineering, and by international earthquake response agencies. Key strong-motion data providers operating in the Euro-Mediterranean area are being organised as an ORFEUS Service Management Committee (SMC). The main goals of the SMC are: (a) encouraging, enabling and ensuring open access to event-based waveforms, derived parametric quantities (e.g., peak ground motions) and engineering parameters, and to downstream ORFEUS products / services; (b) enhancing the interoperability with other Earth science disciplines, in the framework of the EU project EPOS-IP (www.epos-ip.org). Feedback from the users' community is ensured through a User Advisory Group which reviews practices and services and suggest improvements on all matters related to the implementation of services and products. Two main infrastructures were created and are seamlessly being improved for the dissemination of earthquake information, ground-motion parameters and response spectral amplitudes, mainly based on the European Integrated Waveform Data Archive (EIDA): i) a Rapid Raw Strong-Motion database (RRSM; http://www.orfeus-eu.org/rrsm), purely automatic, that makes peak-motions and spectral amplitudes available within minutes of the occurrence of any event with M>= 3.5; ii) an Engineering Strong-motion database (ESM; http://esm.mi.ingv.it/), that distributes only manually processed and expert revised event-based waveforms, peak-motions, response spectra, earthquake and station metadata of events with M >= 4.0. Other products related to these core infrastructures include software for strong-motion data processing and selection of waveforms compliant to building codes, webservices to access waveforms, strong-motion parameters and USGS ShakeMap input files. A constructive collaboration with the European seismic hazard community has been established as strong-motion parameters are the necessary input to derive / rank ground motion prediction equations (GMPEs). A novel integrated European ShakeMap service – ShakeMapEU - has been established based on the USGS ShakeMap codes and the input from EMSC event-, RRSM and ESM peak-motion webservices, to deliver maps of expected and recorded ground shaking within

minutes of the occurrence of any event with M >= 4.0 in the Euro-Mediterranean region.

ESC2018-S34-453

SITE CHARACTERIZATION OF SWISS STRONG MOTION STATIONS: THE BENEFIT OF COMBINING APPROPRIATE METHODS

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The data of a seismic station can only be used to their full extent when a good characterization of the underground surrounding the station is available. Such a site characterization can be done using a variety of methods, where each method has its strengths and weaknesses and the different methods are in the best case complimentary. Active seismic techniques such as MASW or refraction seismics using signals generated by hammering are very useful for measuring velocity profiles in the shallow parts of the underground. However, they are usually not energetic enough to resolve deeper parts of the structure. In that case, stronger sources like explosive sources or falling weights can be used. Alternatively, passive seismic methods measuring ambient seismic vibrations with an array of sensors have proven to be very successful in retrieving dispersion curves of surface waves over a wide frequency range, but generally lack energy at high frequencies and therefore fail to retrieve the very shallow structure. The measured phase-velocity dispersion curves of surface waves, irrespective of the way they were obtained, can subsequently be inverted for the velocity profile of the underground. Complementing the dispersion curves with H/V or ellipticity information helps not only to better constrain the velocity profiles, but also to better constrain deeper parts of the structure. Other properties of the underground, such as non-linear soil response and the potential for liquefaction, can be measured with different geotechnical methods such as SPT or CPT. In the framework of the ongoing renewal project of the Swiss Strong Motion network (SSMNet), 100 new strong-motion stations will be installed by 2020. All of these stations are systematically investigated using the methods most appropriate for the respective site, taking into account the geology of the site and the location in an urban or rural environment. We will present our current state of the art with an example of the measurements performed at the planned borehole station in Buochs, on the southern shore of Lake Lucerne in central Switzerland. At this site, we combined a variety of methods to get a comprehensive view of the underground structure from the shallow surface to the deeper structure. CPT measurements were used to estimate the liquefaction potential. SCPT measurements yielded the shallow S-wave velocity profile down to 26 m. With an array of 16 seismic sensors, we measured ambient seismic vibrations and retrieved dispersion curves of Love and Rayleigh waves between 1 and 20 Hz using different methods. Moreover, the ellipticity curve of the site can be retrieved and shows a clear singularity at around 0.65 Hz. An inversion of these data allowed us to obtain the velocity profiles in the shallow and deeper parts of the structure. The different methods proved to be complimentary and will help us in selecting the depths at which the borehole sensors shall be installed. At other sites, we also performed active MASW and refraction measurements. The preferred methods are selected with respect to the local possibilities and the expected results. The quality of the site characterization at each site is finally assessed by comparing the S-wave amplification measured during earthquakes with the theoretical amplification function of the velocity profile obtained with the site characterization measurements.

ESC2018-S34-602

NEW ACHIEVEMENTS IN THE PORTUGUESE STRONG MOTION NETWORK

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The accelerometric network in Portugal has undergone a major evolution since the first record obtained during the earthquake of February 28, 1969. Under the coordination of the Instituto Superior Técnico - IST, accelerometric network has evolved significantly since 1994 with the installation of new digital stations in the Azores

and Mainland, initially with 12 bit equipment which evolved into 16 bit, 18 bit and 22 bit later in the period 2010-2011. In the context of the modernization of the national seismic network, conducted between 2006 and 2011, the then-Meteorological Institute (now Instituto Português do Mar e da Atmosfera - IPMA) has equipped the broadband 24 bit new stations with accelerometric sensors co-located with broadband equipment, and these devices have been installed in the Azores, Madeira and Mainland. In 2015, IST and IPMA establish a cooperation agreement aimed at the joint use of the largest possible number of accelerometric stations transmitting real / near real time, allowing for significant gains relative to the coverage of the national territory. With this collaboration it has been possible to improve noticeably the national accelerometric network with advantage in the rapid determination of earthquake parameters, the development of "shakemaps", and the future use of "early warning systems" (EEWS) for many areas of the country. With this new configuration of strong-motion network it has already been possible to collect particularly relevant data corresponding to earthquakes with epicenter inland and also in submerged area, with records obtained in the near field and also at higher distances. This dataset allows the study of new attenuation laws for different parameters of ground motion, such as PGA and PGV, for earthquakes originating on the Portugal mainland, offshore and also in the Azores. In addition to parameters such as distance to seismic source and magnitude, ground motion amplification is also considered as a function of the local Vs30. These new attenuation laws (GMPE´s) are essential to improve the quality of the shakemap generated for the region of Portugal, as well as for hazard and impact studies.

ESC2018-S34-615

SITE AMPLIFICATION FACTORS FOR BOTH HORIZONTAL AND VERTICAL COMPONENTS OF S-WAVE: A NEW APPROACH FOR SITE CHARACTERIZATION

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One of the important purpose of the analysis for regional strong motion data is to derive site amplification factors (SAFs) of S-wave because the characteristics of the strong motions are controlled primarily by the site-specific SAFs. The Horizontal-to-Vertical spectral ratios of earthquakes (EHVRs) as well as microtremors (MHVRs) have been utilized as a convenient tool to extract a predominant frequency of SAF. The so-called "Nakamura" method assumed that MHVR provides us directly the SAF of earthquakes in the horizontal component (hSAF). However, we need to validate two main assumptions to support the idea of the Nakamura method; MHVR and EHVR should be the same and the SAF in the vertical component (vSAF) should be unity. Based on the diffuse field concept (DFC, Sánchez-Sesma et al., 2011; Kawase et al., 2011), MHVRs correspond to the square root of the ratio of the imaginary part of horizontal Green's function and the vertical one, while EHVRs correspond to the ratio of the horizontal motion for a vertical incidence of S-wave with respect to the vertical correspondent of P-wave. Thus there should be a systematic difference between EHVRs and MHVRs because of the difference in their primary contribution of wave types. We have reported the average EHVR to MHVR spectral ratios (EMR) at 100 strong motion stations of K-NET and KiK-net in Japan, which is an effective tool to transform MHVRs into pseudo EHVRs (Mori et al., 2018). For vSAF we have used generalized spectral inversion technique (GIT, Nakano et al., 2015) to separate SAFs from S-wave portions of strong and weak ground motions observed by K-NET, KiK-net, and JMA Shindokei Network in Japan. We included all sources larger than MJMA4.5 observed from 1996 to 2011 if we observed more than three sites for one event. Total numbers of data is more than 77,000 site-source pairs observed at 2,105 sites in total. We used RMS Fourier spectral values for two horizontal components, or all three components separately for different SAFs in which the incident S-wave spectra at the seismological bedrock is assumed to be the same. The ambiguity in GIT is coming from the choice of the additional constraint needed for the separation of variables. In Nakano et al. (2015) we used YMGH01 site with small site correction to obtain SAFs relative to the real seismological bedrock outcrop with an S-wave velocity higher than 3 km/s. Since the correction was made for the horizontal RMS spectra at this reference site, the resultant vSAFs at the other

sites are relative to the horizontal outcrop spectra of the seismological bedrock. First we check the average vSAF at YMGH01 relative to the reference RMS spectra. We found that the vSAF at YMGH01 is close to one and has small fluctuations with respect to frequency, about ±30%, except for the frequency higher than 15 Hz. When we compare the vSAF at YMGH01 with the theoretical prediction based on DFC, which is a frequency independent value of 0.76, we found that it is very close to the lower bound of the average. We then check the variability of the vSAFs at all the sites that we analyzed and found that the vSAFs are closer to each other than the hSAFs. This is because the P-wave velocity contrasts at most of the sites tend to be smaller than the S-wave velocity contrasts. If the water level is shallow, then P-wave velocity of saturated soil would be no less than 1.5 km/s and so the maximum contrast should be no more than 4. Thanks to the relative stability of the vSAFs, we can correct EHVRs at the target sites with vSAFs to obtain hSAFs. If we use observed vSAF, the operation is circular, but if we replace vSAF with the averaged vSAF for categorized sites with different predominant frequency in EHVRs as done in Mori et al. (2018) for MHVRs, then we can obtain pseudo hSAFs. As long as the site-specific variation in vSAF is much smaller than that of hSAF, the pseudo hSAF can be conveniently derived from EHVRs without doing tedious GIT analysis. The advantage of this approach is that we need no P- and S-wave velocity structures at the target site (no Vs30, either). We can directly evaluate the S-wave site amplification factor for frequency range from 0.1 to 15 Hz, as long as we have small numbers of weak-motion data at the target site. Once we get the site amplification factor, then we can use it for the site categorization. If we want to start from MHVRs, we can first transform them in to pseudo EHVRs through EMR (Mori et al., 2018). We are planning to extend the dataset to California and Europe to see the regional differences in vSAF and EMR if any.

ESC2018-S34-628

SITE AND SEISMIC STATION CHARACTERIZATION: AN EUROPEAN INITIATIVE

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Site characterization is a key input in seismic hazard and risk assessment (e.g. Ground Motion Prediction Equation, microzonation studies, damage scenarios) and seismic design (building codes, critical facilities). Although the number of strong-motion stations in free-field and engineering structures has largely increased over the world in the last twenty years, only a limited number of sites includes detailed site condition indicators: mostly geology and EC8 soil class, more rarely shear-wave velocity (Vs) information (e.g. Vs30 and Vs profiles), without proper documentation and quality assessment in most cases. This lack of information is a critical issue, e.g. for deriving reference rock/soil velocity profiles for region-specific GMPEs, site-specific hazard assessment, vs-kappa adjustments, seismic response of engineering infrastructures, risk modeling at urban or regional scale. Within the framework of the SERA "Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe" Horizon 2020 Project, a networking activity has been set up to propose a comprehensive European strategy and standards fostering site characterization of seismic stations in Europe. We will present the status of this networking activity that focuses on several issues. The first target is to evaluate the most relevant site characterization scalar, depth and frequency-dependant indicators (e.g. Vs30, resonance period, velocity profiles, kappa, amplification factors and functions, etc.) for seismic hazard purposes and, thereafter, to propose best practice for site characterization together with standards for overall quality metrics on site characterization. The second target focuses on disseminating, within the broader seismological and engineering community, site characterization metadata developed within the EU NERA and EPOS-IP projects in order to validate and/or further develop metadata format schemes for wide use. Based on available site characterization information in Europe and considering the research and engineering needs, the third target proposes to set up a road map to prioritize strong motion site characterization in Europe for the next

decade. Finally, a task is dedicated to investigate relevance of new site condition and amplification proxies (for example combining resonance frequency, local slope and other parameters, proxy for non-linear effects, wavelength-scaled curvature and topographic position index position as proxies for topographic effects, aggravation factor for basin effects, etc.) and their implementation at the European scale and into site characterization metadata.

ESC2018-S34-642

STRONG MOTION MONITORING AND DATASETS IN CANADA AND SOME CHALLENGES FOR REGIONS THAT EXPERIENCE LARGE EARTHQUAKES (BUT LACK RECORDINGS OF LARGE EARTHQUAKES)

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In this presentation, we outline the history of Canada's strong ground monitoring program (including current upgrades that are underway), summarise the existing Canadian strong motion data set, and discuss some of the challenges in regions that experience large, infrequent earthquakes and therefore lack "strong motion" recordings. Canada spans a variety of tectonic and geological settings, including an active plate boundary (with active subduction as well as divergent and transcurrent plate motions), a stable craton with the oldest rocks on earth, and an ancient passive margin. As the second largest country in the world, and with such a variety of tectonic settings, understanding strong ground motions from rare, large earthquakes is a challenging endeavour. The first strong motion instruments were deployed in Canada in 1963. The goal of this monitoring program was (as it is today) to obtain strong ground motion recordings on a variety of environments (bedrock, soft soil, firm soil, basins, etc.) By 1968, 14 accelerographs (and 48 seismoscopes) were deployed in the seismically active regions of coastal British Columbia. Over the years this network expanded across Canada, by 1999 including more than 70 instruments. Starting in 2002 a modern, digital "internet accelerometer" network with more than 100 instruments was deployed to take advantage of low-cost instrumentation, on-site computation, and internet communications. Beginning in 2017, as a part of the modernisation of the Canadian National Seismograph Network (CNSN), more than 100 broadband seismic sites will have Nanometrics "Titan" accelerometers added. These standard CNSN sites are all situated on bedrock. Ongoing questions and discussions include the adaptation and validation of GMPEs developed with data from elsewhere around the world, site effects, basin effects, non-linear effects, and more. In the current National Building Code, subduction earthquake GMPE's are dominated by recordings of the Tohoku earthquake, with corrections made for geological differences between Japan and Canada's west coast. Many of these topics are also relevant for seismic hazard evaluations in Europe and elsewhere in the world.

ESC2018-S34-667

FEEDBACK FROM THE CHARACTERIZATION OF THE SITE CONDITIONS OF STATIONS OF THE FRENCH ACCELEROMETRIC NETWORK (RAP) LOCATED IN NORTH-WEST FRANCE

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The previous estimations of site conditions (soil class, VS30) of the French accelerometric network (RAP) stations located in North-West France were only based on geological map interpretation. In order to provide more reliable estimation for these stations located in an area where significant historical and instrumental earthquakes occurred and were seismic hazard cannot be neglected; a geophysical survey was organized in July 2017. This survey consisted in surface wave-based methods involving both active (Multichannel Analysis of Surface Waves: MASW) and passive methods (Ambient Vibration Array: AVA) using array from 10 m up to 1 km of aperture. Thanks to the availability of a quite large number of seismometers, it was possible to record several circle-shape arrays at once, which allowed long duration recording time for larger aperture arrays

in comparison to previous surveys conducted on other regions of France (Hollender et al., 2017). We were accordingly able to get consistent dispersion curve on a wide frequency band for all sites, allowing deriving S-wave velocity profiles with a satisfactory resolution up to depth of several hundreds of meter. At large depth, we obtained high velocity values (>2000 m) for all stations, which is consistent with geological context (Hercynian igneous/metamorphic rocks or Mesozoic limestone depending on the site). Contrariwise, at shallower depth, we obtained much lower velocity corresponding to weathered rocks. In comparison to previous evaluation from geological maps, the obtained VS30 values are significantly lower. This survey also gave us the opportunity to introduced site condition metadata derived from our results (current survey and previous ones) into the French RESIF web service.

ESC2018-S34-702

DEVELOPMENT OF A UNITED STATES COMMUNITY SHEAR WAVE VELOCITY PROFILE DATABASE

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We describe a multi-institution effort to develop an open-access shear-wave velocity (VS) profile database (PDB), which will include a public repository for VS profile data and associated metadata in the United States. VS profiles are an essential resource for ground motion modeling and other applications. The minimum requirements for a site to be included in the database are in situ geophysical VS measurements and location metadata. Other information is included as available, including geotechnical logs, penetration resistance, laboratory test data, ground water elevation, and P-wave velocity profiles. Various secondary site information such as surficial geology and topographic slope will be included from available geospatial data. The data collection stage of the project is largely complete, with over 4500 VS profiles in our possession. A prototype data model and database schema have been developed, and ongoing work includes digitization of data and its unification across various disparate formats. The database will be presented as an online map-based interface with downloadable VS profile and metadata information. This abstract serves as a progress report to the engineering seismology community, as we continue to seek engagement and support, and continue to seek out new potential data sources. Funding for this project was provided by the USGS Earthquake Hazards Program under contract number G17AP00018.

ESC2018-S34-771

COMMON BEST PRACTICE PROCEDURES FOR SITE-EFFECTS CHARACTERIZATION: RESULTS FROM AN INTERNATIONAL QUESTIONNAIRE

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Setting-up standard practices, together with a clear evaluation of their quality, are becoming very important to reach high-level site-characterization metadata, useful for site effects studies, seismic microzonation, seismic hazard assessment and many other research fields. In the last years, several efforts have been done at national and international level to define standards and guidelines for seismic site characterization (e.g., Foti et al., Bull Earthquake Eng, 2017, doi:10.1007/s10518-017-0206-7; Geological Survey of Canada, Open File 7078, 2012, doi:10.4095/291753; Consortium of Organizations for Strong Motion Observation Systems, http://www.cosmos-eq.org; WP12-Deliverable D23.12, SESAME European research project, 2004). Within the 2017-2020 activities of the "Networking databases of site and station characterization" (WP7-NA5 of the SERA "Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe" Horizon 2020 Project), European teams are working on the best practice for site characterization and related quality assessment target to network operators and seismological and engineering communities. More specifically, the

goals of this task are: (i) to evaluate the most relevant site effects indicators; (ii) to write practical guidelines for site effects characterization and related site condition parameters at rock sites (including topography effects) and soft soils (including non-linear and basin effects); (iii) to propose a quality metrics on the site characterization parameters. As a first step, we have prepared a Questionnaire for collecting existing bibliography and best practice schemes to compute indicators for site effects characterization. We sent the Questionnaire to selected research groups of different countries, both partners of the SERA project (ISTERRE-CNRS, France; ETH, Switzerland; INGV, Italy; AUTH, Greece) and several external groups involved in site characterization (Caltech-USGS, USA; AFAD, Turkey; Virginia Tech USA; GFZ, Germany; ITSAK, Greece; University of Potsdam, Germany; UoT-University of Texas, USA; INGV, Italy), and collected back the answers. Each team provided the list of site effects indicators, their importance for site effects assessment (based on expert judgment) and their preferred methods of analysis for retrieving the indicators. In the Questionnaire, the site-effect indicators were grouped into (i) Scalar (e.g. resonance frequency), (ii) Depth-dependent (e.g. shear-wave Vs profile), (iii) Frequency-dependent (e.g. spectral ratio), (iv) Geological/Morphological (e.g. Surface geology/lithology unit) and (v) Advanced site-effects (e.g. numerical 2D or 3D modeling) parameters. Each indicator is described through several fields, summarized into five main subsets: Importance - in-depth index related to the amount of knowledge on site-effects characterization supplied by each indicator, and it can assume three values (basic, intermediate and top), depending on the expert judgment; Feasibility - level of difficulty to measure the target indicator (easy, average and difficult); Data - type of data used to measure the proposed indicator; Analysis - method of analysis and suggested code to derive the indicator, including the value's selection and uncertainty estimation; Bibliography - references and guidelines related to the best practice of measurement and analysis. A preliminary analysis of the Questionnaires reveals a consensus on several basic indicators, such as the resonance frequency, Vs30 or the 1D Vs profile, even if the teams use different data acquisition, analysis methods and metrics. Fewer teams indicated more advanced parameters, such as 2D-3D site effects estimators or specific geotechnical parameters. The filled Questionnaires represent the basis of the development of standard best practice, definition of quality metrics and improvement of site condition metadata. The final results of this activity will be shared and discussed with the broader scientific community and they will be finalized in an international workshop early 2019.

ESC2018-S34-815

USE OF STRONG GROUND MOTION RECORDS FOR RISK MITIGATION: RECENT STUDIES ON NORTH ANATOLIAN FAULT ZONE (TURKEY)

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Estimation and mitigation of seismic risks in urban regions concern a wide range of authorities including geophysical and earthquake engineers, physical and economic planners as well as insurance companies. Risk mitigation efforts naturally involve inputs from multiple disciplines. Related studies include seismic hazard assessment, forward and inverse wave propagation models, site characterization, building fragility models and seismic loss functions. Strong motion records are the key components of these efforts. It is thus significant to continuously operate and maintain strong motion networks in seismically active regions worldwide. In this study, initially the current status of the strong motion network in Turkey is described. Next, various uses of the recently-compiled strong motion database of Turkey in engineering seismology and earthquake engineering practices are presented along with the corresponding physical processes and the mathematical models. Specific applications will be presented on ground motion prediction equations, seismic hazard analyses, high-frequency spectral attenuation (kappa) estimates, strong ground motion simulations, site characterization, intensity-peak motion correlations, building fragility functions and nonlinear time history analyses in earthquake engineering. The study areas of these applications are Istanbul, Duzce and Erzincan regions located on North Anatolian fault zone in Turkey. In addition to the current practice, data-related

challenges and potential future collaborations are also presented.

ESC2018-S34-855

LONG-RUN IMPACTS OF EARTHQUAKES ON ECONOMIC GROWTH

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The social science literature has so far not reached a consensus on whether and how earthquakes actually impact economic growth in the long-run. The same is true for most types of natural disasters in general. The long-run impacts of natural disasters on economic productivity have been widely discussed by the literature. The conclusions range from significant sizable negative impacts on growth to even positive impacts. However, studies that sufficiently take into account the physical nature of a natural hazard are scarce. Some progress has happened for other natural hazard types, such as cyclones. Nevertheless, in the case of earthquakes the predominant use of inadequate measures for the exogenous natural hazard of an earthquake is still a weakness in the literature. The most common problems are the lack of individual event size (e.g. earthquake dummy or number of events), the use of magnitude instead of a measure for surface shaking, and endogeneity issues when traditional qualitative intensity scales or actual impact data is used. This study uses strong ground motion data to tackle this weakness in the literature. Peak ground acceleration (PGA) is used as the ground motion intensity measure to investigate the impacts of earthquake shaking on long-run economic growth. I construct a data set from USGS ShakeMaps that can be considered the universe of global relevant earthquake ground shaking from 1973 to 2015. This data set is then combined with World Bank GDP data. A panel dataset of country-year observations of earthquake shaking and economic variables from 1973 to 2015 is constructed and the random within-country variation of shaking over years is exploited to identify the causal effect of earthquakes on economic growth. The econometric analysis is similar to the approach of Hsiang and Jina [1], who investigate the impact of cyclones on GDP. Furthermore, the impacts of earthquake shaking exposure on different industries and countries of different income levels is investigated, which can help to identify the mechanism of how earthquakes impact long-run growth. The results confirm that natural disasters do have a significant negative overall impact on GDP per capita years after an exposure. In particular, the results suggest a reduction in GDP of almost 2% 8 years after an average non-zero exposure. A comparison with an approach that uses magnitude instead of shaking data shows that using actual shaking data is crucial to identify the impacts of earthquake exposure. Unlike the findings of Hsiang and Jina [1] the results here suggest that the impacts are primarily incurred by low and middle-income countries and that high-income countries are potentially even able to experience positive "building back better" effects. Additionally, the importance of the spatial pattern of the natural hazard is discussed and empirically evaluated. I find that impacts are primarily driven by (local) high intensity events and not by spatially large exposure to lower intensity shaking. This result combined with other considerations suggest that the different natural hazard types might require systematically different approaches in how they are integrated in a quantitative model to study impacts, due to the geophysical differences between them. Particularly the inherent spatial pattern of a natural hazard and how it relates to the underlying assumptions of a spatial aggregation approach need to be considered. To my knowledge, this is the first application of global earthquake shaking data to investigate long-term earthquake impacts. This study illustrates how strong ground motion data can be used in social sciences to address questions on the socio-economic implications of earthquakes.

[1] Hsiang, S. M. and Jina, A. S. (2014). The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence From 6,700 Cyclones. National Bureau of Economic Research, No. w20352.

ESC2018-S34-872

SITE CHARACTERIZATION DATABASE OF INGV ITALIAN SEISMIC NETWORK

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A critical issue in the performance of a seismic network is the characterization of site response where stations are located. This information is essential to improve some aspects related to seismic surveillance and the publication of products in near-real time following an earthquake. A proper evaluation of the site effect is also necessary to improve the quality of recordings databases, facilitating their use for research purposes. The Italian National Seismic Network of the INGV (Rete Sismica Nazionale, RSN) consists of about 400 seismic stations equipped with a velocimeter and, for one-third of the sites, an accelerometer. They are connected in real time to the INGV data center in order to locate earthquakes for civil defense purposes and their records are distributed through the EIDA node (eida.rm.ingv.it/). Recently INGV has addressed the site characterization of RSN with an internal project (funded within the INGV research line T3 "Seismic hazard and contributions to the definition of risk"), as well as within the INGV-DPC Agreements (INGV-DPC Agreement 2016-17-18, Annex B2 Objective 1 - Task B "Characterization of accelerometric sites", funded by the Civil Protection Department), with the purpose of characterizing the seismic response of all the stations acquired in real time by its data center. The basic goal is building a geographic relational database, integrated with the other INGV infrastructures, designed to archive homogeneous parameters through the seismic network useful for a complete site characterization, including housing, geological, seismological and geotechnical features as well as site and topographic class according to the European and Italian building codes. The system resides on a dedicated server and the data are organized in an internal storage based on PostgreSQL DBMS (acronym CRISP). It will be directly related to SeisNet, the INGV database used for the network management, but it is still possible to insert new sites not belonging to the RSN. The backend of the system includes several procedures that allow the information updating through web services created ad-hoc, such as those of the Institute for Environmental Protection and Research (ISPRA) for geological and lithological attributes and for visualization of geological maps and related legends. On the other hand, specific programming interface services – API- expose the shared information to allow the transfer to other strong-motion data providers (e.g. ITACA, http://itaca.mi.ingv.it, and ESM, http://esm.mi.ingv.it) in semi-automatic way. The collection of geological, morphological and seismological data followed a nationwide approach, aimed at obtaining homogeneous data for the RSN sites. We started from the revision of all available geological and geophysical data and the analysis of noise waveforms, storing the analysis results as images and searchable data. Thanks to the collaboration with the Geological Survey of Italy (ISPRA-SGI), a review of the geological map of Italy (at a scale of 1:100,000 and 1:50,000) and their relative explanatory notes, including also many other available published data (borehole logs, local geographical portal, etc.), allowed to develop a stratigraphic conceptual model under each site. As for the attribution to each site of a topographic class according to the Italian building code, a morphometric analysis using an automatic procedure has been carried out on two DEM datasets with resolution at 30 m and 10 m. Regarding the seismological parameters, noise velocimetric records at all the stations were homogeneously analyzed by using mostly continuous data, as follow: 1) estimation of data quality with annual and seasonal noise analysis; 2) selection of noise traces (day/night and seasonal), horizontal-to-vertical spectral ratio computation and determination of directionality of the amplification peaks; 3) in case of directionality, we proceeded with the polarization analysis of the signal to identify the preferred direction of the movement, slope and straightness. A preliminary statistical analysis highlights that only 26% of the RSN accelerometric stations do not have amplification peaks, while 29% show a polarization of the signal in a preferential direction. Finally, we are collecting all the available information about the station housing, to account for possible soil-structure interaction. The database includes also 15 sites that have been fully characterized by performing a geological survey followed by the 1:5,000 geological and lithotechnical maps, a geological cross section and report, the S-wave velocity profile inferred through seismic noise arrays and, for one site, downhole measurements. With the contribution of the Site-Characterization Team: S. Amoroso, R. Azzaro, R. Bianconi, M. Cattaneo, R.

Cogliano, D. Di Naccio, C. Felicetta, A. Fodarella, S. Lovati, A. Mandiello, C. Marcocci, C. Mascandola, M. Massa, A. Mercuri, G. Milana, S. Pucillo, G. Riccio, G. Tusa, M. Vassallo, et al. (INGV); M. Amanti, G. Conte, C. Cipolloni, G. M. Monti, C. D'Ambrogi, M. D'Orefice, P. Di Manna, D. Fiorenza, R. M. Gafà, B. Roberto, M. Roma, L. Vita (ISPRA)

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ESC2018-S35-130

FUNDAMENTAL STUDY ON INFLUENCE OF TSUNAMI SOURCE HETEROGENEITY ON TSUNAMI HEIGHT DISTRIBUTION ALONG A COAST

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Many tsunami mitigation measures, such as tsunami inundation estimations and tsunami warnings, assume simplified homogeneous fault models. However, actual faults are complex and heterogeneous. In particular, large-slip zones (LSZs) and super-large-slip zones (SLSZs), which correspond to asperities on the fault and tsunami earthquake generation zone respectively, are dominant parameters in the formation of a tsunami source. In this study, the influence of fault heterogeneity on the tsunami height distribution along a coast was investigated. Homogeneous fault models for Mw 8.0 to 9.0 events, and heterogeneous fault models having the same magnitudes and epicenters as the homogeneous fault models, were assumed. The homogeneous fault model had a LSZ, in which the dislocation was 1.5 to 2.5 times as large as the background value, and which had an area of 15 to 25% of the entire fault area. To take into account the uncertainty in the location, the LSZ was placed at either end of the fault or in the center along the trench axis. In addition, faults models for events of greater than Mw 8.5 had a SLSZ, in which the dislocation was 3.5 to 4.5 times as large as the background value, and which had an area of 3 to 8% of the entire fault area. The SLSZ was placed at a shallower depth than the LSZ. Tsunami sources were calculated using the homogeneous and heterogeneous fault models. Long wave theory using a leap-frog scheme with a staggered grid was used to simulate tsunami propagation. A simplified model of the ocean surrounding the Nankai Trough was constructed using uniform-slope bathymetry. The calculated tsunami height distributions along the coast were compared, and the influences of the Mw value, the epicenter position, the presence of a LSZ or SLSZ, and the bathymetry were studied. It was found that the heterogeneity of a tsunami source is highly influential when the Mw value is large and the epicenter is close to shore. To improve tsunami disaster mitigation, it is important to better understand the mechanism whereby homogeneous and heterogeneous faults produce tsunamis with differing heights. This may be particularly effective for preventing underestimations during tsunami warnings.

ESC2018-S35-406

TSUNAMI MODELING OF THE 20TH JULY 2017 MW 6.6 EARTHQUAKE IN THE AEGEAN SEA

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Western Turkey which includes a part of the East Aegean Sea is located at the boundary of the African and European plates where subduction, collision and extensional processes are going on. The active seismicity of the area is moderate with small and intermediate earthquakes of magnitude rarely greater than 6. The 20th of July 2017 a M6.6 earthquake occurred in the rift zone of the Gulf of Gokova, 100 km away from the cities of Kos and Bodrum. A tsunami was generated and impacted the coasts of Turkey and Kos Island, with reported waves of up to 1.5 to 2 m and floods and damages in many harbors. Two fault models in agreement with the rift geometry and the actual known faults are possible: a fault dipping to the South favored by GPS and waveform inversion models and a fault dipping to the North favored by GPS and INSAR inversion models. Several tsunami simulations were performed to constrain the source and to solve this fault plane ambiguity, by comparing the modeling results with the field survey data and the available tide gauge record of Bodrum harbor. The Turkish coast and Kos Island have complex geometries with numerous gulfs and bays. To obtain accurate simulation results, two grids of 5 m resolution of Kos and Bodrum harbors were built in addition to a 10 m resolution grid kindly provided by the Turkish research team. The resulting water elevation maps present coherent 1 to 2 m waves at proper places depending on the sources. By comparing those maps to the survey maps, we try to discriminate the source parameters. For instance, the tsunami simulations favor the North dipping fault. So far, the high sensitivity of the tsunami propagation and the complexity of the coastline do not allow solving clearly the plane ambiguity. Further studies including finer bathymetric data and other high resolution grids may help to improve the results.

ESC2018-S35-412

TSUNAMI EVACUATION SIMULATION CONSIDERING ROAD BLOCKADE BASED ON BUILDING COLLAPSE RATIOS EVALUATED FROM PREDICTED STRONG GROUND MOTIONS

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This study simulated tsunami evacuations for an earthquake or earthquakes along the plate boundary of the Nankai Trough in order to evaluate the effectiveness of the current refuge sites in terms of their locations and capacities. The novelty of our study is that we considered the probability of collapsed houses that will block escape routes to the designated refuge sites. It aimed to quantitatively demonstrate the effect of earthquake-resistant reinforcements on evacuation speed from tsunami, and thus provided vital information for selecting the most effective countermeasures for tsunami evacuation from the mega-thrust earthquakes along the Nankai Trough. We chose a district comprising 1-, 2-, and 3-Chome of Kamiyashiki and Katamachi, located along the coastline of Tanabe City, Wakayama Prefecture. The population is approximately 1,250 people in 641 households. The predicted maximum seismic JMA intensity in the district is 7 (equivalent to the MMI scale of X or higher), in the event of the simultaneous rupture with three consecutive segments, with a 12 m high tsunami estimated to arrive approximately 15 minutes at minimum after the earthquake. In the present study, the time history of the ground motion predicted by the conventional statistical Green function method for the target district in the event of a consecutive rupture scenario for three Nankai-Tonankai-Tokai segments was applied to the building models, and the damage ratios were computed. The source model used considers the strong motion generation areas (SMGAs) and small variation of slips within each SMGA. The amplification factor for the surface subsoil was generally homogenous (between 1.4 and 1.6 according to the J-SHIS amplification factor based on the GIS information); therefore the seismic wave was not corrected for the effect of surface subsoil at different ground points. The tsunami evacuation simulation is performed by using an agent-based simulator, and the space-time geographic information system was structured in such a way as to share the same database. The former was constructed on a multi-agent platform called "Aritsoc" developed and distributed by Kozo Keikaku Engineering Inc. and the latter was built on "DiMSIS", a space-time GIS system. The only agents in this platform are people, and the underlying data is provided from a database. The data comprises the basic attributes of the residents, information collected from site surveys, and the geographic characteristics of the target district. The geographic characteristics, based on publicly available data, are organized on the space-time GIS system and stored in the database. In the simulations, the number of collapsed buildings was calculated using the building damage simulation program developed by Nagato and Kawase. For the collapsed buildings, the number of each type of building was multiplied by the damage ratio from Nagato and Kawase's simulation program in order to determine the number of buildings that would suffer major damages or collapse. This number was then multiplied by 3/7, which is the estimated proportion of buildings that would collapse among buildings that suffered major damages and higher, in order to compute the total number of collapsed buildings. The buildings that collapsed were selected using a random number generator across the number of buildings of each construction type (wooden, non-wooden, and unknown). After the shapes of the buildings chosen in step were determined, road blockages were created based on the height of the collapsed building and the width of the road in front of the building. First the performance of the designated evacuation sites at present was evaluated under the assumption that there would be no building collapsed. By adding the evacuation buildings inside, namely, the NTT building and the Primary School, 333 additional people, which is 27% of the whole residents, would be able to evacuate to these locations. However, 391 people, or 31.4% of the residents, would not be able to evacuate in time. Thus the current evacuation plan was found to be inadequate. It is necessary to consider additional evacuation sites in terms of numbers, locations, and their capacities to save all the residents in time. Then the effects of road blockages due to building collapse were eliminated for different cases with the percentage of earthquake-resistant houses from 0% (the current situation) to 100%

(no collapse). It was found that about 3 to 4% of residents (40 to 45 people) could not successfully evacuate when we consider the collapse of houses. This means that those numbers of people who would take too much time to evacuate due to road blockages by collapsed houses could be decreased if we increase the earthquake resistance of houses sufficiently to prevent their collapse. Thus seismic reinforcement should be continued to promote not only to prevent direct consequence of casualties but also to reduce evacuation time.

ESC2018-S35-527

NEW INSIGHT INTO THE TSUNAMI HAZARD IN THE BLACK SEA: HISTORICAL AND SEISMOTECTONIC CONSIDERATION

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Being seismotectonically and historically a part of the Mediterranean region, the Black Sea is almost completely isolated from it in terms of hydrodynamics, so all its tsunamigenic events are localized within its basin (which also includes the Sea of Azov). In the present study, made under the Russian Science Foundation Project 14-17-000219, the previous historical catalog for the Black and Azov Seas has been almost doubled and now contains 50 events of different origin and level of validity, occurred here during the last 3000 years. Among these events, there were devastating tsunamis with the run-ups of 4-5 m, in exceptional cases up to 7-8 meters, resulting in disastrous consequences for several ancient cities (Dioscuria, Sebastopolis, Bizona, Panticapaeum), and for many coastal settlements. For all tsunamigenic events, the available information on their sources and coastal manifestations was parameterized, the tsunami intensity on the Soloviev-Imamura scale was evaluated and classification of tsunami sources by their origin was proposed. While the majority of the sources were associated with submarine earthquakes, there were tsunamis and tsunami-like water disturbances resulting from in-land earthquakes (on the North Anatolian Fault and in the Wranch deep focus seismic zone), generated by underwater and coastal landslides, mud-volcano eruptions and possibly meteorological disturbances. Historically inhabited only in several isolated areas (Bosporus, Thrace, Crimea, Colchis), all the Black Sea coast is now densely populated and its infrastructure is rapidly developing, hence a great demand for estimating long-term tsunami hazard and risk for its coastline is obvious. We analyze this hazard based on newly discovered historical data, seismotectonics features and geodynamics of the region. The diversity of tsunami generation mechanisms for the Black Sea, the rarity of destructive events and the lack of instrumental data on weak tsunamis complicate the tsunami hazard assessment based on conventional PTHA methodology, so the new approaches for hazard assessment are needed. The present study has demonstrated once again that in the restoration of regional earthquake/tsunami history any new systematic search for the data on regional and local levels and in languages others than English (in this study, the sources in Russian, Ukrainian, Bulgarian, Polish, Romanian, Italian, German, Turkish languages were used) reveals a wealth of data previously inaccessible on the international level. However, even this new catalog is still incomplete and has obvious gaps in the data (for instance, the large gap from the 6th to the 13th century AD). Such a gap can be filled only by an extensive search for the geological traces of paleotsunami that is still in the infancy stage in this region.

ESC2018-S35-562

INITIAL RESULTS OF A SYNERGETIC GEOTECHNICAL AND SEISMOLOGICAL STUDY TO ASSESS SLOPE STABILITY IN LAKE LUCERNE, CENTRAL SWITZERLAND

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The investigation of tsunamigenic processes is mostly concentrated on mega-events within the oceanic setting. However, a tsunami may occur in the lacustrine realm on a smaller spatial scale, but

with wave heights comparable to mega-tsunamis and with similar devastating effect on coastal infrastructure and human life. Assessing subaqueous slope stability is important for tsunami hazard mitigation. Subaqueous slope failures can be generated by diverse triggers amongst which earthquakes are one of the main causes. Historical documents and paleo reconstructions based on the lake sediments have revealed that tsunamis happened in Swiss lakes. Lake Lucerne in Central Switzerland, for example, has experienced a tsunami of around 4 m wave height caused by earthquake-triggered sublacustrine mass movements in 1601 which produced significant damage along the shoreline. In 1687 another tsunami was generated by a spontaneous delta collapse. Given the easy accessibility, Lake Lucerne provides a natural laboratory to study the pre-conditions and trigger mechanisms (e.g. seismicity, overloading) of slope failures related to different geomorphological settings (e.g. slope, delta system). Based on the already available geophysical and sedimentological database (high-resolution bathymetry map, reflection seismic sections), we are able to identify locations where slope failures have occurred and where they might potentially occur in the future. Here, we present the initial results of the first campaign executed in March 2018 using a dynamic CPTu (Cone Penetration Testing) system (FF-CPTu). This geotechnical method allows a rapid estimation of the sediment-mechanical properties (strength, pore pressure) and, thus, the characterization of pre-conditions and potential of failure of the slope sediments. A total of 150 CPTu profiles up to 6 m at 11 different sites in the entire lake were performed (pore pressure, sleeve friction and cone resistance were measured). In addition, 20 sediment cores (up to 1.5 m length) have been recovered using a gravity coring system. CPTu data attest the occurrence of mechanically weaker layers and very stiff thin layers, which may relate to overconsolidated and/or coarser-grained material. Based on sediment-mechanical conditions of the lake floor derived from the CPTu data, locations for a consecutive ocean bottom seismometer (OBS) campaigns have been chosen. Ambient seismic vibrations data recorded by OBS are intended to be processed using both single station and array techniques in order to reveal the subsurface structure and stability of the slopes. For an appraisal of the water column effect on the slope sediment cover, we interpret the existing reflection seismic lines and use a resulting approximated 1D elastic (+fluid layer) media together with the newly developed generalized microtremor H/V algorithm to estimate in a synthetic analysis the variations in the H/V peak frequency and amplitudes. In addition, Scholte waves and Rayleigh waves dispersion curves are compared. Keywords: Lake Lucerne, Tsunami, Ocean bottom seismometer, Cone penetration test, Ambient seismic vibrations, Slope stability

ESC2018-S35-575

TSUNAMI HAZARD MAPS BASED ON NUMERICAL SIMULATIONS IN THE BLACK SEA REGION

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In this study we perform assessment of hazard scenarios of earthquake-induced tsunami for the Black Sea region. Numerical simulations were performed with UBO-TSUFD software, coupled with bathymetry and topography data. We selected several potentially seismic source zones and for each of them we determined the maximum credible earthquake magnitude as well as the associated fault geometry and focal mechanism. We performed the "worst case" scenario for each zone and built hazard maps according to the computed maximum tsunami heights. Tsunami travel-time maps for every earthquake zone are also computed and travel time of "dangerous" tsunami is taken in consideration. The northeastern Bulgarian Black Sea coast is more vulnerable to tsunami effects therefore two additional improved grids are built. Nonlinearity is applied and the maximum inundation and maximum moment flux are computed for this area. Synthetic mareograms were estimated for a number of points close to the coastline of big cities. The obtained results may be implemented in the design of early-warning strategies for the Black Sea region.

ESC2018-S35-671

GENERATION OF GRAVITY WAVES IN THE OCEAN BY SURFACE SEISMIC WAVES: OBSERVATION, NUMERICAL SIMULATION AND PHYSICAL MECHANISM

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Small-amplitude free gravity waves in the ocean were registered by DONET ocean-bottom pressure gauges just after the passage of surface seismic waves during the 2011 Tohoku earthquake. The amplitude and period of these free gravity waves amounted to 3 cm and 150 s, respectively. Based on theoretical estimates we assume that generation mechanism of these free gravity waves is related to horizontal movements of ocean-bottom slopes during the passage of low-frequency Love and Rayleigh waves. To verify our hypothesis we made numerical simulation of these free gravity waves inside the DONET stations region. For our simulation we used combined 3D/2D numerical model, which consists of two modules: deep-water module (based on the linear potential theory) and shallow-water module (based on the linear long wave theory). Dynamics of bottom movement during the passage of surface seismic waves was reconstructed with the use of DONET ocean-bottom seismometers data. Earthquake epicenter was located quite far from DONET stations (approximately 800 km), so we assumed that surface seismic waves were plain inside the simulation domain. Their profiles were calculated by double integration of DONET accelerograms. The results of our numerical simulation are in good agreement with the observed values. We made two different simulations for two different types of bottom boundary conditions: (1) only vertical movements and (2) only horizontal movements of ocean bottom. The results of these simulations confirmed that horizontal movements of ocean-bottom slopes play the key role in the free gravity waves generation whereas the role of vertical movements is negligible. We made another simulation to find, whether residual (coseismic) bottom deformation generates free gravity waves with the observed amplitudes or not. The results of this simulation showed that it is necessary to take into account dynamics of bottom movement in the far-field. DONET data were transfered and processed according to Implementing Agreement Between Faculty of Physics of Lomonosov Moscow State University and Japan Agency for Marine-Earth Science and Technology on Early tsunami detection methods on the base of real-time seafloor observatory network (2013). Keywords: gravity waves, surface seismic waves, linear potential theory, 2011 Tohoku tsunami, bottom slopes

ESC2018-S35-742

APPLICABILITY OF 2D GAUSSIAN SLIP DISTRIBUTIONS TO REPRESENT REALISTIC CO-SEISMIC SLIP HETEROGENEITIES: CONSEQUENCES FOR TSUNAMI MODELLING AND EARLY WARNING

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The process of earthquake faulting consists in the relative slip of the two sides of the fault surface itself, which, especially in the case of large magnitude events, is characterised by a highly heterogeneous pattern. Such heterogeneous slip distributions are the result of the interaction between the focal mechanism of the seismic source and the local characteristics of the crust and may exhibit one or more regions of higher slip concentration (asperities). In the case of tsunamigenic earthquakes, it is well known that the slip heterogeneity strongly influences the spatial distribution of the largest tsunami effects along the nearest coastlines. Unfortunately, when an earthquake occurs, the so-called finite-fault solution (FFS) describing the co-seismic on-fault slip pattern becomes available over time scales which are incompatible with early warning purposes, especially in the near-field. We propose an approach in which the slip heterogeneity can be determined in the form of a 2D Gaussian distribution (2D-GD) whose relevant parameters (semi-major and semi-minor axes, maximum slip) are retrieved from proper regression laws against earthquake magnitude. In turn, the regression laws are determined on the basis of the fitting of historical FFSs contained in the SRCMOD database with 2D-GDs. So far, the approach applies to earthquakes exhibiting a single asperity. We test

the performance of our approach by simulating two earthquake-generated tsunamis occurred over the last few years and producing severe damages especially in the near-field (Tohoku 2011, Chile 2015). For each of them, we compare the tsunamis obtained by taking one of the FFSs contained in SRCMOD as the reference source case against those obtained by representing the on-fault slip distribution through 1) our 2D-GD, 2) a heterogeneous pattern obtained by means of the smooth-closure condition (SCC), 3) a uniform pattern. The comparison is made on time-histories at selected coastal and offshore sites and on the distribution of the maximum sea level heights along the coasts in the near-field. The 2D-GD solution is found to be a very good representation of the "true" source SRCMOD model, in general much better than the SCC and uniform pattern sources. Moreover, being much "easier" and "faster" to be computed, it may find possible application in the tsunami early warning context.

ESC2018-S35-746

TSUNAMI HAZARD FOR FRENCH COASTLINES: RESULTS AND PRESPECTIVES FROM THE PROJECT TANDEM (TSUNAMIS IN THE ATLANTIC AND THE ENGLISH CHANNEL: DEFINITION OF THE EFFECTS THROUGH NUMERICAL MODELING) (2014-2017)

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The TANDEM project (Tsunamis in the Atlantic and the English ChaNnel: Definition of the Effects through numerical Modeling) has been funded (2014-2017) in France to provide a better appraisal of coastal effects due to tsunami waves on the French coastlines, with a special focus on the Atlantic and Channel coastlines, where civil nuclear facilities have been operating since about 30 years. Launched after the 2011 tsunami, it first aimed at drawing lessons from the 2011 catastrophic tsunami, and, together with a Japanese research partner (Meteorological Research Institute, MRI), at adapting and validating numerical methods of tsunami hazard assessment, using the database of the 2011 tsunami. The validated methods have been applied to estimate the tsunami hazard for the French Atlantic and Channel coastlines. TANDEM follows the recommendations of International Atomic Energy Agency (IAEA) to analyse the tsunami exposure of the nuclear facilities, as well as the recommendations of the French Nuclear Safety Authority (Autorité de Sûreté Nucléaire, ASN) in the aftermath of the 2011 catastrophe, which required the licensee of nuclear facilities to conduct complementary safety assessments (CSA), also including "the robustness beyond their design basis". TANDEM aims at defining the tsunami effects expected for the French Atlantic and Channel coastlines, basically from numerical modeling methods. A series of 19 test cases has been defined to benchmark numerical methods accounting for the various steps of a tsunami from generation to impact, thus down to the interaction with coastal structures (3D approaches). Then the methods have been tested to characterize and quantify the associated uncertainties (in the source, the propagation, and the coastal impact), and have been used to compare models to the large observational dataset gathered in 2011, specifically for coastal sites such as in Kamaishi. Finally the numerical models have been applied to the French coastlines to provide hazard estimations for various sites and scenarios. Using high resolution bathymetric and topographic data in the frame of Litto3D (a French project whose main objective is to build a seamless integrated topographic and bathymetric coastal Digital Terrain Model), TANDEM partners investigated possible worst case scenarios, through a detailed seismotectonic zonation and analysis of the slope stability off the coastlines (for the Celtic and Armorican margins, Bay of Biscay. Far field scenarios have also been used (Canaries, Lesser Antilles) to complete worst case sources. The results indicate, for return periods of a few centuries, a moderate possible tsunami impact for the Atlantic coastline, and a low impact for the English Channel, while the expected tsunami heights can exceed a few meters for extreme catastrophic sources (generally from landlisde origin) with return periods above several thousands of years.

ESC2018-S35-758

A LARGE SUBMARINE COLLAPSE ALONG THE GELA BASIN MARGIN (STRAIT OF SICILY) AND ITS CONSEQUENCES ON THE COASTS OF SICILY AND MALTA

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The Gela Basin Margin (GBM), located in the Strait of Sicily (Central Mediterranean) between Sicily and Malta, is characterized by a steep slope, which breaks the wide shelf, known also as Malta Plateau, from about 200 m water depth down to over 700 m. The slope has been repeatedly affected by mass wasting processes during the Quaternary, as testified by several scars along the northern shelf edge and by the numerous deposits at its base (Minisini et al., 2007). The sequence and mechanisms of failure are rather complex and difficult to reconstruct exactly, due to the overlapping of different episodes that are hard to discriminate. Although some events have been well described and characterized (Minisini and Trincardi, 2009), one large landslide located in the southern portion of the margin, about 30 km north of the coasts of Malta, has received so far little attention. The seafloor morphological characteristics include a large amphitheater, approximately 7 km wide starting just from the margin at less than 200 m sea depth, and a depositional area with a 15-km-long run out from the slope base. The reconstruction of the slide scenario, hereafter called Southern Gela Basin Slide (SGBS), entails a volume ranging between 3 and 4 km3. The genesis of the slide might be due to local seismicity that is characterized by medium-size earthquakes with sources off South Sicily. The focus here is on the tsunamigenic potential of such event that is evaluated through in-house numerical codes (see for example Zaniboni et al., 2016). The slide dynamics is computed by means of the numerical code UBO-BLOCK1, implementing a block-model approach, providing the complete time history of the mass motion along the sea bottom. From this, the perturbation on the sea surface is evaluated with an intermediate code (UBO-TSUIMP) that accounts for the attenuation of the slide impulse due to the sea depth, filtering higher space frequencies. Note that the tsunamigenic trigger from landslides is not instantaneous as in the case of earthquake-tsunamis, but extends in time. The propagation of the wave is computed on a regular grid via the finite-difference code UBO-TSUFD (Tinti and Tonini, 2013), which allows us to compute the impact of the generated tsunami on the coasts of Sicily and Malta. Considering the possible seismic genesis of this landslide, it is worth stressing that tsunamis induced by landslides, in turn triggered by even small earthquakes, can exceed the direct effects of the shake itself. In the present case, the tsunami is shown to affect the coasts of south-east Sicily and of the Malta archipelago.

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ESC2018-S35-773

PYSPTHA: A REUSABLE APPROACH TO DEFINE AND MANAGE SEISMIC PROBABILISTIC TSUNAMI HAZARD ANALYSIS FRAMEWORKS

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PySPTHA: a reusable approach to define and manage Seismic Probabilistic Tsunami Hazard Analysis frameworks Paolo Perfetti(1), Jacopo Selva(1), Roberto Tonini(2), Andreas Hoechner(3) & The TSUMAPS-NEAM Group (1)Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy (2)Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Roma 1, Roma, Italy (3)Deutsches GeoForschungsZentrum (GFZ), Germany Probabilistic tsunami hazard analysis is a computationally heavy task: both long-term (for planning and emergency strategies) and short-term (for early warning systems) assessments need thousands to millions tsunami scenario simulations, due to the large uncertainty

associated to the causative sources. Despite the increasing potential of modern computational resources, onthefly computing and real-time solutions are hardly feasible, and even simplified solutions require to handle very large datasets (big data) to describe or emulate complex geophysical processes. PySPTHA (Python Seismic Probabilistic Tsunami Hazard Assessment), is a FLOSS (Free-Libre Open Source Software) Python object oriented library designed to manage all the steps needed for a quantitative tsunami hazard analysis. PySPTHA was used to implement the approach defined in TSUMAPS-NEAM (www.tsumaps-neam.eu), a project aimed to produce the first long-term SPTHA for the region of the North-Eastern Atlantic, the Mediterranean and connected Seas. The library is meant to be the connecting tool for the steps going from the scenario definitions to the final probabilistic hazard assessment on chosen forecast points. Internal procedures are designed to be independent from the particular algorithms used to compute tsunami scenarios, probabilities and uncertainties (currently implemented as different external tools), relying on standard extensible I/O modules to read/write text-based data files. The cornerstone of PySPTHA is the Event Tree concept, where each level of the tree corresponds to a geophysical parameter and both its variability and probability can be expressed conditionally to one or more previous levels in the tree. Proceeding with a complete exploration of the branches, the complete list of defined scenarios can be retrieved as well as the corresponding absolute annual rate of each scenario, by multiplying the probabilities of each node along the selected branch. The library is designed to be highly flexible and configurable: event tree structures and levels, their variability and probabilities, the dependencies on previous levels, the domain regionalization, the list of forecast points, the used metrics, the metrics thresholds and several other configurations can be easily customized to adapt this method to any domain of interest. PySPTHA is the probabilistic core of the near-future Probabilistic Tsunami Forecast (PTF) module of the Italian Tsunami Alert Center (CAT – Centro Allerta Tsunami) and the Italian Seismic Tsunami Probabilistic Hazard Map (MTPS18) currently under implementation. This work was funded by the TSUMAPS-NEAM (Grant agreement ECHO/SUB/2015/718568/PREV26) project and the Agreement between Istituto Nazionale di Geofisica e Vulcanologia (INGV) and the Italian Department of Civil Protection (DPC).

ESC2018-S35-795

FROM REGIONAL TO LOCAL SEISMIC PROBABILISTIC TSUNAMI HAZARD ANALYSIS: AN APPLICATION TO SOUTH-EASTERN SICILY, ITALY

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Many human settlements and activities are located along coasts or very close to oceans, seas or estuaries, and, as consequence, are exposed to tsunami risk. Nowadays, the execution of risk mitigation actions is becoming an essential process for any long-term land use planning and the implementation of emergency strategies. In this framework, Probabilistic Tsunami Hazard Analyses (PTHA) provide an important input to quantitative risk analyses. However, detailed tsunami hazard assessments for specific target areas need to consider a huge number of potential tsunamigenic scenarios, due to the large uncertainty associated to the causative sources. Since explicit tsunami inundation simulations require high resolution numerical models, the associated computational cost is still very expensive. In this work, we perform a site-specific Seismic PTHA (SPTHA) for a coastal segment placed in the South-Eastern Sicily, Italy, between Catania and Siracusa, two touristic and commercial urban areas, comprising harbour infrastructures and a petrochemical complex. This area has experienced destructive tsunamis in the past (e.g., 1693 and 1908) and the coast presents very different terrain morphologies (e.g., flat beaches, steep rocky slopes, jagged inlets). In our approach, the regional SPTHA, developed in the framework of the TSUMAPS-NEAM project (http://www.tsumaps-neam.eu/) and revised by a scientific pool of experts, is used as input to assess a local SPTHA, through an innovative filtering procedure, accounting for the separate contribution of local and remote sources, to reduce the number of required explicit inundation simulations. A subset of representative scenarios approximating the regional hazard in the target area is selected and then modeled with T-HySEA,

a non-linear hydrostatic shallow-water multi-GPU code, using high resolution topo-bathymetic data to produce detailed inundation maps. Finally, results for both regional and local analyses are presented with the goal of evidencing lights and shadows of the two kind of procedures in terms of their different use for risk mitigation strategies. The work is funded by the TSUMAPS-NEAM (Grant agreement ECHO/SUB/2015/718568/PREV26) project and the Agreement between Istituto Nazionale di Geofisica e Vulcanologia (INGV) and the Italian Department of Civil Protection (DPC).

ESC2018-S35-806

MALTA'S TSUNAMI INUNDATION HAZARD: PRELIMINARY RESULTS

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The Maltese archipelago, located in the central Mediterranean Sea, is a prominent holiday destination, visited by almost two million tourists every year. The archipelago is exposed to numerous potential tsunami sources. The eastern coastal topography of the Maltese archipelago is characterised by a low-lying coast with numerous densely populated rias. This is also where the majority of touristic and other economic activity is concentrated, which increases the risks of potential tsunami disasters compared to less populated locations elsewhere. Probabilistic tsunami hazard assessment for all the Mediterranean coast (Sørensen et al, 2012) demonstrated a considerable tsunami hazard of about 2m of Peak Coastal Tsunami Amplitudes every 500 years for the Maltese archipelago. This motivated us to simulate inundation impact for a small number of potential “worst-case” scenarios, since no inundation studies have been conducted for Malta to date. Our simulations took into consideration four different sources:

- Source A: Submarine landslide on the top of the Malta Escarpment (Micallef et al. 2016)
- Source B: Submarine landslide in the southern Gela Basin (Foglini et al. 2011).
- Source C: Earthquake on the Western Hellenic Arc (Gailler et al. 2016)
- Source D: Earthquake south east of Sicily (Piatanesi and Tinti, 1998)

Simulations were conducted with the Cornell Multi-grid Coupled Tsunami model (COMCOT). All source scenarios, except for the Gela Basin landslide, cause considerable inundation land threads with decimetres to meters of flow depths and inundation extents of up to 2 km in low lying rias of Malta. The Source B scenario generates increased currents posing a potential hazard to boats in harbours, swimmers and people on beaches. It is important to note that the source mechanisms in the scenarios investigated here are currently first order approximation examples (in particular the submarine landslides) and need further refinement.

ESC2018-S35-819

SLIP DISTRIBUTION OF THE 2010 MAULE, 2014 IQUIQUE, 2015 ILLAPEL EARTHQUAKES THROUGH NONLINEAR INVERSION OF GEODETIC DATA AND TSUNAMI WAVEFORMS USING THE OPTIMAL TIME ALIGNMENT (OTA) METHOD

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The Chile subduction zone, one of the most seismically active regions in the world, hosted a number of great tsunamigenic earthquakes in the past. During the last 7 years three M8+ earthquakes occurred nearby the Chilean coasts, that is the 2010 M8.8 Maule, the 2014 M8.1 Iquique, and the M8.3 2015 Illapel earthquakes. Different kind of geophysical observations such as seismic, geodetic, and tsunami data have been used to infer the rupture process of these earthquakes; in particular, tsunami waveforms are important for constraining the slip on the offshore portion of the fault. However, it has been shown that forward modelling of tsunami data can be affected by unavailability of accurate bathymetric models, especially in the vicinity of the tide-gauges; and in the far field by water density gradients, ocean floor elasticity, or geopotential

gravity changes, generally neglected. This could result in a mismatch between observed and predicted tsunami signals thus affecting the retrieved tsunami source image. A method, named optimal time alignment (OTA) to automatically correct during the nonlinear inversion the mismatch has been proposed by Romano et al. (GRL, 2016). Here, we present a reappraisal of the joint inversion of tsunami data with OTA procedure and geodetic data, for the Maule, Iquique, and Illapel earthquakes. We compare the results with those obtained by tsunami inversion without using OTA and with other published inversion results.

ESC2018-S35-908

VALIDITY CRITERIA OF THE LONG-WAVE APPROXIMATION FOR DESCRIBING DISPERSIVE TSUNAMI WAVES

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The long-wave approximation is widely used for numerical simulation of tsunamis. Under assumption that wave length is large enough in comparison with water depth the original 3D hydrodynamic problem is reduced to a number of 2D problems which employ depth-integrated equations. The simplest version of the depth-integrated equations are referred as long-wave or shallow water equations. These equations describe non-dispersive waves which phase and group velocities are equal to each other and do not depend on wavelength or frequency. In contrast to the model object “long wave”, real tsunami waves clearly exhibit the phase dispersion. Manifestations of tsunami wave dispersion are well observed in measurements of tsunamis in the open ocean by bottom pressure sensors and satellite altimeters. When tsunamis propagate a rather long distance, dispersion, that exhibit the property of accumulating, are capable of essentially altering the amplitude and the structure of the wave perturbation. This is why the neglecting of phase dispersion represents a serious disadvantage of models based on shallow water equations. A more complicated kind of depth-integrated equations – known as Boussinesq equations – allow to describe slightly dispersive waves. However, Boussinesq equations as well as shallow water equations have their own restrictions in reproducing of tsunami waves. In this study we quantify these restrictions and specify validity criteria of shallow water equations and Boussinesq-type equations for describing dispersive tsunami waves. Our approach involves the concept of distance of dispersive destruction, i.e. the distance, at which manifestations of dispersion effects should turn out to be quite significant. This distance we determine as the product of the velocity of long waves by the time, required for a wave packet to lag behind the front at a distance equal to the wavelength. The sought validity criteria are formulated as a low limit for wave period which can be easily calculated from the size of calculating area and average ocean depth within this area. Ultimately, we compare results of numerical simulation of some recent tsunamis carried out within the framework of fully-dispersive model (3D potential theory) and non-dispersive model (2D shallow-water theory). This work was supported by the Russian Foundation for Basic Research, projects 16-05-00053.

ESC2018-S35-918

IMPROVING THE CAPABILITIES OF TSUNAMI WARNING IN THE NORTH EAST ATLANTIC - THE PORTUGUESE TSUNAMI WARNING SYSTEM

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Tsunamis are high-impact natural disasters. The 2004 Boxing Day tsunami killed more than 250 000 people in the Indian Ocean. Seven years later the Tohoku-Oki tsunami in 2011 devastated Japan, one of the world best-prepared countries for a tsunami. These events set the stage for new improvements on tsunami early warning. Tsunami Early Warning Systems must be able to detect an on-going tsunami event, compute robust estimates of time of arrival and potential impact for a dense network of coastal locations, and provide decision makers and citizens with timely alerts, and additional accurate information to be used to guide protection measures for lives and

goods. On November 2017 the Portuguese Tsunami Warning System (PtNTWC- Portuguese national tsunami warning centre) started its operation. The centre housed at the Instituto Português do Mar e da Atmosfera (IPMA) in Lisbon became fully operational, on a 24/7 basis, similarly to the Tsunami service providers of the NEAM region (France, Greece, Italy and Turkey). The PtNTWS includes three main components: the seismic detection, the tsunami detection and the alert dissemination. For the detection of the earthquake the system relies on a dense regional broadband network complemented with seismic stations globally distributed, with data being automatically managed and processed within a SeiscomP3 platform. The tide-gage network, distributed along the northeast Atlantic includes stations in Portugal mainland, Azores and Madeira Islands, and on the Atlantic coasts of Spain and France. The Tsunami Analysis And Report (TAAR) tool, operational at IPMA, allows for a rapid tsunami detection, automatic analysis of sea-level data and warning message issuing based on the use of a standard decision matrix approved by the ICG-NEAMTWS. On-duty officers, using the TAAR, revise and analyse the information on a real time basis to ensure the issuing of the alert messages within 8-10 min after the onset of a submarine earthquake. This work received support from ASTARTE – Assessment Strategy and Risk Reduction for Tsunamis in Europe (Grant 603839 – FP7, Env. 2013), TSUMAPS-NEAM (DG-ECHO), ARISTOTLE - All Risk Integrated System TOwards Trans-boundary hoListic Early-warning and FCT-project UID/GEO/50019/2013 – IDL

ESC2018-S35-958

BUILDING AN ENSEMBLE SEISMIC HAZARD MODEL FOR THE MAGNITUDE DISTRIBUTION BY USING ALTERNATIVE BAYESIAN IMPLEMENTATIONS

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In this work we show how we built an ensemble seismic hazard model for the magnitude distribution for the TSUMAPS-NEAM EU project (http://www.tsumaps-neam.eu/). The considered source area includes the whole NEAM region (North East Atlantic, Mediterranean and connected seas). We build our models by using the catalogs (EMEC and ISC), their completeness and the regionalization provided by the project. We developed four alternative implementations of a Bayesian model, considering tapered or truncated Gutenberg-Richter distributions, and fixed or variable b-value. The frequency size distribution is based on the Weichert formulation. This allows for simultaneously assessing all the frequency-size distribution parameters (a-value, b-value, and Mc), using multiple completeness periods for the different magnitudes. With respect to previous studies, we introduce the tapered Pareto distribution (in addition to the classical truncated Pareto), and build a novel approach to quantify the prior distribution. For each alternative implementation, we set the prior distributions using the global seismic data grouped according to the different types of tectonic setting, and assigned them to the related regions. The likelihood is based on the complete (not declustered) local catalog in each region. Using the complete catalog also allows us to consider foreshocks and aftershocks in the seismic rate computation: the Poissonicity of the tsunami events (and similarly the exceedances of the PGA) will be insured by the Le Cam's theorem. This Bayesian approach provides robust estimations also in the zones where few events are available, but also leaves us the possibility to explore the uncertainty associated with the estimation of the magnitude distribution parameters (e.g. with the classical Metropolis-Hastings Monte Carlo method). Finally we merge all the models with their uncertainty to create the ensemble model that represents our knowledge of the seismicity in the studied region.

ESC2018-S35-984

ESTIMATION OF SEISMOTECTONIC TSUNAMI HAZARD USING FOCAL MECHANISM: THE PROTOTYPE OF FULLY AUTOMATED SYSTEM

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The fast and reliable estimation of seismotectonic tsunami hazard is still a challenging task. In this talk the prototype of fully automated system for estimation of seismotectonic tsunami hazard

focused on simplicity and speed with usage of minimum of input data is introduced. The only input for system is focal mechanism which is usually becomes available within 15-30 minutes after seismic event. The focal mechanism data could be obtained from number of providers around a world, e.g. USGS and GEOFON. Proposed system involves three consecutive stages. At the first stage vector field of coseismic bottom deformation is obtained using earthquake fault parameters. At the second stage the initial elevation in tsunami source is calculated and estimation of Soloviev-Imamura tsunami intensity is performed. Initial elevation is calculated taking into account vertical and horizontal components of bottom deformation, local bathymetry and smoothing effect of water layer. An auxiliary study was conducted to obtain relationship between potential energy of initial elevation of water in tsunami source and intensity of resulting tsunami. More than 200 historical events from HTDB/WLD and NGDC/WDS databases was statistically processed. The obtained relationship is used to assess the intensity of tsunami generated by earthquake under consideration. At the final stage numerical simulation of propagation of tsunami wave is performed if event is considered significant. Water surface time-histories in desired points as well as animations of wave propagation are produced. Details of implementation, physical constraints and future development of system will be discussed during the talk. This work was supported by the Russian Foundation for Basic Research, project 16-05-00053.

ESC2018-S35-997

TSUNAMI RISK PERCEPTION AND UNDERSTANDING IN SOUTHERN ITALY: IMPLICATION FOR AWARENESS AND MITIGATION STRATEGIES

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In late 2017 and early 2018 the Tsunami Alert Centre of the Italian National Institute of Geophysics and Volcanology (hereinafter CAT-INGV) has put in place a pilot research on tsunami risk perception and understanding, first aimed at improving both risk and scientific communication strategies and activities. The research arises from a decennial debate on risk communication failures, which started by an in-depth analysis of the L'Aquila earthquake wrong predictions issued during the 2009 seismic crisis and the following trial, that started by 2010 (Cocco et al. 2015; Amato, Cerase and Galadini, 2015). The notorious L'Aquila case shocked the community of geo-scientist across the world, thus demonstrating that "good intuitions" are very likely to turn into "undue assumptions" and then in "risk communication failures" or worse, in "communication disasters". According to a well - established ethical principle, delivering untested risk communication should be considered as an unacceptable practice, as well as delivering an untested drug (Fischhoff & Morgan, 1993: 199), and any effective and sustainable risk communication strategy should be grounded on well-researched principles instead of "good" intuitions (Bostrom and Löfstedt, 2003). As a consequence, the lack of knowledge about the way complex phenomena such as tsunamis are perceived and understood by coastal population may result in serious misunderstandings and even in rising outrage towards both tsunami early warning and risk governance systems, implicating the risk for scientist to be targeted by harsh criticism and / or to have a serious reduction of the intended effectiveness of risk mitigation measures. Our pilot research foresees a sample of > 1000 interviews to be administered in two tsunami-prone regions of Southern Italy - Calabria and Apulia - and data collection is nowadays ongoing. Although research is not yet completed at the time we write, evidence from first 374 interviews provides an amount of relevant implications about the ways demands placed on risk reduction strategies both at local and regional level. Along with the investigation of risk awareness, risk cultures and tsunami mental models, the research enlists some questions aimed at investigating knowledge and preferences of respondents regarding Tsunami Early Warning systems operations, the media most frequently used to get information on a daily basis and the most appropriate channels to spread timely and effective early warning messages. Research was also intended to identify the most appropriate message and channels to effectively spread both risk communication and alert messages: as Science pointed out "warnings often fail to travel the 'last mile' to people living in areas, often remote, that are at risk of being swamped" (Science, 2014). Although Italy coastal setting and

tsunami exposition could not be compared to Indonesia or Japan ones, overcoming the last mile still remains a big challenge for risk and crisis communication Despite commonplaces and stereotypes people appear being not so misinformed on tsunamis as one may suppose, and they also have high expectations regarding authorities, civil protection and research institutions capabilities to face tsunami risk and manage with early warning issues. In addition, some target categories (e.g. elder women) would like to be getting early warnings through "traditional" broadcast media and sirens rather than receiving information by SMS or smartphone apps, hence suggesting the need of modulating EWS from actual conditions of recipients (age, education, media channels availability and literacy etc.).

ESC2018-S35-1041

THE ALGERIAN MARGIN: ONE OF THE MAIN TSUNAMIGENIC AREA IN THE WESTERN MEDITERRANEAN REGION

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In the western Mediterranean region, the algerian margin remains one the main tusnamigenic area. In the past, several tsunamis related to important Algerian seismic events have been reported as the one of Algiers 1365, Oran 1790 or Djidjelli in 1856. During the instrumental seismic period, the El Asnam event of October 1980 and the recent Boumerdes earthquake of May 2003 are the well-known tsunamigenic events. Modelling of these events contribute to understand better their triggering, their propagation through the Mediterranean Sea and their impact. To understand better tsunamis along the Algerian margin, several marine surveys have been conducted mainly the Maradja surveys of 2003 and 2005 or the last Spiral survey in 2009. The main active faults identified from west to east and also the main marine slides areas suppose a high tsunamigenic potential mainly in the Annaba region, the Djidjelli region, the Béjaia region, the Algiers-Cherchell area or the Oran area. Today, data analysis of these surveys focus in more specific areas as the major Khayr Eddine fault system (Algiers) or the Annaba fault system (Eastern Algerian region) which could generate important tsunamis hitting the several South European coastlines as the Spanish, the French Mediterranean or the Italian ones.

ESC2018-S35-1062

PROBABILISTIC TSUNAMI HAZARD MAPPING IN THE NEAM REGION TSUMAPS-NEAM PROJECT

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Probabilistic Tsunami Hazard Assessment (PTHA) is an indispensable step toward long-term coastal planning and for effectively designing and using Tsunami Warning Systems. The TSUMAPS-NEAM project was devoted at producing the first region-wide long-term homogenous PTHA map from earthquake sources for the coastlines of the North-East Atlantic, the Mediterranean, and connected Seas (NEAM) region. The hazard assessment was built upon state-of-the-art procedures and standards, enriched by some rather innovative/experimental approaches such as: (1) the statistical treatment of potential seismic sources, combining all the available information (seismicity, moment tensors, tectonics), and considering earthquakes occurring on major crustal faults and subduction interfaces; (2) an intensive computational approach to tsunami generation and linear propagation across the sea up to an offshore fixed depth; (3) the use of approximations for shoaling and inundation, based on local bathymetry, and for tidal stages; and (4) the exploration of several alternatives for the basic input data and their parameters which produces a number of models that are treated through an ensemble uncertainty quantification. This presentation will summarize how the TSUMAPS-NEAM project achieved its goals, illustrate the PTHA online data, and discuss possible strategies for future PTHA efforts. The TSUMAPS-NEAM Team Agalos Apostolos, Agrebi Jaouadi Hedi, Attafi Kheireddine, Babeyko Andrey, Baptista Maria Ana, Basili Roberto, Ben Abdallah Samir, Benchekroun Sabah, Bouallegue Atef, Brizuela Beatriz, Canals Miquel , Carrilho Fernando, Glimsdal Sylfest, Hamdi Hassene, Harbitz Carl B., Herrero André, Hoechner Andreas, Iqbal Sarfraz, Lorito Stefano, Løvholt Finn, Maesano Francesco Emanuele, Murphy Shane,

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The TSUMAPS-NEAM Project (http://www.tsumaps-neam.eu/) was co-financed by the European Union Civil Protection Mechanism, Agreement Number: ECHO/SUB/2015/718568/PREV26

ESC2018-S35-1063

THE ITALIAN TSUNAMI ALERT CENTER (CAT) AT INGV

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The INGV Tsunami Alert Center (CAT-INGV) is one of the Tsunami Service Providers of the NEAMTWS IOC-UNESCO ICG, and is part of the "Sistema italiano per l'Allertamento Maremoti di origine sismica" (Italian System for seismic tsunami alerting, SiAM), officially constituted in 2017, after a Directive of the Prime Minister published on June, 5th. The national System is coordinated by the Italian Department of Civil Protection (DPC) and includes INGV, for tsunami hazard assessment and real time analysis and alerting (to Civil Protection), and ISPRA for sea-level data. All three Institutions cooperate for the definition of inundation areas. Operations of the Center have started experimentally in 2014, when INGV set up the CAT and started issuing messages as candidate Tsunami Service Provider (cTSP) in the NEAMTWS framework. The area of competence of CAT is the entire Mediterranean basin, and the alert messages are issued to several circum-Mediterranean countries and institutions and to the other c/TSPs operating in the area (namely, CENALT, KOERI, NOA, IPMA). CAT-INGV has been accredited as a NEAMTWS Tsunami Service Provider (TSP) in September 2016 and became operational at the national level on January 1st, 2017. CAT-INGV analyzes the global seismicity and issues real time warning messages for potentially tsunamigenic earthquakes, but limited to an internal list of recipients. This is done in order to test the procedures and continuously train the personnel on duty. Only for the Mediterranean region the alerts are sent officially to the subscribers. More than 900 events have been analyzed in the past three years for earthquakes worldwide, whereas eight earthquakes in the Mediterranean basin were processed (four in Greece-Turkey area, three in Italy, one in northwestern Africa). The tools at CAT-INGV include a rapid and robust procedure for the automatic estimate of earthquake parameters (Lomax and Michelini: see http://early-est.rm.ingv.it/warning.html), and the analysis of sea level data of the National Mareographic (RMN) network managed by ISPRA, as well as of the other networks in the Mediterranean. People on duty 7/24 guarantee the real time surveillance, assisted by a senior officer on-call. In this presentation we describe the current status of the CAT-INGV, reporting on the performance with earthquakes at global level and in the Mediterranean. In particular, we will describe the analysis of the two 2017 earthquakes in Greece-Turkey (Lesvos and Kos-Bodrum) for which first alert messages were issued by the CAT-INGV within 10 minutes from the earthquakes' occurrence. We will discuss the present challenges, that include a) the reduction of the time for the first alert issuance, particularly for local sources; b) the introduction of a Probabilistic Tsunami Forecast (PTF) in substitution of the presently used NEAMTWS Decision Matrix to compute the alert levels. Moreover, other activities include the study of tsunami risk perception in Italy, and the analysis of the responsibility/liability of the CAT-INGV personnel. While we write this abstract (April 2018) a coordinated activity among DPC, INGV and ISPRA is going on to define the inundation areas predicted on the basis of the tsunami hazard results from the TSUMAPS-NEAM project, that will serve as a basis for the guidelines addressed to local municipalities related to the tsunami risk governance.

ESC2018-S35-1064

THE RISKS OF RISK GOVERNANCE: LIABILITY OF SCIENTISTS IN TSUNAMI WARNING

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In recent years, several "natural" events have brought scientists, civil protection officers, local authorities, in front of some Courts. In Italy, the well known "Grandi Rischi" trial had sentenced in

2013 the so called "L'Aquila seven" (scientists and Civil Protection officers) to six years of jail in the first degree of judgment for manslaughter, after the 2009 earthquake in L'Aquila. One of them (the vice-head of Italian Civil Protection Dept.) was sentenced also in the Appeal verdict and finally by the Supreme Court. Other (criminal) trials have been or are being celebrated for other events, such as death of people and large damage during meteorological emergencies, avalanches, floods, volcano-related accidents. Most of these inquiries and trials are related to ineffective risk communication, due to inappropriate interviews (such as for L'Aquila case), or to untimely or incorrect warning issuance (such as for the 2010 Chilean and the 2011 Japanese tsunamis), or for an unclear distribution of responsibilities among the different operators of the risk management chain (as in the case of the Genova flood in 2011, where the Mayor was found guilty of manslaughter in the first degree and recently in the appeal trial). In the past ten years, in other countries (Chile, Japan, Spain and others) similar circumstances have brought different categories of experts to trials and in some cases to convictions, for earthquakes, tsunamis, volcanic eruptions, etc. The outline of each of these legal cases is different among the various countries, due to differences in the national law regulations. However, some general elements are common among the different cases. For tsunami warning, the risk of either a false alarm, an overestimate or an underestimate of the alert level is highly likely, due to large uncertainties that characterize the risk management during an emergency, and the very limited time available to release an alert message. In this framework, scientists are the first ring of the chain and are therefore highly exposed to the risk of being pursued in case of a real emergency. As recognized by the Tsunami Service Providers worldwide, the first necessary response is in following best practices and guidelines, and in the adoption of well established Standard Operational Procedures. These are needed as guiding tools for risk operators, and hopefully will serve to the prosecutors and to the judges to verify the correctness of the operators, including those having written the documents and those who have specifically released the alert message in the event of a tsunami alert. The Italian Tsunami Alert Center (CAT) is investigating the primary and secondary regulations for natural risks (and particularly the tsunami risk), in order to understand as well as possible, the responsibilities of each of the experts involved, trying to find solutions that might mitigate the risks, also considering the work done in other scientific fields where these issues have been faced since long time (such as in medical science and practice). One of the basic points on which we must rely is the existence of a common, well established, updated documentation according to the best science and experience. In the IOC-UNESCO framework, this has been done through the years with several general documents (as for instance the Global Service Definition Document, n. 130/2016), that contain precious indications on the best practice and the limitations of the methods and of the results. However, there are some specific issues that cannot be adopted in the same way and at the same time by the different TSPs, and this could rise some criticism and identification of liabilities in case of an alert. In the framework of NEAMTWS, a work is currently ongoing to update the relevant documents. Scope of this presentation is to stimulate a discussion on these topics among the NEAM (and possibly other ICGs) Tsunami Service Providers, as well as with all the people and Institutions working on this topic, possibly involving the European Commission to issue a common legislation as a guide the the national ones.

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SESSION 36

ESC2018-S36-95

EVIDENCE OF ROMAN EARTHQUAKE SURFACE FAULTING IN THE ARCHAEOLOGICAL SITE OF ST. VENERA AL POZZO (CATANIA, SICILY, SOUTHERN ITALY)

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We report a case of surface faulting on ancient man-made structures belonging to the archaeological site of St. Venera al Pozzo placed on the eastern flank of Mt. Etna volcano in eastern Sicily (southern Italy) through an analysis carried out with a multidisciplinary approach, which benefits from dialogs among history, archaeology, geology, geochemistry, geophysics and seismotectonics. This study provides new insights on the seismic history of Catania, which is characterized, on one hand, by numerous historical sources providing ample description of past volcanic events, but on the other hand, by only a vague picture of the local seismicity, especially in Antiquity. However, knowledge of the Catania seismic history can only be improved by combining historical data with archaeological and geological data, avoiding circular reasoning. Our investigations focused on finding evidence of coseismic damage on ancient structures discovered during archaeological excavations or in still standing monumental buildings. The site refers to an ancient statio mainly composed of both a thermal bath complex and a Roman factory, located in a territory very rich in natural water springs. Indeed, the presence of numerous water springs in the Greek period has favored the birth of a settlement where the cult of the associated deities was of great importance. The study area is affected by well-developed tectonic faults; indeed, some archeological ruins are cut by remarkable fractures, suggesting the occurrence of a capable fault zone across the area. Archaeological evidence of faulting on ancient remains always improves our knowledge on the seismicity and seismotectonics of regions, for which information about the historical seismicity as well as about the evidence of tectonic features is often scarce or uncertain. From an historical point of view, this area was continuously inhabited since 3000 BC due to the presence of copious sulphurous thermal springs, which are normally associated with tectonically active areas. Anomalous changes in the composition of gases emitted with water (mostly regarding CH4, H2S and CO2 contents) highlighted by the geochemical monitoring of these springs, suggest that the fault that damaged the archaeological site at least once in the past could be still active. Time constraints on earthquake occurrence in the past are inferred through the dating of buildings phases of the archaeological site. Evidence is linked to a strong earthquake that probably occurred in the Roman period, around mid-end of the 3rd century AD.

ESC2018-S36-96

THE 847 AD EARTHQUAKE: HISTORICAL SOURCES AND ARCHEOSEISMOLOGICAL INDICATIONS FOR A BETTER DEFINITION OF THE DAMAGING AREA

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This study provides deeper insights on our knowledge of the 847 AD earthquake through a critical review of historical written sources and new archaeological evidence that allow to characterize the effects of this earthquake in Central-Southern Italy (northern Campania, Molise and Latium). Our approach addresses the earthquake effects based on separate analysis of historical accounts and archaeological evidence, avoiding circular reasoning. The research has allowed to better define the area of maximum damaging through the territorial approach. The archaeoseismic evidence regards structural modifications carried in the St. Vincenzo Abbey (Isernia area, High Molise) shortly after the earthquake and documented by English excavations in 1990's, as well as some still visible evidence of deformation and collapse. The most significant evidence is the oriented collapse of a large wall, which connected the workshops area with the eastern corridor in the Abbey, in addition to minor damage as cracking in walls. Also in the basilica of Alvignano (High Volturno Plain, Campania) we surveyed deformed arches, tilted but still standing pillars, and partial rebuilding of the apsidal area. For the Isernia settlement,

unfortunately, archaeological data relative to destruction and following reconstruction of buildings have not been found. Conversely, historical sources report total destruction of the town. Although historical sources did not explicitly mention damage in Roma, the traces of the 847 AD earthquake have been largely documented in the archaeological excavations and seismological literature. Starting from the documented effects of earthquake shaking, a wide area of damage has been defined in northern Campania, Molise, and Latium, and includes the localities of Benevento, Ariano Irpino, Isernia, St. Vincenzo al Volturno, Cassino and Roma. The historical seismicity record indicates that several strong earthquakes occurred in this area. Some of these destructive seismic events (such as those occurred in 346 AD, 1349 AD, 1456 AD and 1805 AD), are reported by first-hand accounts and historical documents. The Medieval event targeted in our study seems very similar to the 1349 and 1456 earthquakes whose macroseismic and archeoseismic effects are better known than the ancient one. The younger earthquakes are documented by various scholars as multiple events with damaging effects comparable with the middle 9th century AD event, although the latter affected a smaller area.

ESC2018-S36-195

EARTHQUAKE HISTORY OF THE GREEK TEMPLES AT SELINUNTE, SW SICILY

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Selinunte, located at the south coast of western Sicily was one of the first ancient Greek colonies, underwent enormous building activity around 550 B.C.E. Within a short time span, at least nine classical temples were constructed, measuring in size from 100 to 4500 m2. Previous archeoseismological studies presented interpretations for at least two earthquakes that caused partial or complete destruction of some of the temples. However, identification of the earthquake sources has not yet been quantified and only speculations about the nature of the damaging processes were made. Historic reports describe a siege of Selinunte in 409 B.C.E. by the Carthaginians, and the degree of anthropogenic damage to the temples during the attack is also not clear. In this work we discuss preliminary results of the interdisciplinary SELINUS project. We chose three locations in Selinunte in close proximity to each other. The temples at these locations (La Gaggera Hill, Acropolis, and East Hill) varied in size and type of structures. We applied active and passive seismic in situ experiments, including the deployment of wireless seismic arrays, to better understand the seismic site effects, which in places proved to be particularly challenging due to the presence of a low velocity sand layer under a strong layer of calcarenite. Since each location has distinct seismic site effects, this study provides an interesting test case for quantitative archaeoseismological modeling with different earthquake scenarios of temples in close proximity. We combine the site effects with earthquake-source scenarios based on recent active tectonics and geomorphological studies, including offshore surveys, and with parametric discrete element models of temple buildings. The general dynamic behavior of these temple models is studied with analytic ground motion signals and synthetic seismograms of the selected earthquake scenarios. This approach does not resolve the question of when damage occurred but can distinguish degrees of probability among the tested earthquake scenarios. Because of the long, partially undocumented, excavation history of Selinunte, quantifying a time frame is difficult, but the method in this study makes good use of the differently-structured temples as large seismoscopes. Thus, we can test the plausibility of existing hypotheses about the damage process and better quantify the source parameters of potentially damaging earthquakes.

ESC2018-S36-243

SEISMIC AND DYNAMIC ASSESSMENT OF MONUMENTS MADE UP OF RIGID BLOCKS: NEPTUNE TEMPLE

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The paper describes the outcomes of a research aimed to investigate the dynamic response of monuments of architectural importance like the

temple of Neptune in Paestum (southern Italy), included in the World Heritage List. Despite the fact that this temple do still exist, it has to be pointed out that it is exposed to a medium seismic risk, being Paestum in a region characterized by such a high seismic activity. Moreover, the fact that the temple has survived until today, it does not mean that it will survive over time, taking into account the degradation of materials or the possible damage to natural or man - induced events. In this regard, it includes a knowledge of the aspects related to material conservation and static and seismic safety. An innovative methodology to respond to these needs of knowledge is the real time measuring of the dynamic behaviour. Only in this way it will be possible to identify the minimum intervention compatible with the criteria of the Venice Charter. This paper highlights the importance of the knowledge of the seismic and dynamic behaviour of such structures made up of rigid blocks, that are very recurring in many structures of monuments in Italy and all around the world. Even if the dynamic behaviour of a single block or a column, generally built by slender blocks, is presented and discussed in several theoretical studies, only few experimental data are instead available. The work describes an extensive experimental study on the behaviour of rigid blocks outlined by 1/3 slender ratio and using different base surface – drum interactions to assess the mechanical and dynamical characteristics like friction, impact restitution ratios, vibration periods and equivalent damping ratios. The obtained results, interpreted using a statistical analysis, have been compared with the ones carried out by theoretical formulations and, as case study, the Temple of Neptune is considered to preliminary assess the seismic risk against the overturning collapse of the columns.

ESC2018-S36-440

EARTHQUAKE BEHAVIOR OF ÇANAKKALE HISTORICAL CLOCK TOWER, NW TURKEY

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The Marmara Region was affected from destructive earthquakes since historical times. The North Anatolian Fault with 1,200 km length is the main source of the earthquakes in the region. In the last century, 1999 Kocaeli Earthquake (Mw 7.4) damaged residential and industrial areas of the large cities in Marmara. 24 May 2014 Gokceada earthquake (Mw 6.9) occurred in the northwestern Marmara region. Its epicenter located in the west of Gokceada Island, northern Aegean Sea at the western end of the North Anatolian Fault zone (NAFZ) that is one of the significant right-lateral strike-slip faults in the region. 2014 Gokceada earthquake was felt in Turkey, Greece and Bulgaria according to a report of Bogazici University - Kandilli Observatory and Earthquake Research Institute (BU-KOERI). The earthquake caused moderate damage to about 300 buildings (50 of them in Çanakkale city and 200 of them located in Gokceada Island) and slight damage at eight school buildings in the Marmara Region. Ground motions are observed by nationwide seismic networks by Prime Ministry Disaster and Emergency Management Authority, Republic of Turkey (AFAD). In this study, we used the strong ground motions record of 2014 Gokceada earthquake at 1701 AFAD station located in Çanakkale city center to analyze the dynamic behaviors of the Çanakkale Historical Clock Tower. Three dimensional discrete element code (3DEC) for dynamic behavior analyze is used to create the numerical structural model of Çanakkale Historical Clock Tower. The tower is studied in the inelastic range. Seismic behavior is simulated by means of 24 May 2014 Gokceada earthquake time histories. Assessment of its dynamic behavior is significant due to the expectation of a large event in the near future. This study shows the preliminary results of the dynamic nonlinear analysis of clock tower through finite difference principle and dynamic relaxation approach.

ESC2018-S36-441

SEISMIC RESPONSE OF THE ACROPOLIS OF ATHENS: ACCELEROMETRIC DATA, NUMERICAL MODELS AND THEORETICAL CONSIDERATIONS

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We discuss in this contribution the seismic response of the Acropolis of Athens (Greece) and part of its monumental elements by means of recorded seismic data and numerical modelling. Our dataset consists of earthquake and ambient vibration data acquired by the high-quality accelerometer array operated by the Institute of Geodynamics, National Observatory of Athens (NOA-IG), in collaboration with the Acropolis Restoration Service (YSMA). The array consists of 10 strong-motion sensors (Guralp CMG-5TD) recording in continuous mode on 24-bit digitisers and streaming in real-time to NOA-IG and YSMA. The Acropolis strong-motion network samples the main geological units constituting the hill - Athenian Schist, limestone and anthropic infill - and includes two sites devoted to monitoring monumental elements of the Parthenon. We compare the experimental amplification curves (SSRs with respect to a reference station located on Athenian Schist, HVSRs, 5%-damped SRs) with those obtained from numerical simulations of the seismic response of the hill. The simulations are carried out using the discontinuous Galerkin spectral element computer program SPEED, naturally oriented to the evaluation of multi-scale wave propagation problems. The 3D computational mesh is designed in CUBIT. The dominant features of site response are captured well by our simulations and further confirmed by analytical models: the fundamental frequency of the limestone rock outcrop is found at ~ 5-10 Hz, with amplification values up to 3-5 most likely controlled by weathering and fracturing; the site response on man-made infill is characterised by a multiplicity of maxima, with amplification up to 20; the foundation of the Parthenon mitigates effectively the dominant frequencies of site response of the limestone outcrop, possibly reducing the impact of local earthquakes at the site.

ESC2018-S36-510

COMPUTER-AIDED INVESTIGATION OF THE SEISMIC RESPONSE OF ANCIENT COLUMNS

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Strong earthquakes are common causes of destruction of ancient monuments, such as classical columns and colonnades. Ancient classical columns of great archaeological significance can be abundantly found in high seismicity areas in the Eastern Mediterranean. The seismic behaviour of these structures exhibits complicated rocking and sliding phenomena between the individual blocks of the structure that very rarely appear in modern structures. The investigation of the dynamic response of such monumental structures, combined with the research fields of paleoseismology and archaeoseismology, may reveal certain information from past strong earthquakes that have struck the respective regions. In this research work the seismic behaviour of ancient monumental structures with monolithic or multi-drum classical columns and colonnade systems is investigated. In particular, the Discrete Element Method (DEM) is utilized in the study of ancient columns under strong ground excitations, by simulating the individual rock blocks as distinct bodies. A specialized software application is developed and utilized, using a modern object-oriented programming language, in order to enable the effective simulation of multi-drum columns and colonnades. A number of parametric studies is performed in order to investigate the effect of excitation characteristics on the behaviour of multi-drum columns under harmonic and earthquake excitations.

ESC2018-S36-607

MICROTREMORS - A TOOL FOR STRENGTHENING RESILIENCE OF CULTURAL HERITAGE IN HERAKLION (CRETE, GREECE): THE SAINT MINAS CHURCH BELL TOWER

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The importance of strengthening resilience of cultural heritage against natural disasters has been annotated in the 2013 EU Civil Protection legislation and articulated in the 2015-2030 Sendai Framework, that is the successor instrument to the Hyogo Framework for Action (HFA) 2005-2015. In this direction, the global agenda 2030 for sustainable development proposes a new way to manage and prepare for disasters based on proactively managing risks and

fostering risk-informed sustainable development. For national and local levels, this new well stated framework, promotes the application of simple and low-cost early warning equipment and facilities. Moreover, non invasive methodological approaches for assessing seismic structural response - particularly for historical and monumental structures - are essential in a proactive managing strategy towards to the seismic risk resilience undertaken by the civil protection authorities. The contribution of local site conditions on the excitation of seismic ground motion has been well documented after destructive earthquake events worldwide (e.g Loma Prieta, 1989; Athens, 1999; L'Aquila, 2009 and the most recent earthquake 2016 in Norcia in Italy and Kos earthquake 2017 in Greece), while recent advances in soil-structure interaction highlight the importance of local site condition to the observed unequal spatial damage distribution. In addition, several studies have indicated structural failures due to the interaction with the surface fault rupture after the occurrence of earthquakes events (e.g. Kawashima 2001; Faccioli et al. 2008). The Port-au-Prince Cathedral in Haiti is an outstanding example of high rise bell tower failure due to complex rupture during the devastating (Mw 7.0) Haiti earthquake on the 12th January 2010. The Defterdar Mosque's minaret in Kos (Greece) collapsed after the recent 20th of July 2017 devastating (Mw 6.6) earthquake in the Aegean Sea. Considering the above and conforming to the Sendai framework, this study aims at assessing seismic structural response and potential soil-structure interaction of historical and monumental high rise structures in Heraklion (Crete), using ambient noise vibrations (microtremors). The main purpose of this study is to assess the frequencies of vibration using ambient noise recordings processed through Horizontal to Vertical Spectral ratio (HVSR) technique. The study gives prominence to the case study of Saint Minas Church bell tower – the highest and one of the most historically important church bell tower in the town of Heraklion. The geological setting of the studied historical and monumental structures is mainly characterized by Quaternary alluvial (Holocene) and Neogene (Pliocene) deposits - locally very loose deposits - and by the presence of large scale fault zones. The study highlights the importance of incorporating the determination of prone resonating buildings into urban planning towards to a proactive earthquake risk management planning of Crete, considering the high seismic activity of the area, the surface geology, the fault zones and the numerous historical and monumental structures. Therefore, non-invasive methodological approach, soil-structure interaction studies and the development of integrated tools for situational awareness are important issues in Crete with the purpose to support civil protection preparation and local operational decision making authorities of Crete in terms of earthquake disaster.

ACKNOWLEDGMENTS
This work is supported by the project HELPOS (MIS 5002697) which is implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the EU.

ESC2018-S36-659

HERITAGE AND EARTHQUAKES

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Historic technical solutions have being used to consolidate the damages caused by earthquakes in so many countries, during centuries. In places where people wants to remain, as they have their lives, for economic and cultural reasons. Before industrial revolution, the construction systems were adapted to the materials and way of doing of the place. But when modern materials and modern construction systems appeared, the compatibility between the old systems and the new methods of reinforcement, disappeared in many cases. The last earthquakes in Abruzzos, in Italy, showed us what happened when the reinforced concrete has being used everywhere, without taking notice of compatibility and reversibility. We have examples in l´ Aquila, Acciano…and specially in Onna. In this work we will like to give notice of the new techniques and technologies used in these last years, in some small villages of Abruzzos, employing the concepts of historic consolidation and compatibility to the new materials and construction systems.

ESC2018-S36-751

INVESTIGATING THE DYNAMIC BEHAVIOR OF HISTORICAL WATCH TOWERS IN MALTA AND GOZO

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Seventeenth century coastal watch towers, which are part of the Maltese cultural heritage, are at risk due to natural processes such as coastal weathering, erosion and land movement. In some cases, this makes them even more vulnerable to earthquake ground shaking and thus subjected to a possible considerable seismic risk. In this study, we present the results related to seismic vulnerability of these significant cultural heritage sites. In order to do so, the dynamic characteristics of these towers as well as soil-structure interaction were investigated. The three chosen towers were Isopu Tower and Dwejra Tower (located in Gozo) and the Ghajn Tuffieha Tower (located in Malta). Measurements of ambient noise were recorded inside each tower at each level. The towers' fundamental frequencies were determined from the Horizontal-to-Vertical Spectral Ratio and the Horizontal-to-Horizontal Spectral Ratio techniques. In addition to this, "free-field" measurements were also taken around the towers in order to study the ground response and also the soil-structure interaction. Based on a geometric survey, 3D CAD models of each watch tower were built that were subsequently employed to build the finite element models. To this aim the commercial code ANSYS was employed. To properly investigate the effect of seismic loading on these historical towers, synthetic seismograms (for different magnitude and distances) were computed, taking into account also the local site conditions, and applied as input to the base of the towers.

ESC2018-S36-810

ARCHAEOLOGICAL EVIDENCE OF SEISMIC DAMAGE IN OSTIA ANTICA

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Damage to ancient buildings is a major source of information about the parameters of ancient earthquakes. Cracks in survivor structures, as off plumb of original side walls and collapse profiles, represent a unique and useful index of investigation to highlight the most serious seismic events that affected an archaeological site. Ostia Antica is located in the Mediterranean region, a region characterized by a high seismicity. During its millenary history, the ancient Roman town has been affected by natural degradation, progressive prolonged abandonment, lack maintenance, human damage and natural calamities. The original position or exact collapses modalities sequence have been modified by ancient spoliation to reuse building materials and has lacked a critical structural interpretation during the past excavations. Fortunately, various traces of seismic shaking have been preserved on the ancient remains after their burial and provide us a mean to recognize possible seismic deformations. Excavation journals support suppositions dynamic collapses and on seismic wave propagation. In this contribution, we present archaeological evidence of seismic damage in the ancient Roman town of Ostia performing structural analysis on damaged buildings based on an application of the principles of mechanical analysis. In the analysis of some relevant failure cases of masonry structures, the collapse dynamic is illustrated. The richness and variety of observable deformed structures in situ allow us as an interdisciplinary team to re-examine the effects and causes of the collapses through mechanical perspectives. The adoption of interpretation criteria of mechanical analysis can result useful to collect, quantify and measure the large number of collapses preserved in situ.

ESC2018-S36-940

LANDSLIDE PROCESSES AND EARTHQUAKE DAMAGE AT GHAJN HADID TOWER (MALTA) INVESTIGATED THROUGH AMBIENT NOISE ANALYSIS

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Ghajn Hadid Tower represents an important cultural heritage site of the island of Malta (Central Mediterranean Sea). This tower was built in 1658 on the Selmun Promontory (Northern Malta) by the Grand Master Martin de Redin as the first of the thirteen watchtowers distributed all along the coastline of the Maltese Archipelago. Ghajn Hadid Tower was severely damaged on October 12th 1856 by the Crete earthquake (MW 7.7), which caused damage to several buildings on the Maltese Archipelago. Currently only its ruins are preserved. The Selmun Promontory and, in particular, the area where the Ghajn Hadid Tower ruins stand, are involved in a significant landslide process as testified by the large block-size talus at its bottom and by the dense joint net clearly visible at the top of the promontory. Such a landslide process is related to the geological succession of the Selmun area. The over-position of a stiff rock formation (Upper Coralline Limestone, UCL) on a plastic deposit (Blue Clay, BC) leads to a large lateral spreading phenomenon: the horizontal deformation affecting the clays induces fracturing of the overlying stiff rock and development of joints. Consequently, the edges of the stiff rock plateau are bordered by jointed unstable cliffs, favouring the detachment of single rock blocks by the typical gravity-induced instability mechanisms (i.e. toppling, sliding and falling). During 2015 and 2016, field activities were carried out to investigate a possible relation between the landslide process and the damage of Ghajn Hadid Tower due to the Crete earthquake. Detailed engineering geological field surveys were carried out to define the geological setting of the area and to obtain the mechanical properties of the jointed rock mass. In particular, such surveys have demonstrated a main system of sub-vertical joints in the tower zone, characterised by a strike parallel to the plateau edge direction (mean dip direction 330°, strike 60°), with an important joint that can be inferred as passing exactly under Ghajn Hadid Tower. At the same time, seismic ambient noise was recorded in 116 single-station measurement points over a wide area on both unstable and stable regions, with the highest number of stations distributed around Ghajn Hadid Tower. The 3-component time histories were processed both by the Horizontal-to-Vertical Spectra Ratio (HVSR) analysis (Nakamura, 1989) and in terms of polarization and ellipticity of the particle motion by the WAVEPOL package (Burjánek et al., 2012). All the stations located on the UCL plateau show HVSR curves characterised by a ubiquitous resonance peak in a frequency between 1.5 and 2.0 Hz followed by a sharp dip of the spectral ratio. This peak can be considered representative of the fundamental frequency of the site (f0) since it is always present in the Maltese Archipelago where the complete sedimentary sequence outcrops. In addition, the HVSR curves obtained on the unstable zones show significant further resonance peaks at higher frequency that are not present in the measurements carried out on the stable zone. In particular, the Ghajn Hadid Tower area is characterised by a prevalent HVSR peak at frequency around 3.5 Hz. The polarization analysis confirms the features observed in the HVSR analysis results and provides additional evidence to characterise the seismic response of the Ghajn Hadid Tower zone. The frequencies associated with the first peak of the HVSR(f) function do not show evidence of polarization and linearity of the particle motion in any station, confirming the hypothesis that this peak is mainly related to the stratigraphic setting (i.e. 1D resonance effect). On the other hand, all the measurements carried out near Ghajn Hadid Tower show strong directivity effects as well as a strong polarization of the particle motion at 3.3-3.5 Hz, the same frequency range characterised by a peak in the HVSR analysis. The particle motion polarization ranges through azimuthal values between 135° and 150°, values similar to the dip direction of the joint system prevalent in the zone. In conclusion, despite a dense net of open fractures, the Ghajn Hadid Tower zone is characterised by a uniform seismic response that seems to be related to the vibrational behaviour of a unique unstable rock block. In the light of this, it is possible to conjecture that the damage of the tower was due to the interaction between the seismic waves and the polarized resonance frequency of the rock blocks composing this area, which favoured displacement along pre-existent and/or new joints and induced the masonry collapse. Such a result can provide a basis for designing consolidation interventions and/or monitoring networks for early warning, in the framework of strategies devoted to ensure safety of tourists as well as cultural heritage preservation.

ESC2018-S36-987

CASE STUDY ABOUT THE SEISMIC BEHAVIOR AND POSSIBLE RETROFIT OF HISTORICAL MASONRY MINARET

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The paper deals with the dynamic behaviour and proposed retrofit method of a block masonry minaret, towerlike structure, of a historical mosque in Istanbul. There are large number of historical mosques and large number of minarets which were built since Ottoman Empire times. Since Turkey located in highly seismic zone, the probable damage to the masonry minarets should be determined and if necessary, safety measures should be considered. It is engineering communities' responsibility to preserve the existing cultural and built heritage by using state-of-the art science, knowledge and information. To achieve this objective, the minaret of historical mosque in Istanbul is chosen and 3D finite element model of structure prepared to obtain probable lateral displacements, crack pattern and failure modes under seismic loads. The problem becomes more complex when the dynamic analyses are also involved. However, after the developments in the dynamic testing of structures and computational methods in structural analysis, studies in this field have led some significant results about the mechanical behaviour of the old buildings. These types of studies are essential not only in protection/retrofit viewpoint but also assessment of similar ancient/historical towerlike structures. The results obtained from the numerical analysis presented have shown that the greatest damage accumulated near the base and the lower part of the minaret and FRP or FRCM material wrapped along and around these critical cross sections improves the lateral behaviour and the results are promising in terms of seismic protection of these heritages by using minimised intervention on the structure.

ESC2018-S36-990

EVALUATION OF 1939 ERZINCAN EARTHQUAKE DYNAMIC BEHAVIOUR OF ERZINCAN DE?IRMENLIKöY CHURCH OVER THE ABSCISSA DAMAGE

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In this study, dynamic behaviour of Erzincan De?irmenliköy Church abscissa of which is mentioned to collapse during 1939 Erzincan Earthquake is evaluated. The only formal document related to the church building is defined to be the registration card. Any study related to the structural behaviour of the church is encountered in the literature. Primarily, information about the church is collected and architectural drawings are prepared. Material properties are defined by experimental methods and the support of the literature. Operational modal analysis is done in-situ in order to define modal shapes and modal frequencies of the structure. Considering the results obtained by the operational modal analysis theoretical modal which will be the basis for dynamic analysis is calibrated. When final material properties are obtained, the collapsed abscissa part of the church is added to the model. Dynamic analysis is carried out in on the model with abscissa in order to evaluate the thesis which states the collapse of the abscissa during 1939 Erzincan Earthquake. For the dynamic analysis, 1992 Erzincan Earthquake records are used since there is no numerical record for 1939 Erzincan Earthquake. At the end of the study, it is concluded that; the abscissa did not collapse during the earthquake, damage over the abscissa and the church connection area was occurred, and this damage might progress in time and result in the separation of the abscissa from the structure and end up with total collapse of the abscissa.

ESC2018-S36-995

AN EVALUATION ON EFFECTS OF HIGH LEVEL OF SOUND ON HISTORIC STRUCTURES EXAMPLES OF ERZURUM LALA MUSTAFA PASHA MOSQUE AND YAKUTIYE MADRASAH

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The approach of keeping the architectural heritage of Anatolian peninsula alive and moving them to the future is appearing one of the widely adopted method of protection. During the function imposing phases of historic structures,

lots of monumental buildings are hosting massive events either in their large inside places or on their large scale open spaces at the centre of which themselves stand. As a result of music broadcasting, speeches, and etc. activities realized in massive events; production of high level of sound is frequently observed. If this high level of sound is not controlled, it may reach to the levels that can damage the historic structure. Because of this phenomenon, sound level limits have been stated in national and international standards in order to avoid detrimental effects of the sound which spreads in the atmosphere as waves. Writers of herein manuscript have searched effects of high level of sound on historic structures within the research project 114M280 that was supported by TÜBITAK. Within the concept of the study, two historic structures located in Erzurum city centre were investigated: first one is the Yakutiye Madrasah of 14th century Ilhanl period which is currently serving as museum and the second is 16th century Ottoman era product of Lala Mustafa Pasha Mosque which is still functional. As an important part of the research, sound level measurements in accordance with national standard conditions were repeatedly done in and around the related historic structures during normal days and as well as during the times when massive events were realized. Obtained data was compared by that of national standard limit value stated for historic structures. In addition to this, acoustical analysis on mathematical model of Yakutiye Madrasah which was verified through operational modal analysis was planned. At the end of the study, it was found out that during the busy days of massive events both historic structures were subjected to sound levels which were defined to be quite higher than that of the standard limit of 55 dbA. Because of this it was concluded that; high level of sound producing massive events should not be permitted in and around the investigated historic structures, by taking necessary precautions for normal days the level of the sound can be lowered than that of standard limit and hence, the structures may be protected against detrimental effects of the sound. Keywords: Erzurum, sound intensity, dbA, Lala Mustafa Pasha Mosque, Yakutiye Madrasah

ESC2018-S36-998

GEOPHYSICAL INVESTIGATIONS AT THE MNAJDRA TEMPLES UNESCO WORLD HERITAGE SITE (MALTA)

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Mnajdra is a megalithic temple complex located in the south of Malta. It consists of three buildings facing a common oval forecourt and listed as a UNESCO World Heritage Site since 1992. Mnajdra's Central temple (as well as the small one on the eastern side) is built on an artificial platform while the Lower Temple is built directly on hard rock. In this study, several single station ambient vibration measurements were performed as well as seismic array measurements, from which dispersion curves were extracted and analyzed (mainly using the Extended Spatial Auto-Correlation technique). The latter was used to characterize the velocities of the limestone formation outcropping at the site. Single station measurements were used to map the thickness of the artificial platform as well as the depth of the infill between the stone walls. Results were also compared with the ground penetrating radar survey taken in 2008. Several measurements were also taken on single monoliths constituting the temple walls and experimental observations were compared with the Finite Element method results.

ESC2018-S36-999

AN INVESTIGATION ON EFFECTS OF TRAFFIC INDUCED GROUND VIBRATIONS ON HISTORIC STRUCTURES EXAMPLES OF ERZURUM LALA MUSTAFA PASHA MOSQUE AND YAKUTIYE MADRASAH

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Anatolian peninsula hosted numerous civilisations during the centuries and carefully hid existence prints of each era. On almost each point of our occupation area, there exist numbers of historic structures, each of which is unique, from civilisations like Byzantine, Ilhanl, Artuklu, Seljuks and Ottomans. Our primary mission is to protect and carry our architectural heritage to the future

by civil engineering point of view. As a result of modern urban life, our centuries old historic structures were located at the city centres; neighbouring to highways of high density traffic. Writers of herein manuscript investigated effects of ground vibrations created by moving vehicles of the traffic on historic structures within the research project 114M280 supported by TÜBITAK. Within the concept of the study, two important historic structures which are located at the city centre of Erzurum and surrounded by the streets over which most dense traffic flows of the city are observed were considered. These structures are Yakutiye Madrasah dated to 14th century Ilhanl period and Lala Mustafa Pasha Mosque of 16th century of Ottoman era. In this study, together with simultaneous traffic count on main streets, ground vibration measurements were taken on several points located in between historic structure and the street which is the vibration source. Since Turkey has no national standard for performance evaluation in this area, the comparison was done in between the maximum PPV values which reached to the outer wall of the structure and that of damage limit values of the referred international standards. In addition; dynamic analysis was carried out on OMA calibrated structural model of Lala Mustafa Pasha Mosque by using recorded traffic induced ground vibrations. At the end of the study it was defined that; measured maximum PPV values were under the damage limits of the international standards and stresses obtained by structural model analysis did not reach the related material strength values.
Keywords: Erzurum, traffic induced vibration, PPV, Lala Mustafa Pasha Mosque, Yakutiye Madrasah

ESC2018-S36-1035

THE RUINS OF THE BASILICA OF MAXENTIUS IN ROME - A RESULT OF SEISMIC EVENTS ALREADY IN LATE ANTIQUITY?

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The history of the Basilica of Maxentius in Rome, built in the 4th century A.D., and its location at a sensitive point between the Roman Forum and the Colosseum, has moved and inspired artists and researchers for centuries. Restoration work done on the ruins of the monument during the Great Jubilee in 2000 included building-archaeology investigations under a project funded by the Fritz Thyssen Foundation, Cologne (TU Berlin, Soprintendenza Archeologica di Roma and Università di Roma “La Sapienza”). As a “by-product” of the classical architectural-historical analyses of the Basilica of Maxentius it was possible to gain a number of insights into the process of its turning into the ruin, including its connections with seismic events in Rome in Late Antiquity and the early Middle Ages. So far, the two years most favoured by researchers for the basilica´s collapse are 847 and 1349, the latter being the year when Rome was shaken by what was probably the most severe earthquake it has ever known. In the course of the documentation and analysis of the monument’s structure, it was discovered that some sections of medieval architecture, whose type of masonry can be dated back to around 1100, was built into the space left by the already-destroyed parts of the basilica’s walls. Since these walls occupied parts of the statically-essential support areas for the side aisle vaults, it can be assumed, that during the construction of these structures, both parts of the southern façade and vaulted sections of the southern side aisle (and thus, in a kind of domino effect, probably also the statically-dependent areas of the nave) had already fallen in, too. The chronological assignment of post-antique building activities in this area could therefore provide a terminus ante quem of the 11th/latest 12th century for at least the partial collapse of the vaults. It is therefore highly doubtful that the earthquake of the 14th century was the main trigger of the ruining. In addition, in several places in the north and east of the complex, the closing of windows and secondary supporting structures can be proven; the masonry technology and building material of which suggest that extensive structural interventions were made in as early as the 6th and 7th centuries. An unexpected scene emerges here, namely, that as far back as this, the eastern part of the basilica at least could have been already severely restricted or its original function abandoned in this time. Particularly noteworthy is the use of various reused material and entire fragments of walls and vaults were used in the secondary walling up. Some of this material is a clear match with the material characteristics defined for the basilica´s construction. The question therefore inevitably arises as to whether material from the vaults of

the Basilica of Maxentius itself could have been used in the secondary filling of the openings – a material that would by definition only have been found in the debris of the collapsed building. Keeping to this hypothesis and endeavouring to determine if seismic triggers would have been possible before 847, two earthquakes mentioned in the "Fasti Vindobonenses Posteriores" (Vienna, Nat. Bibl. 3416) 443 and 508 A.D., would be potential candidates. In this context, the significance of the result of recent archaeological research on the Fori Imperiali is gaining in importance: an inscription uncovered on the Augustus Forum could prove that between 486 and 546 A.D. parts of the temple of Mars Ultor had already fallen in. Taking into account the proximity of the Augustus Forum and the Basilica of Maxentius it does not seem impossible that the catastrophe that destroyed the Forum Temple could also have been the cause of the collapse of (parts of) the basilica. The suggested period placing the (partial) ruining of the Basilica of Maxentius as far back as the 5th or 6th century could have a not unimportant impact on the interpretation of the history of urban development of Late Antiquity and early medieval Rome. However, these statements are based solely on observations and interpretations of the monument itself. We therefore hope that the seismology experts will provide us exciting material for discussion from a different perspective!

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SESSION 37

ESC2018-S37-37

EARTHQUAKES IN THE WEST OF SCOTLAND IN 1732: AN EXERCISE IN SOURCE CRITIQUE

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In various modern studies of British earthquakes, different dates and interpretations are assigned to earthquakes in Western Scotland in the year 1732, making it a case ripe for reinvestigation with a suitable source critique. Contemporary sources reveal two events, two days apart, one similar to the 1999 earthquake off the coast of the Isle of Arran, the other near Glasgow, similar to one that occurred just over twenty years later. References to a larger event felt the length of the Scottish coast on 29 November can be shown to be due to a misreading of Mallet, at least as regards the date. The original source for this event, which fails to mention a precise date, it is not affirmed by any contemporary evidence, and is highly suspicious. While it would be convenient to combine all the reports into a single earthquake, there are insufficient grounds for doing so, and the final conclusion is that two separate smallish earthquakes occurred, with a third event being uncertain.

ESC2018-S37-118

RESEARCH ON SEISMIC DENSITY AND ITS RELATIONSHIP WITH STRONG HISTORICAL EARTHQUAKES IN CHINA

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In practice, how to determine the parameters of strong historical earthquakes is sometime still a big problem, especially when we only have few intensity points. Generally, it is difficult to solve the problem with traditional methods, because we cannot expect to find newfound historical archives to add intensity points. Recent years, we try a new approach to solve this kind problem. The idea is that we first analyze the seismic pattern of instrumental recorded moderate and small earthquakes quantitatively. We try to make clear the relationship between the pattern and the strong historical earthquakes which having credible parameters. Finally, we utilize the quantitative seismic pattern to find right epicenter of the strong historical earthquakes with few intensity points. We introduce a metric known as the 'seismic density index' that quantifies the degree of clustering of moderate and small earthquakes. For a given map location, this multi-dimensional index depends on the number of events, their magnitudes, and the distances to the locations of the surrounding population of earthquakes. Firstly, we apply the method to Beijing, where have both high-quality modern instrumental catalogue and credible strong historical earthquakes. We then compare the seismic index with the epicenters of six strong historical earthquakes. Here we have examined that there are always persistent seismic clusters around the epicenters of strong historical earthquakes (Wang J., et al., 2017). This persistence has also been observed on a much smaller scale in the location of acoustic emissions (AE) during cyclic loading in laboratory rock deformation tests (Sondergeld, et al., 1981). Accordingly, the seismic density index is more likely to be picking out the location of persistent weaknesses in the lithosphere. Then we apply this method to Kunming, which is the capital city of Yunnan Province, located in Southwestern China. The history of Kunming is shorter than that in Beijing. The earliest recorded strong historical earthquake occurred in 1500 AD with few intensity points. The largest one occurred in 1833 with not enough intensity points around meizoseismal area. There are controversies about the epicenters of the two strong historical earthquakes for a long time. With the seismic density index, we have solved the problems just now. Our results imply zones of high seismic density index could be used in principle to indicate the location of unrecorded historical of palaeo-seismic events, in China and elsewhere. Key words: Seismicity; Historical Earthquakes; Earthquake Clustering.

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ESC2018-S37-133

ON THE STUDY OF HISTORICAL EARTHQUAKES ATTESTED TO BY SPARSE DATA

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Sparsity of data may complicate the analysis of historical earthquakes at every stage. Intensities are estimated on the basis of written documentary materials of various provenance and purpose, uncovered in archives and libraries. Modest amounts of textual information cannot be critically collated. Inadequate or skewed documentation of earthquake effects, and poor survival of documents to the present time, lead to uncertain intensities or only descriptive notations. Written documents and earthquake parameters may appear incompatible, but parameters are customarily derived for historical earthquakes when compiling parametric earthquake catalogues. The main focus of the presentation is on the parameters of historical earthquakes that are derived on the basis of sparse sets of intensity data. Here sparsity means few intensity data points per earthquake. The accuracy of parameters is important input for studies of regional seismotectonics and seismic hazard. Extensive simulations have been carried out to obtain insight into the topic.

ESC2018-S37-178

INTENSITY PREDICTION EQUATIONS AS AN INTENSITY PROXY FOR HISTORICAL EARTHQUAKES

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Equations that predict ground-shaking distribution (Ground Motion Prediction Equations -GMPEs) expressed in terms of PGA, PGV or intensity and as a function of magnitude and distance, are key for hazard and risk assessment, providing information beyond focal parameters. Real-time ShakeMaps provide a prompt assessment of the scope and impact of an event and also aid in decision making, through estimation of losses by calculating the extent of the affected area, which is the area that likely experiences the highest intensities when an earthquake occurs. GMPEs also play an important role in the development of seismic hazard maps, public information and education. Intensity Prediction Equations (IPEs) can also be used to study historical earthquakes, where there are usually difficulties in gathering information, testimonies and identifying consequences of the event. The purpose of this work is to test the IPE for Austria with historical earthquakes and compare the results with recent earthquakes with similar epicenters. Therefore, three strong historical earthquakes were selected from the Austrian database: these were in Hall in Tirol (1670 – with an epicentral intensity (I_0) of VIII), Wiener Neustadt (1768 – with I_0=VII), and the Schwadorf earthquake (1927 – with I_0=VIII). In agreement with this selection, three earthquakes with similar locations were selected in the period from January 1992 to February 2018: Schwadorf (21.11.2001 with I_0=V and local magnitude (ml) of 3.5), Wiener Neustadt (25.07.2005 with I_0=V-VI and m_l=3.5), and an earthquake in Hall in Tirol (09.08.2013 with I_0=V-VI and m_l=3.7).

ESC2018-S37-186

EARTHQUAKE CATALOGUE FOR SOUTHWESTERN GERMANY

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In a five years project we have completed the earthquake catalogue for Baden-Wuerttemberg / Southwestern Germany. The “LED catalogue” covers the time span of the last millennium. For the first time in Germany, a systematic and comprehensive search for information about historical earthquakes has been carried out tracing back information to the primary sources whenever possible. We visited more than 30 archives and libraries on-site, and many others online. 1100 relevant historical sources from the 15th to the 19th century could be found – of which 700 were unknown to seismology before – referring to 3000 historical intensity data points (IDP) and to more than 400 historical earthquakes. We found earthquake information in official records, chronicles, church registers, sermons,

diaries, letters and newspapers, for example. We also implemented processed seismological data from existing regional and national catalogues of Germany, Switzerland and France, from seismological bulletins and collections as well as from unpublished documents. Digital intensity data point information (IDP) was consistently determined using the EMS-98 scale, giving special emphasis to a well-balanced use of the scale over historical and modern times. In particular, we considered the incompleteness of historical information. A guideline paper has been written documenting the best practice of intensity assessment based on EMS principles under historical, social, engineering and seismological aspects. Examples for determination of maximum and epicentral intensity as well as epicentre location and source time of historical earthquakes will be given. For the 20th century, we re-evaluated a collection of 25.000 macroseismic questionnaires available in SW-Germany using the EMS scale, whereby consistency of intensity assessment could be achieved. Instrumental epicentres were preferred over macroseismic ones whenever proven to be more reliable. A data base now hosts the entire catalogue, including IDP data and all relevant information about the sources. The LED catalogue currently contains about 10.000 earthquakes within the project area. Depending on catalogue completeness, conclusions about earthquake activity rates over the past five centuries can be derived. Recommendations for similar work in other parts of Germany will be given.

ESC2018-S37-200

USING DAMAGE EVALUATION FORMS FOR A HISTORICAL EARTHQUAKE – A CASE OF 29 JANUARY 1917 BREŽICE, SLOVENIA, EARTHQUAKE

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The earthquake had happened near town of Brežice (today in Slovenia, at that time in Styria, Austro-Hungarian Monarchy) on 29 January at 08.22 UTC (09.22 local time). At least two persons were killed and many were wounded; hundreds of people were left homeless in a very difficult situation due to the World War I, poverty and low winter temperatures. After the earthquake, the reparation process was difficult, as the building material was needed on the frontlines, and majority of able-bodied men were serving in the army away from homes. A new study was performed in 2016 and 2017 in order to collect and analyze the macroseismic data for this earthquake. Historical and seismological archives, as well as libraries and museum collections, were searched and many new data sources were found: photographs, macroseismic questionnaires, eyewitness reports, newspaper reports, as well as numerous secondary sources. A collection of 14 black and white photographs of the earthquake damage in Brežice are kept Museum of Posavje. Some photographs and drawings were published in newspapers or studies, as well as In some books. The Earthquake Commission of the Austrian Academy of Sciences was in charge of collecting macroseismic data at the time of the 1917 Brežice earthquake. The questionnaires for today's Slovenia and Austria are not preserved, and those for Croatia are kept in the archive of Department of Geophysics at Faculty of Science, University of Zagreb. For this study 35 different newspapers from two (now 5) countries were checked and the articles about the earthquake were published in 26 among them. In total, there are 323 articles about this earthquake effects, voluntary aid contributions and rebuilding. The most interesting data source was by all means the folder with handwritten damage evaluation lists. It was produced by the expert teams, sent by the government, in the months after the earthquake. The lists that are today preserved in The Archives of the Republic of Slovenia in Ljubljana include the descriptions of the inspected buildings, as well as the descriptions of damage for Brežice, its suburbs and 21 nearby localities. The lists consist of the following data: house number, the name of the owner, size of the building/s (in m2), description of the building/s, and description of the damage and the evaluation of the expenses (in Krona). The experts that were inspecting the buildings wrote concise descriptions of buildings (materials, floors, roof, number of rooms, sometimes quality of workmanship etc.). This has enabled us to convert the data from the damage lists into the input for EMS-98 intensity evaluation, although the purpose of these documents was not estimating the intensity, but collecting the data on damage suffered by the owners of the real estate. However, the interpretation was not always

straightforward due to the following reasons. As each owner used to have a building for residence and a few more for livestock, woods, pantry, shed etc. the descriptions of all of them are often merged. Moreover, the description of damage is often cryptic (e.g. "Chimneys, cracks in the walls, plaster") and can mean a wide range of damage types, from cracks to destruction. The column with the estimated cost of repair is not really helpful, as the sums vary very much and are not consistent with the description of damage. In many cases the buildings were of mixed material – one part masonry, other part wooden; roofs partly covered by tiles and partly by straw; floors partly earthen and partly of wood or stone. The damage lists do not give the information about the number of buildings in each settlement. Therefore a largest house number mentioned in the reports, combined with the total number of mentioned edifices, was taken as a conservative approximation, when doing the statistics for EMS-98 evaluations. Nevertheless, the documents about the damage caused by Brežice earthquake were extremely valuable for seismologists to get a detailed insight into the situation in the epicentral area and also helped to get better constrained intensity estimates in some localities. According to the new study, the maximum intensity of this earthquake was VIII EMS-98 (in four localities), and its macroseismic magnitude 5.0. It was the strongest earthquake with the epicentre in Slovenia in XX century by means of maximum intensity.

ESC2018-S37-206

RE-ASSESSMENT OF THE SEISMICITY IN SWITZERLAND IN THE PRE- AND EARLY INSTRUMENTAL PERIOD OF SCIENTIFIC EARTHQUAKE OBSERVATION

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The next logical step in the process of improving historical earthquake information for Switzerland after the compilation of the Swiss Earthquake Catalogue ECOS-09 is the historical-critical revision of the Swiss earthquake catalogue for the period from 1878 to 1974. A special focus is set on intermediate-size events of epicentral intensities in the range IV–VI (EMS-98). The revision of this period is presently carried out in an interdisciplinary project funded by the Swiss National Science Foundation (2015–2019). The period in question covers the pre-instrumental [1878–1912] and early-instrumental period [1913–1974] of systematic scientific earthquake observation in Switzerland. Due to their relatively high frequency of occurrence and the increased production of scientific data in this period, the examined event class provides a broad dataset to improve our understanding of seismicity and source-depth distributions as an important element for future seismic hazard and risk assessments. The re-assessment of the pre- and early instrumental period of scientific earthquake observation in Switzerland involves a multi-tiered analysis of a broad variety of sources containing both qualitative and quantitative data: descriptive as well as parameterized macroseismic information on the one side and historical seismograms and instrumental parameters on the other. The macroseismic re-assessment of events in question according to the European Macroseismic Scale EMS-98 is based on descriptive primary information documented in scientific and non-scientific sources. This data is completed by the integration of original intensity parameters that had been assessed by earlier generations of scientists, generally in the Rossi-Forel scale in the form of tables and macroseismic maps. The maps have been preserved in an unpublished historical "Macroseismic Atlas" covering the whole period of examination. Because the Swiss seismologists adhered to the Rossi-Forel scale from the 1880s to the 1960s, this set of data consists of one of the longest lasting relatively homogeneous set of macroseismic data. The examination of the historical practice of data production and the comparison of this historical macroseismic dataset with macroseismic re-assessment in the modern EMS-98 scale can provide valuable insights for an empirical scale conversion. This may enable us to use the historical assessments in Rossi-Forel (for most of which the primary data have been lost and cannot be reproduced in EMS-98) in the ongoing catalogue revision process. In addition to the macroseismic method, the historical seismograms recorded by the Swiss network of mechanical seismographs are analyzed as a complementary source of information for the characterization of 20th century seismicity. In 1911, the first instrumental earthquake observatory was

installed and in the 1920s a network of sensitive mechanical instruments designed at the SED was set up, that was kept in place for more than 40 years. The three (later four) very similar devices were equipped with inert masses of up to 21 tons that gave them a particularly large sensitivity allowing not only the study of global events as it was common at that time, but also weak and intermediate local and regional earthquakes. The very large repository of historical seismograms recorded by the Swiss seismograph network held by ETH library is being classified and made accessible in a common project with the ETH-library archives, and all available recordings of events that have potentially been felt in Switzerland have been scanned in high resolution. The macroseismic method can therefore be supplemented by an instrumental approach in a next step.

ESC2018-S37-229

SHAKEMAP VERSION 4 AND ITS APPLICATIONS TO HISTORICAL EARTHQUAKES

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The U.S. Geological Survey's ShakeMap post-earthquake information and scenario tool has been significantly enhanced in a recent upgrade (Version 4). ShakeMap Version 4.0 is a redesign of the entire ShakeMap system in the Python programming language. ShakeMap 4.0 significantly improves the ground-motion interpolation scheme based on the conditional multivariate normal distribution (MVN). The MVN approach fully accounts for the correlation between observations, thereby providing consistent modeling of ground motions and macroseismic intensities and their uncertainties. The MVN, combined with the well-established conditional mean spectrum approach, allows for multiple conditioning periods. We anticipate expanding the sampling of response spectral periods so as to better characterize the spectral shape at each location, thus facilitating improved loss calculations. ShakeMap 4.0 also supports more flexible fault rupture representations, enhanced rupture distance measures as well as new directivity, spatial correlation, ground motion to intensity conversion equations, and it accommodates many of the vast collection of GMPEs supported in GEM's OpenQuake libraries. One of the critical problems ShakeMap solves is the assimilation of data from historical earthquakes in a unified, consistent representation of the ground motion field. This is true whether the event is poorly constrained such that only GMPE's and site conditions are applied, or where various combinations of ground motion, macroseismic intensity, and finite-fault inputs are available as additional constraints. In contrast, traditional isoseismal representations cannot be readily used in analytical or geospatial analyses as the contours do not have an interpretable value. From an historical earthquake research perspective, ShakeMap's smart interpolation is invaluable for analyzing various datasets of varying quality and coverage, particularly for calibrating loss models. We present several case studies depicting the value of our revised interpolation algorithms by calibrating with macroseismic data from several historic events in the Himalayas, Puerto Rico, and Ghana. Once calibrated, the ShakeMap operator can gain some confidence in producing scenario shaking estimates for future events in such regions.

ESC2018-S37-266

THE 1348 EARTHQUAKE OF EASTERN ALPS: THE QUESTION OF SOURCES – A SOURCE OF QUESTIONS ...

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On 25th January 1348, a strong earthquake occurred in a portion of the Eastern Alps at the junction between the regions of Carinthia (now in Austria), Friuli (now in Italy) and Carniola (now in Slovenia). It was felt over a wide area and the news of it spread even farther: more than a hundred European chronicles of the 14th-century record it, often in association with the "Black Death" plague epidemic that followed in its wake. From the seismological point of view, the 1348 earthquake is one of the twenty-three biggest events located in Europe between 1000 and 1500 AD (see AHEAD) and one for which a particularly high number of macroseismic data points is available. Yet, despite the amount of available macroseismic data, our understanding of the 1348

earthquake is far from exhaustive and many very important questions about it are open still. First of all, unlike the 1356 Basel earthquake, the 1348 earthquake occurred in a politically marginal area of 14th century Europe and none of the historical sources that describe were produced in that same area; in fact, some of them very far from it. This poses many interpretative problems to the researcher who tries to use these sources to their full extent to gain knowledge of. First of all, there is the problem of how to recognize which sources are "direct" or "indirect", primary" or "secondary" and whether we can trust equally a text produced a few days or months after the earthquake and others that were written years later. And again, how to deal with uncertain or ambiguous place-names? How to assess intensities from descriptions that are often vague and concerning buildings that are not considered in macroseismic intensity scales (castles)? How to combine the earthquake sequence and the sources indications of damages? This paper describes how we tried to find answers to these questions and, at the same time, to reassess the whole body of information available for the 1348 earthquake with homogeneous criteria.

ESC2018-S37-274

UPDATING THE HISTORICAL SITE EARTHQUAKE CATALOGUE OF THE MALTESE ISLANDS

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In recent years, teams of researchers from several European countries combined their efforts to create a common "European-Mediterranean Earthquake Catalogue". The work, carried out under the coordination of INGV - Milan, was based on the data collected in the Archive of Historical Earthquake Data – AHEAD (Locati et al., 2014) and followed the methodology developed in the frame of the I3, EC project "Network of Research Infrastructures for European Seismology" (NERIES), module NA4. As a result, homogeneously compiled national earthquake catalogues and databases are now available. Despite the effort done, however, there are still wide margins for improvement, filling time gaps in the catalogues, retrieving information on "forgotten earthquakes" and carrying out joint studies of "transfrontier earthquakes", whose effects were felt in neighbouring countries and that may have been contradictorily or partially represented in different catalogues and databases. For these reasons, all national catalogues and database should be periodically updated. We present the first stage and the earliest results of an Italo-Maltese joint venture, which was started with the objective of compiling a new site catalogue of the Maltese Islands. In keeping with the standard methods of historical earthquake research already well tested in Italy, the starting point of the work was the integration of the Maltese catalogue by Galea (2007), with information retrieved from two main sets of data repositories: the Italian and European descriptive earthquake compilations of the 17th-19th century and the large digital collections of European historical serial sources (newspapers, diaries, chronicles and so on) now made available by many cultural institution through the Internet. The first draft of the new site catalogue includes about 130 earthquake records, with a noticeable increase with respect to the Galea (2007) catalogue, particularly for what concerns the 18th and 19th centuries; for the periods before 1650 and after 1923 there was, on the contrary, little increase in knowledge. At least six of the new earthquakes caused damage in the Maltese Islands. Three of them (1658, 1726, and 1780) appear to be located in the area of the Sicily channel, and the others (1756, 1810, and 1846) are large Greek events. Macroseismic intensities in European Macroseismic Scale 1998 (EMS-98) were assigned to several localities of the Maltese Islands. Particular attention was devoted to collect background information on earthquake-induced natural phenomena (liquefaction, landslides, tsunamis) to be used as a further constraint of the location and magnitude of the associated earthquakes or for paleoseismological studies. An additional bonus of the study was the retrieval of new macroseismic information on already known earthquakes located in Sicily and Greece and the discovery of a few previously unknown Sicilian earthquakes. References

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ESC2018-S37-277

PUTTING AUGUST SIEBERG'S "ERDBEBENGEOGRAPHIE" (1932) INTO A FRESH PERSPECTIVE

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Beside being known for his contribution to the the 12-degree Mercalli-Cancani-Sieberg (MCS) macroseismic scale, August Sieberg (1875-1945) holds a prominent position and a global recognition as compiler of a worldwide descriptive list of earthquakes. His 319-pages chapter “Erdbebengeographie” (earthquake geography), published in 1932, has been largely used and quoted, starting from Gutenberg and Richter in their 1949 “Seismicity of the Earth” and in their wake by catalogue compilers all over the world. Content and method are defined by Sieberg himself in some introductory guidelines. The “Erdbebengeographie“consists of 98 “tables” (lists) of dates with succinct descriptions of the effects of ca 2,300 large earthquakes from 2200 BCE up to 1931 in ten large geographical areas. Each list is preceded and followed by geological and seismological considerations, also illustrated in some 60 maps. Intensity degrees are indicated in about 150 isoseismal maps, while values of intensity at sites are randomly given for a few earthquakes. Epicentral intensity and epicentre’s co-ordinates are not supplied anywhere for any earthquake. Structure, background, and data of Sieberg’s global list of earthquakes are analysed by means of some case histories from different areas of the world. How this ‘big data’ set was used by later seismic catalogue’s compilers, and likely reasons behind this long-lasting success in macroseismology studies are investigated. Finally, some suggestions are advanced on how to downscale its influence in the compilation of the pre-twentieth century section of today’s regional and global catalogues.

ESC2018-S37-301

90TH ANNIVERSARY OF THE 1927 SCHWADORF / LOWER AUSTRIA EARTHQUAKE

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The Schwadorf earthquake in the Vienna Basin fault system, which occurred on 8th October 1927, was one of the strongest in this area and therefore of particular interest. In the Austrian Earthquake Catalogue kept by the Zentralanstalt für Meteorologie und Geodynamik (ZAMG), the epicentral intensity of the Schwadorf quake is listed as 8° EMS-98, the magnitude as 5.2 and the depth as 6 km. A critical review was undertaken on the occasion of the Schwadorf earthquake anniversary. In collaboration with the local government and the inhabitants of Schwadorf, it was possible to obtain new information. After an official appeal, several pictures of damaged houses were collected and even one of the last eye-witnesses, a citizen of Schwadorf, could be interviewed. A manuscript by the former district commission of Bruck an der Leitha, giving a detailed description of the damage, was discovered in the municipal office of Schwadorf. The manuscript is of great value in order to reassess the degree of damage. Additionally, several newspapers and the many questionnaires by the Earthquake Survey of the ZAMG were reviewed. The earthquake could not be properly recorded by the Wiechert seismographs at the ZAMG station in Vienna/Austria. Vienna is located only 25 km from the epicentre of the quake, so the needles were jumping off of the delicate seismograph. Fortunately, a seismogram from the Wiechert seismograph at the Observatory of the Alberoni College in Piacenza is available. The goal of the study was to use all the available information in order to reassess one of the strongest Austrian earthquakes. With regards to Citizen Science, a well-attended event was also organized on the occasion of the anniversary in order to inform the population about the earthquake hazard in the area.

ESC2018-S37-345

A REVISION OF THE SOURCE PARAMETERS OF THE 1755 EARTHQUAKE

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The Lisbon earthquake of 1755 poses a challenge to seismic hazard assessment. On one end, the scenario of its repetition dominates the EC8 hazard zonation for Portugal; on the other end, the EMSHM13 European hazard model does not reflect a significant contribution from the assumed source region, since no published ground motion model propagates strong shaking amplitudes to such high distances. Current assumptions about magnitude (8.7 according to Johnston, 1998 or 8.5 according to Martinez-Solares, 2004) and source location (Gorringe-Horseshoe region offshore SW Iberia) are difficult to reconcile with reports of MMI in the range VIII to X onshore. In this paper I propose an alternative interpretation whereby the macroseismic data reflect the combined effect of three different ruptures, with magnitudes between 7.3 and 7.8, separated in time by a few minutes. The latter value corresponds to an offshore rupture in the Horseshoe Abyssal Plain, whereas the smaller ones were either onshore or very near the shore. The analysis of tsunami traveltimes has led to disparate source models, sometimes separated by a few hundred kilometers. This probably means that multiple tsunamigenic ruptures were also involved, as is indeed the case in most published models. The extreme impact of the tsunami in the margins of the Cadiz gulf may indicate that part of the rupture occurred along the basal surface of the Cadiz accretionary prism (Pelayo and Wiens, 1992). I argue that the Lisbon 1755 earthquake is an example of a distinct class of earthquake previously unrecognized, of which the Indian Ocean earthquake of 2012 and the M7.8 Kaikoura are instrumentally recorded instruments, showing space and time correlation over scales of the orders of a few hundred km and a few minutes. Other examples may exist in the historical record, such as the M8 1556 Shaanxi earthquake, with an unusually large damage footprint (MMI equal or above 6 in 10 provinces; ~830000 fatalities). The ability to trigger seismicity globally, observed after the 2012 Indian Ocean earthquake, may be a characteristic of this type of event: occurrences in Massachussets (M5.9 Cape Ann earthquake on 18/11/1755), Morocco (M6.5 Fez earthquake on 27/11/1755) and Germany (M6.1 Duren earthquake, on 18/02/1756) had in all likelyhood a causal link to the Lisbon earthquake. This may reflect the very long period of surface waves generated by the combined sources as a result of the delays between ruptures. Recognition of this new class of large intraplate earthquakes may pave the way to a better understanding of the mechanisms driving intraplate deformation.

ESC2018-S37-419

HISTORICAL UNDERSTANDING OF DATA-QUALITY AND DATA-INTERPRETATION IN EARLY INSTRUMENTAL SEISMOLOGY

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When Inge Lehmann was taught basic theory of seismology by Beno Gutenberg in September 1927 she first learned it by reproducing Gutenberg's original 1914-calculation of the P-waves paths through the Earth. Moving on to travel-time tables in general, she began under Gutenberg's supervision, to study the existing tables and the various methods by which they have been produced, different methods of establishing epicenter and what degree of accuracy it was possibly to achieve or could be expect with existing data. At that time, no authoritative travel-time table existed, and different time curves had been worked out by various seismologists and varied greatly, making it difficult to determent which was the most correct to use. Part of it was due to poor recording and imperfect time-service. While studying the pros- and cons of the different tables Lehmann noted several types of problems with seismic data and how they were used. Firstly, the available data was of poor quality (compared to data of today), incomparable and often used indiscreetly by scholars. Secondly data creation at the stations was not uniform because there were no international standards for best praxis and new scientific knowledge spreads slowly. Thirdly, the station-bulletins published by the different seismic stations did not contain enough information for research purposes and estimates of epicenters were often based upon obsolete methods. It led her to the conclusion that because of the lack of uniform records it was essential to see the original seismograms to compare the recorded phases. At the time generalized travel-time curves was often constructed on single events. Drawing on her training in statistics, Inge Lehmann considered the problem of travel-times curves essentially a statistical one, arguing that if enough high-quality data was used it would be possible to establish a standard tables of travel

times for earthquake waves, to which new events should be compared to highlight individual animalities. With founding from IASPEI she began studying several large earthquakes in 1930, collecting seismograms from all available stations to create her improved travel-time curve. In Cambridge Harold Jeffreys was working on the same problem, but with data from the published bulletins. Over the next years the two keep close contract, often writing to each other several times a week, and with great zest and humor discussing and criticizing each other findings. Ultimate their studies lead Lehmann to publish her evidence of the earth inner core in 1936, and Jeffreys, with Bullen, to publish their reference table of travel-time in 1940. The above historical study on data-quality and data-interpretation in early instrumental seismology is based upon document and research notes from Inge Lehmann's private archive kept at Danish National Archive.

ESC2018-S37-447

ASMI - THE ITALIAN ARCHIVE OF HISTORICAL EARTHQUAKE DATA

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The quality and reliability of historical earthquake catalogues strongly relies on the accuracy of the basic data from which earthquake parameters derive. Data for the compilation of earthquake catalogues are to be found in historical earthquake studies, intensity data distributions, previous catalogues, etc., and are presented in a variety of different formats (descriptive texts, tables and maps) and on different medias (online databases, scientific papers, books, bulletins, etc.). A comprehensive archive of studies providing data on Italian earthquakes has been continuously implemented since the 1990s, with the aim of collecting and qualifying the datasets for the compilation of the Italian earthquake catalogues. The archive was used to compare different datasets and to identify the most reliable one, when alternative datasets refer to the same earthquake. Through time, the content of the archive has been digitized, it has been organized in a relational database structure, and it has been recently made publicly accessible on the web (http://emidius.mi.ingv.it/ASMI/) under the name ASMI "Archivio Storico Macrosismico Italiano" (Italian Historical Macroseismic Archive). ASMI is the Italian node of AHEAD, the European Archive of Historical Earthquake Data (https://www.emidius.eu/AHEAD), which, in turn, is the node providing historical earthquake data to EPOS, the European Plate Observing System (https://www.epos-ip.org/). As AHEAD, ASMI is a platform granting access to multiple studies and alternative earthquake parameters, and represents a fundamental resource for collecting, homogenizing, comparing, and validating data related to each earthquake. At present, ASMI gives direct access to the information related to more than 5800 Italian earthquakes in the period between 461 BC and 2014. It contains all the 4584 earthquakes (in the period 1000-2014) contained in the latest version of the Parametric Catalogue of Italian Earthquakes (CPTI15), with the additions of nearly 1000 earthquakes below the threshold of CPTI15 (intensity 5 and/or magnitude 4.0), traces of 88 earthquakes occurred before the year 1000, and 200 ca. records of fake earthquakes. ASMI considers about 345 different data sources and also contains about 5800 sets of macroseismic data related to nearly 4000 earthquakes, with a total of about 510'000 intensity data points. ASMI is accessible through a dedicated web portal, either by earthquake or by study. The query by earthquake is possible from either a list or a map, and gives access to the earthquake parameters as defined in CPTI15 (if it lists the earthquake) and in many other alternative and/or previous catalogues, together with all the archived studies, included the one selected for DBMI15, and their respective intensity data. The content of each study is also accessible in different ways according to its own peculiarities. The query by study is possible through the complete list of the archived studies. The selection of a study gives access to its bibliographic metadata and, when possible, to the PDF file of the study itself or to its original webpage via a direct link. To increase the accessibility and usability of the data archived in ASMI, a series of web services(https://emidius.mi.ingv.it/ASMI/services/) complaint to the EPOS interoperability guidelines are available. Through these web services, external users may develop their own machine-to-machine procedures that

programmatically query the archive in search of earthquakes, macroseismic intensity data, studies or mentioned places. As typologies and formats of studies providing data on historical earthquakes are heterogeneous, the ways in which they are available through ASMI are manifold. As of today, ASMI grants full access to the 65% of the 345 considered studies, the 54% in their original format as PDF files, and the 11% as an external web resource. The 27% of the studies cannot be reproduced because of their copyright, consequently, only the full bibliographic reference and the link to the website that makes them available are provided, as in all the other cases. The content of 16 recent studies, related to more than 1600 earthquakes, is directly accessible through the website without downloading their PDF files. The transposition into the database structure of the content permitted to identify, manage, and make easily accessible a wealth of information on earthquake effects additional to intensity data. Such information consists of the description of the earthquake effects both as a whole and at a given place, details on the reported casualties, and effects on the environment, depending on both how the study is structured and the characteristics of the earthquake(s) it deals with. The bibliography of the analyzed historical sources is also presented, as well as their original texts when available. In such a way the full informative content of a study supporting the assessed macroseismic intensity data is readily searchable and accessible. The wealth of information available through ASMI is going to increase in the future, as it is conceived as an open archive to be continuously integrated with new data, as soon as they are published.

ESC2018-S37-482

A NEW MACROSEISMIC MAP FOR THE LURøY, NORWAY EARTHQUAKE OF 31 AUGUST 1819

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Introducing the rigorous rules of historical seismology has definitely been a leap forward in comparison with the prevalent standards prior to the late 1970s. Instead of relying on earlier seismological compilations and forwarding their possible errors to new studies, priority is given to original and contemporary documentation of local and regional earthquake effects. Despite the advances, many regionally important earthquakes have not been re-appraised. On the one hand, a new investigation may not appear warranted, if competent, albeit old, studies exist. It can be complicated to argue convincingly how the potentail improvements justify the invested time and effort. On the other hand, knowledge of past earthquake effects is needed for an understanding of the seismic histories of localities and for seismic hazard related to sites of engineering interest. This presentation attempts to conclude the ongoing re-appraisal of the Lurøy earthquake of 31 August 1819. Its epicentre is located near Lurøy, coast of Nordland, Norway. It is challenging to study by macroseismic means, because the region, northernmost Fennoscandia, was very sparsely populated, and there were only a few documentation centres located along the coasts. The previous two macroseismic maps were published in the 1980s and show that the earthquake had an exceptionally large area of perceptibility crossing country borders. It has been assigned magnitude Ms5.8, the largest in the historical seismicity record of the region. Basic research has been carried out in archives and libraries to uncover new and confirm old data points. Different types of revisions have been made: new data points have been found, existing ones removed because no report of any kind could be found to support them, and in-depth confirmation of localities with relatively ample or newly uncovered documentation. There is previously disregarded information about Stockholm, Sweden and Kola, Russia that are crucial for defining the radius of perceptibility and the macroseismic magnitude. Intensity assessment using the typically short descriptions available is uncertain; however, the approximate attenuation from Nordland to the outskirts of the area of perceptibility appears to be consistent.

ESC2018-S37-561

INTENSITY-DISTANCE ATTENUATION: COMPARISON BETWEEN ESI AND TRADITIONAL SEISMIC INTENSITY FOR MEDITERRANEAN EVENTS

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Earthquakes, and earthquake-related phenomena, are among the deadliest and costliest natural disasters. Traditional intensity scales (i.e., MCS, MM, EMS) are mostly based on the effects on the built environment, and thus seismic intensity is inherently related to the characteristics of the building stock. As a consequence, the comparison between historical and modern events can be biased and it is hard to test if results are consistent within different time intervals. On the contrary, Earthquake Environmental Effects (EEEs), essentially observed during strong seismic events, are time-independent. In the last years, events such as the 2008 Sumatra or 2011 Tohoku tsunamis raised awareness in the public opinion on EEEs societal impact. In the scientific community, EEEs are described for an increasing number of seismic events and categorized in a consistent way by means of the ESI (Environmental Scale Intensity) scale. Nevertheless, a quantitative assessment of the ESI scale is still lacking, and its potential is not fully exploited. Here we focus on the analysis of intensity attenuation with distance for moderate to strong (Mw > 5.5) events occurred in the Italian Apennines and Greece. We aim at i) compare the ESI scale with traditional intensity and ii) find quantitative parameters for estimating building stock vulnerability changes through time. For Italy, we analyze 14 normal faulting events occurred between 1688 and 2016, for which both ESI and MCS intensity data points are available. We compute the intensity attenuation with the intensity-binning approach used by Bakun & Wentworth (1997) on western US events. When compared with traditional scales, ESI regressions consistently show a higher slope and higher intercept (i.e., higher intensity predicted at the epicenter). We also apply the distance-binning approach proposed by Gasperini (2001). We find a clear difference in MCS attenuation between 21st century and previous events (Ferrario et al., 2017). We propose that the difference between 21st century and previous events reflects changes in vulnerability caused by the evolution of the building stock and by the introduction or update of building codes. For Greece, we analyze 10 events occurred between 1894 and 2015, comparing ESI and traditional (MM and EMS) intensities. We confirm the different behavior of ESI and traditional intensity close to the epicenter and we found that the adopted macroseismic scale is a first order factor for intensity-distance relation, overwhelming the role of maximum (or epicentral) intensity. Our results suggest that care should be taken when analyzing different time intervals with traditional scales, especially for seismic hazard assessment purposes. We also show that the integration of ESI and traditional fields can assure consistency with previous case histories.

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ESC2018-S37-681

THE 1933 KOS EARTHQUAKE REVISITED

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The island of Kos and the Turkish coast near Bodrum were shaken on July 21, 2017 by a shallow earthquake of Mw6.6, with a focal depth of about 10 km. Its epicentre was located offshore NE of the island. The seismogenic source is a segment 16 km long of a E-W striking and south dipping (38°) fault located east of Kos, a westward extension of the Akyaka-Gökova fault in Mugla province. The earthquake is responsible for the loss of life of two and 10 injured, as well as severe damage to the old buildings of Kos town, failures and subsidence to the port and slight damage to some recent

structures. Secondary effects were slope failures, land and coastal subsidence, liquefaction phenomena and a small tsunami that struck the port. In the past, the area was shaken by few known earthquakes, mainly in 1493 (Mw 6.9) and 1933 (Mw 6.5). For the first one we have seven macroseismic data points. The event of 23 April, 1933 took place in a time-window when the Dodecanese was under Italian administration, with Rhodes as capital, and shook an area already damaged by the great, 1926 Rhodes earthquake. Early epicentral location attempts suggest two candidate epicentres (N. Kritikos, National Observatory of Athens, 1933). Magnitude and epicentral location are known from several sources and catalogues. Locations and M values look very similar: some disagreement may concern the depth. Damage on the island was heavy: Kos main town was party destroyed. Damage was also observed in the nearby Turkish mainland (Datcha peninsula), Nysiros, Leros and Rhodes; It was felt in Simi, Kalymnos and as far away as Santorini. The death toll was almost 200 persons in total.Most Greek newspapers (e.g. “Akropolis”, “Ethnos”, “Estia”) as well as the local Dodecanese ones report extensively on the earthquake, starting from April 25, 1933. On Kos island, besides the damage in Kos town, many villages were completely destroyed or severely damaged. Nisyros also suffered by the earthquake. Little information is found in “Corriere della Sera” and “La Stampa”. Il “Messaggero di Rodi” supplies more detailed information. Earthquake news are found in the “Cumhuriyet” newspaper with percentage of damaged buildings for a number of villages on the coastal area in Turkey. Although the location of that earthquake apparently looks similar to the one of the 2017 event, it would be important to understand whether the source of the 1933 earthquake is the same or it is another segment of the same fault. The particular historical context and the proximity of the Turkish territory, requires investigation in varied repositories, and this stimulated the collaboration between Greece, Turkey and Italy. The so far available data allow to assess macroseismic intensity to at least 30 localities, from which location and Mw can be computed. The investigation of the material contained in the main repositories is still in progress.

ESC2018-S37-759

RE-ESTIMATION OF MACROSEISMIC PARAMETERS OF HISTORICAL AND EARLY INSTRUMENTAL EARTHQUAKES ON THE TERRITORY OF GEORGIA

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Seismicity study and hazard analysis of such regions have big importance from both scientific and practical point of view. Investigation of historical earthquakes and seismicity is crucial part of these studies. Study of historical earthquakes – earthquake effects, intensity data provide means to extend earthquake catalogs backward in pre-instrumental period. In the areas of moderate or low seismicity most of information about strong events comes from historical data. Another important problem is assessment of uncertainties for estimated parameters. The territory of Georgia is situated in seismically active region. The analysis of historical and instrumental seismic data indicates that it is the region of moderate seismicity (on global seismicity scale). Strong earthquakes with magnitude up to M=7±0.5 and intensity 9±1 occurred here. Several moderate and strong events with M>4.5 of late historical and early instrumental periods (1890-1920) have been studied. Intensity data was revised and updated. The maps of Caucasus for that period have been digitized using GIS technology. A dataset of about 10 earthquakes was compiled. 3 events among them hasinstrumental magnitude determination. The intensity values of the studied earthquakes were revised and estimated using criteria and diagnostics of EMS98 and ESI2007 scales. Isoseismals of studied earthquakes we have compiled using Kriging technique. Besides that, modern algorithms for re-assessment earthquake parameters (epicenter location and magnitude) was used (Gasperini et al. 1999; 2010). The uncertainties of the parameters have been estimated.

ESC2018-S37-1013

BRIDGING THE GAP BETWEEN HISTORICAL SEISMOLOGY AND FIELD GEOLOGY USING A COLLECTION OF 2,300 EARTHQUAKE-INDUCED

ENVIRONMENTAL EFFECTS SUPPLIED IN THE NEW CFTI5MED

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A new version of the Catalogue of Strong Earthquakes in Italy and in the extended Mediterranean area, termed CFTI5Med, was released in 2018 by Guidoboni et al. (http://storing.ingv.it/cfti/cfti5/). The Catalogue provides a unique wealth of information on the historical seismicity of Italy that is now fully accessible through a completely re-designed web-interface. CFTI5Med does not only contain parametric data and macroseismic intensities assigned to individual localities, but provides a complete account of the territorial impact of each investigated earthquake sequence through textual descriptions of the earthquake effects. In addition to reporting the effects on the built environment, the catalogue collects and describes also the effects induced by earthquakes on the natural environment, including ground cracks, liquefaction, landslides, rockfalls, changes in the discharge rate of rivers and springs, flooding and tsunami effects. We reinterpreted in a geological perspective, georeferenced and reprocessed over 2,300 descriptions of earthquake-induced effects on the natural environment associated with about 200 different earthquake sequences. The effects caused by each sequence on the natural environment are shown as a list of the types of observed phenomena and described in historical-critical comments for each individual locality where such effects were reported. The relevant bibliography is supplied in an organized form in each comment, allowing the reader to access the original sources used to investigate the specific event. We classified the effects on the natural environment into 30 categories, grouped into 5 macro-groups: changes in the landscape (including landslides, ground cracks, ground uplift or subsidence, etc.), changes in the watercourses and lakes, changes in groundwater (including liquefaction effects), changes in the coastline (including tsunami effects), and others such as gas emission and light phenomena. Of these, nearly 50% are landslides and ground cracks, 25% are changes in groundwater (most of which liquefaction effects); the remaining effects are mostly gas emissions and tsunami evidence. All the effects on the natural environment contained in CFTI5Med can be accessed in a user-friendly web-GIS environment, through webpages describing the effects of individual earthquake sequences and webpages describing the seismic history of individual localities. In addition, we implemented also a page dedicated specifically to the information on the earthquake effects on the natural environment, allowing the user to apply filters by categories and display the effects in a clear georeferenced map. As it is known that earthquake-induced effects on the natural environment tend to occur where they have already occurred in the past, the possibility of an immediate use of these data is crucial in case of an emergency. The effects reported in CFTI5Med are located as points coincident with localities where these effects were observed. In some instances, where historical descriptions allowed us do so, the effects were precisely located on the geographical spots where they have been observed (mountains, rivers, etc.). Thanks to the new digital cartographic instruments, in some instances we have been able to draw rather accurate areal locations, in particular for landslides, by integrating historical, geological, territorial and toponomastic evidence. While treating locations as points, the CFTI5Med web-interface allows the user to load on the map a number of overlays from external WebGIS resources with administrative, topographic, geologic and tectonic information. In addition to the immediate access to the original sources used to identify the effects listed in the Catalogue, this feature allows an expert user to develop his/her own geologic interpretations, further bridging the gap between historical seismology data and field geology observations.

ESC2018-S37-1077

INVESTIGATION OF MACROSEISMIC DATA FOR EARTHQUAKES IN NORWAY AND DENMARK

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Norway and Denmark are regions of low to moderate seismicity, where strong earthquakes rarely occur. For both countries, rich collections of macroseismic intensity data provide important

insight into the larger historical earthquakes and allows comparing these events to more recent earthquakes for which both macroseismic and instrumental data is available. Recently, efforts have been initiated to exploit the macroseismic datasets for a better understanding of the seismicity and tectonics in these countries. In addition to presenting the available data, we will show examples of automatic drawing of isoseismals using a Kriging technique and present some initial results for macroseismic intensity attenuation and event location based on macroseismic data. We will discuss the advantages, but also some important limitations, in applying such methods in regions of low to moderate seismicity with challenges related to varying geological conditions and data coverage.

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SESSION 38

ESC2018-S38-50

VARIABILITY IN THE DEGREE OF REGULARITY OF TEMPORAL DISTRIBUTION OF EARTHQUAKES IN SOUTH CALIFORNIA

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In the present research we investigated a statistical feature of the temporal distribution of earthquakes in southern Californian earthquakes catalogue. Investigation of earthquakes' time distribution is regarded as one of the most important tasks of contemporary geophysics. This is quite logical because progress in such research directions like earthquakes forecast or control of seismic processes can not be achieved without progress in the understanding of earthquakes' time distribution. Thus is not surprising the interdisciplinary attention to this question which has been revealed in last decades by many research groups worldwide. At the same time, in spite of the fact that our knowledges in this field noticeably expanded, the question how the regularity of seismic process is changed over time, still remains unanswered. As a main data analysis tool, in this research we used simple statistical approach based on the calculation of integral deviation times (IDT) from the time distribution of regular markers. By this method we would like to answer the question of how and when the process of earthquakes time distribution approaches to randomness. Usually in order such questions to be answered, methods of complex data analysis are preferable to use. These well known methods (e.g. Lempel and Ziv complexity measure calculation, multiscale entropy calculation, recurrent quantification analysis, etc.) when correctly used are effective for the task of quantification quantification of the dynamics of complex processes: examples can be found in a number of articles from different fields. Each of these methods of modern linear and nonlinear data analysis (mentioned here and others) are developed for the testing of complex data sets from a certain point of view based e.g. on concepts of information theory, phase space population, entropy, fractional dimensions, complexity, etc.It is necessary here to be underlined that they necessitate special conditions to be fulfilled both in the sense of quality and length of data sets, as well as in the sense of calculation purposes (e.g. conditions for reliable phase space reconstruction or coarse-grained series construction, etc.). Therefore, knowing weak and strong sides of these methods for concrete data sets, we aimed to develop testing method based on the assessment of very simple statistical and distributional characteristics of complex process.It was important to get the possibility to look at the complex process of the temporal distribution of earthquakes from a simple new point of view, which will not be complicated by the fundamental principles of method's accomplishment. This is why we preferred to develop IDT method for not the perfect quality and short seismic data sets which we planned to analyze in this research. It should be also pointed out that the IDT calculation method has no practical restrictions on the length of data sets because of its simplicity. Prior to the analysis of data sets from seismic catalogue it was necessary to assess the effectiveness of the IDT calculation method for simulated data sets with predefined dynamical characteristics. Namely, we considered data sequences of different noises and Poisson process. For the testing purpose, it was necessary to know how different are these data sets in the sense of regularity, especially at the small differences between spectral exponents of noise data sets. To quantify these differences we used mentioned above complex data analysis methods. After, the same data sets have been investigated by IDT calculation approach. These analyses indicate that used simple statistical method, IDT, can discern differences in dynamical features of complex high-dimensional processes. After, we have proceeded to the analysis of earthquakes temporal distribution in southern Californian earthquake catalogue. We selected period from 1975 to 2017 at representative magnitude M2.6 in order to have as possible long catalogue at as possible low representative threshold. In order not to change natural structure of earthquakes time distribution we avoided any cleaning and filtering of analyzed catalogue. Analysis was carried out for different subperiods and at different magnitude thresholds. It was found that the extent of the order in earthquakes time distribution is fluctuating over the catalogues time span. Particularly, we show that the process of earthquakes' time distribution becomes most

random-like in periods of relatively decreased local seismic activity. The most important is that the extent of randomness never reaches its maximum in periods immediately prior to strongest earthquakes.Our finding of variability of degree of an order in the temporal distribution of earthquakes has of immense importance because many authors still regard seismic process as completely random, changes in dynamic structure of which can not be quantified. Acknowledgements. This work was supported by Shota Rustaveli National Science Foundation (SRNSF), grant 217838 “Investigation of dynamics of earthquake’s temporal distribution”

ESC2018-S38-58

PHASE SPACE PLOTS OF EARTHQUAKE TIME SERIES: SIGNATURES OF STRONG EARTHQUAKE PREPARATION IN CAUCASUS

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Many studies are devoted to the statistical analysis of earthquake time series (ETS) in the last years. Modern methods of nonlinear dynamics, applied to ETS, give controversial results: some authors prove existence of strange attractors (which means that ETS can be represented by deterministic chaos model), others demonstrate absence of such ordered structures. The present study analyses the spatio-temporal parameters of seismic rate and reveals nonlinear structures in the phase space plots (PSP) constructed for low seismicity areas, as well as for seismic areas before, during and after the occurrence of strongest Caucasian earthquakes: Spitak (1988) and Racha (1991). The seismic phase portraits and recurrence plots constructed for different time windows, epicentral distances and magnitude thresholds, reveal some patterns of seismic process dynamics that could be possibly related to precursors of strong earthquakes. The trajectories in the phase space portraits of earthquake time series generally manifest two main features: a dense "source/basin" area formed by a background seismicity and (reversible) anomalous orbit-like deviations from the source area, related to swarms, foreshock and aftershock activity. Unlike the case of theoretical attractors for deterministic chaos, the “basin" area of earthquake time series is much more diffuse (“noisy”), than in case of chaotic attractors, obtained by solution of model nonlinear equations. The same “noisy” phase portraits one obtains during processing experimental data of various origin, e.g. in biology. Analysis shows that trajectories in the phase space are not very regular, except the smoothing (e.g. by Savitzky-Golay filter) procedure with 10 days window and 1 day step is applied to data. The 1-day step for overlapping windows means that the content of the window is essentially the same, which results in appearance of smooth attractor-like trajectories in the phase portraits of earthquake time series. When we use non-overlapping windows, the attractor-like pattern is still evident in the phase space, though trajectories are not as smooth as in the former case. At the same time even these deformed phase space portraits of ETSs look quite different from the PSPs of random numbers’ “time series”: the ETS sequences have a “basin” (though a “noisy” one), to which the trajectories return after orbit-like deviation. Besides, the pattern of orbits in ETS phase portraits differs from these for random sets. Phase Space Portraits (PSP) can be considered as interesting visualization tools for analysis of seismicity dynamics. On phase space plots of smoothed seismic rate sequences in Racha and Spitak area emerge some attractor-like structures, which begin to deviate from the “basin” area approximately 60 days before 1991 Racha mainshock and 30-50 days before Spitak event and return to the “basin” after the mainshock occurrence. It seems that before/after strong Spitak and Racha earthquake there are some anomalies in ETS (large deviations from the background pattern – basin area), which generate orbit-like structures in PSPs, even using declustered by Matthews-Reasenberg approach catalogs. Presumably, these outlying orbits appear due to presence of remaining after declustering some nonlinear (correlated) structures in seismic activity before/after strong earthquake (Matcharashvili et al, 2015). In principle, this effect can be used for strong earthquake precursors' search in the time domain, though the spatial resolution of anomalous area is not high, as a remote (separated by hundreds of km) strong earthquakes can result significant changes in phase space plots of ETS even in seismically quiet areas. Further investigations are needed to reveal

the EQ prediction potential of seismic phase space plotting.

ESC2018-S38-174

SEISMICITY SPATIO-TEMPORAL EVOLUTION THROUGH INFORMATION NTROPY AND FRACTAL DIMENSION ANALYSIS: AN EXAMPLE FROM N-ADRIA.

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This study analyzes eight seismicity populations, preceding and following moderate earthquake earthquakes occurred in NE-Italy and W-Slovenia, as dynamic systems, using information entropy. The spatio-temporal variability of the seismicity reflects the effect of the tectonic stress field applied to a crustal volume and can be represented as a physical system characterized by chaotic processes, whose level of organization can be quantified by the physical quantity entropy and by the fractal dimension. The former enables to characterize the complex dynamics of an earthquake population (Main and Al-Kindy, 2002). The Shannon's entropy calculates the probability of occurrence of different states during the evolution of a system. Shannon's information entropy was applied to earthquake sequences by Matcharashvili et al. (2002); Telesca et al. (2004); Padhy (2004); De Santis et al. (2011). As regards the fractal analysis, it can provide a quantitative measure of the pattern of the spatial seismicity distribution, and, hence, of the damage evolution. The entropy is calculated using the equation of Shannon (1948), a function of the probability of the occurrence of different states of a system. The Shannon entropy (information entropy) measures the level of disorder of a system, providing the deviation from the equiprobable state, characterized by a uniform distribution (Telesca et al., 2004). The Shannon entropy is calculated in a 3-D regular grid, including the earthquake population and consisting of n = 50 cells each with size 10 x 10 x 10 km. The hypocentre of the mainshock is placed in the centre of the grid (central cell). The fractal analysis of the spatial distribution of seismic events is performed through the correlation integral method (Grassberger, 1983), a fixed-size algorithm suitable to analyse small datasets or limited regions. It is, in fact, poorly sensitive to data number and shape of the spatial point distribution (Hirata et al., 1987; Havstad and Ehlers, 1989; Rossi, 1990; Theiler, 1990; Molchan and Kronrod, 2005; Kagan, 2007). We analyzed the seismicity preceding and following the moderate shocks here listed: 1988 February 1 MD 4.1, 1996 April 13 MD 4.3, 1998 April 12 MD 5.6, 2002 February 14 MD 4.9, 2004 July 12 MD 5.1, 2012 June 9 MD 4.3, 2015 January 30 MD 4.1, 2015 August 29MD 4.3. The seismicity was recorded by the local seismic networks operated by the OGS and by the Seismological Survey of Slovenia, covering NE-Italy and W-Slovenia. Three phases are recognized in the temporal seismic series. The period preceding the mainshock is characterized by oscillations of the Shannon entropy around a nearly constant level and by relevant fluctuations of the fractal dimension. A sudden drop of the information entropy and the fractal dimension characterizes the mainshock and the aftershock sequences, highlighting damage localization and maximum organization of the seismicity. The phase of mainshock and aftershock sequences is characterized by a significant decrease of the Shannon entropy. A simultaneous marked reduction of the fractal dimension is observed in five cases. After the sequences, the seismicity evolves to disorder with fluctuations of the Shannon entropy and the fractal dimension. The decrease of the fractal dimension during this phase appears not significant in three cases, characterized by a low number of aftershocks with low radiated seismic energy. The low production of aftershocks can be explained by the stress release mechanism of the mainshock. The partitioning of the radiated seismic energy between the mainshock and the aftershocks depends upon the Brune stress drop of the mainshock. The higher the Brune stress drop of the mainshock, the lower the residual stresses are in the focal volume, generating few aftershocks with low radiated energy. The variations of the information entropy and fractal dimension are interpreted as spatial and temporal fluctuations of the strain energy resulted from the coupling between the tectonic stress field and the mechanical heterogeneities of the crust. From a thermodynamic point of view, the system, characterized by general disorder and high uncertainty tends temporarily to move towards higher order (local clusters).

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ESC2018-S38-181

EXPLOITING THE INCOMPLETENESS TO FORECAST AFTERSHOCKS: A NOVEL METHOD BASED ON A SINGLE SEISMIC STATION SIGNAL

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There is a growing interest of public authorities in accurate and about real time aftershock forecasting to manage and mitigate post-seismic risk. However, existing methods for aftershock forecasting are strongly affected by the huge incompleteness of the instrumental data sets available soon after the mainshock occurrence. Here we study the logarithmic envelope function μ(t) of the seismic signal recorded soon after the largest mainshocks recently occurred in Italia, Greece and California. We show that the incompleteness, in the first part of aftershock sequence, is an intrinsic property of seismic catalogues caused by the overlap of seismic records. More precisely we demonstrate that the temporal decay of the aftershock coda-waves, combined with the Omori-Utsu law, leads to a logarithmic temporal decay of the average envelope. The true parameters of the Omori-Utsu law can be directly extracted from μ(t) and this allows us to overcome all experimental problems related to aftershock identification and location. We use this information to elaborate a novel method for aftershock forecasting and we test its efficiency in retrospective tests. We find that the novel procedure is not only faster but also more accurate than available ones.

ESC2018-S38-283

UNIFICATION OF SEISMIC CATALOGUES TO STUDY SEISMIC ACTIVITY IN THE CARPATHIANS MOUNTAIN ARC

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Earthquake catalogues are the most important data sets for studying seismic hazard. However, catalogues with unified parameters, like magnitude are highly desirable for these purposes (Grünthal et al., 2009). Homogeneity of the data is considered as one of prime requirements for the catalogue. Most earthquake catalogs are nonhomogeneous because of a variety of factors that depend on both random and systematic errors introduced during the acquisition process and the database construction procedure (Leptokaropoulos et al., 2013). Homogeneous earthquake catalogues with high quality data covering large territories and long historical time spans are lacking for many parts of the Earth. Till now seismologist community of Central Europe countries has not been focused on the analysis of the whole the Carpathian arc, but only on the individual regions of the research area. Analysis of seismicity of the entire area requires data from several different catalogues that need to be completed, standardized and joined. The detailed task of this research was to reach unification of the magnitude values given in different local catalogues contributing to the final catalogue. This work is intended to show the importance of collecting data from various seismic networks, as well as the need for very careful verification of individual seismic catalogues, in order to create a single set of data on seismic phenomena across a large area.

ESC2018-S38-460

ANALYSIS OF SEISMICITY AROUND ENGURI HIGH ARCH DAM, CAUCASUS, BY USING THE VISIBILITY GRAPH APPROACH

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The Visibility Graph method is applied to the inter-event times, inter-event distances and magnitude sequence of the seismicity occurred around the Enguri dam, Georgia from 1974 to 1989 and from 2009 to 2016, to calculate the so-called mean connectivity degree. The time variation of the mean connectivity degree of the three seismic series shows the presence of periods in which it is beyond the 95% confidence band, consistently with significant time-clustering behavior (measured by the coefficient of variation of the inter-event times). In particular the anomalous behavior of the mean connectivity degree between 1979 and 1981 is probably linked with the initial filling of the dam, started in 1978 and ended in 1984; while most of the anomalous mean connectivity degree identified later, can be considered as co- and pre-seismic signatures of a few large earthquakes that struck the area.

ESC2018-S38-729

NON-EXTENSIVE STATISTICAL PHYSICS APPROACH OF EARTHQUAKE CODA-WAVE INCREMENTS.

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Coda waves are composed primarily on backscattered waves caused by lateral inhomogeneity of the earth and may be treated entirely statistically. Those inhomogeneities act as scatterers with sizes varying in a broad range of scaling. In this work, we try to treat statistically the coda part of the seismic wave as recorded in a network of Seismological stations after an earthquake event, using ideas of complexity theory as expressed in terms of non-extensive statistical mechanics. Our effort is to establesed a qualitative correlation of the non-extensivity index (q) introduced in the definition of Tsallis entropy as applied in the incremental distribution and the size of the expected scatterers. We used data from the coda waves generated by three significant earthquakes (M>4) occurred in the front of the Hellenic arc and recorded in seismological stations of the Unified Hellenic seismological network. Our results suggest that coda wave increments follow the q–Gaussian distribution. This indicates that, those wave's fluctuations are not random and present long term memory effects that could be described in terms of Tsallis entropy. Also we found that the q-value is different from station to station indicating dependence from the seismic ray path and probably, the distribution of the existing scatterers .

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ACKNOWLEDGMENTS

This work is supported by the project HELPOS (MIS 5002697) which is implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the EU.

ESC2018-S38-743

NON-EXTENSIVE STATISTICAL PHYSICS APPROACH OF EARTHQUAKE CODA-WAVE INCREMENTS

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Coda waves are composed primarily on backscattered waves caused by lateral inhomogeneity of the earth and may be treated entirely statistically. Those inhomogeneities act as scatterers with sizes varying in a broad range of scaling. In this work, we try to treat statistically the coda part of the seismic wave as recorded in a network of Seismological stations after an earthquake event, using ideas of complexity theory as expressed in terms of non-extensive statistical mechanics. Our effort is to established a qualitative correlation of the non-extensivity

index (q) introduced in the definition of Tsallis entropy as applied in the incremental distribution and the size of the expected scatterers. We used data from the coda waves generated by three significant earthquakes (M>4) occurred in the frontof the Hellenic arc and recorded in seismological stations of the Unified Hellenic seismological network. Our results suggest that coda wave increments follow the q–Gaussian distribution. This indicates that, those wave's fluctuations are not random and present long term memory effects that could be described in terms of Tsallis entropy. Also we found that the q-value is different from station to station indicating dependence from the seismic ray path and probably, the distribution of the existing scatterers.

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SESSION 39

ESC2018-S39-98

CEQID 2018: RECENT PROGRESS TOWARDS A GLOBAL EARTHQUAKE DAMAGE DATABASE AND ITS USE IN FRAGILITY ESTIMATION

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Reliable earthquake loss estimations, whether for real-time impact notifications, for the purpose of insurance catastrophe modelling or for mitigation planning, depend on developing an understanding of the performance of the building structures in each earthquake-risk country. Sufficiently detailed data on the performance in past earthquakes can be used to develop fragility functions for the building classes found in each country, and also to estimate the uncertainty in those fragility functions. Although in recent years there has been a tendency to depend on calculated fragility functions, for most areas of the world there is currently insufficient knowledge of the structural materials and building techniques used in the building stock for fragility estimates to be based on calculations of structural performance. Even where calculated fragility functions can be used, the parameters used, and the uncertainties assumed, need to be calibrated against observed damage. Thus the compilation of damage databases, and the comparison of damage with either observed or estimated ground motion at the same locations, remains a vital activity to support loss estimation. Since the 1980s Cambridge Architectural Research Ltd, in association with the Martin Centre at the University of Cambridge Department of Architecture, has been assembling data on building performance in earthquakes, and on the associated casualties, and since 2007, this data has been made widely available through an online GIS database, CEQID, the Cambridge Earthquake Impact Database. In 2017/18, a major upgrade of this database was carried out, providing many additional earthquake damage and casualty surveys, and streamlining the analysis and download capabilities of the database. CEQID (www.ceqid.org) assembles, in a single, organised, expandable and web-accessible database, summary information on worldwide post-earthquake building damage surveys which have been carried out since the 1960s, and some older survey data. Currently it contains data on the performance of more than 5 million individual buildings, in 620 survey locations following 79 separate earthquakes. The database includes building typologies (where available), damage levels and location of each survey. It is mounted on a GIS mapping system and links to the USGS Shakemaps (www.usgs.gov/shakemap) of each earthquake and the USGS global Vs30 map which enables the ground motion parameters to be estimated for each survey location. Fields of data for each building damage survey include:

- Basic earthquake data and its sources
- Identification of the source of the damage and casualty survey data used
- Details of the survey location and intensity and other ground motion observations or assignments at that location
- Building, damage level and casualty level classfication system used
- Tabulated building damage survey results or casualty data location by location.

An important aspect of CEQID not found in other such databases is that it includes cross-event analytical tools enabling data from different events affecting similar building types to be assembled. This facilitates derivation of fragility relationships for any chosen ground motion parameter, for a given class of building, and for particular countries or regions. The paper discusses problems in developing fragility relationships from data in which both building typologies and damage states are defined in a variety of different ways. It presents a statistical analysis of the data available for three broad classes of buildings, weak masonry (WM), unreinforced masonry (URM) and reinforced concrete frame (RC) across different regions of the world. It presents new fragility curves for damage against peak ground acceleration derived from USGS Shakemap data, assuming a lognormal distribution, for each of these building classes in the global dataset, and develops a set of fragility modifiers applicable to the different regions. It also applies a newly developed approach to the removal of the bias in the fragility curve resulting from the uncertainty in the ground motion used. It briefly discusses the applicability of such fragility functions in earthquake loss assessment for insurance purposes or for earthquake risk mitigation.

ESC2018-S39-111

KNOWLEDGE BASE ABOUT PAST EARTHQUAKES CONSEQUENCES AS A TOOL TO INCREASE THE RELIABILITY OF NEAR REAL TIME LOSS ESTIMATION

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Information on possible damage and expected number of casualties due to strong earthquakes is very critical for taking the proper decisions about search and rescue operations, as well as rendering humanitarian assistance. The experience of earthquakes disasters in different earthquake-prone countries shows that the officials who are in charge of emergency response at national and international levels are often lacking prompt and reliable information on the disaster scope. At present, three global systems exist that allow to provide earthquake loss estimation just after the event. They are: the Russian "EXTREMUM" System which allows to simulate the distribution of seismic intensity, damage to buildings of different types, number of casualties in damaged and destroyed buildings as well as identify effective response measures in the case of emergency; the Global Disaster Alert and Coordination System (GDACS) developed by JRC, European Commission which allows in near-real time to monitor the seismic situation and provide estimation of expected number of inhabitants in the affected area by using the information on population density; and the "Prompt Assessment of Global Earthquakes for Response" (PAGER) System of the US Geological Survey which allows to simulate expected shaking intensity and estimate expected number of inhabitants in zones of different I by using the information on population density. The paper is analyzing the reliability of loss estimation with "EXTREMUM" System application. It is proposed to use the knowledge base on physical and socio-economical consequences of past earthquakes, which may be used for calibration of near real-time loss assessment systems based on simulation models for shaking intensity, damage to buildings and casualty estimates. Such calibration allows to compensate some factors which influence on reliability of expected damage and loss assessment in "emergency" mode. The knowledge base contains the description of past earthquakes' consequences for the area under study. It also includes the current distribution of built environment and population at the time of event occurrence. Computer simulation of the recorded in knowledge base events allow to determine the sets of regional calibration coefficients, including rating of seismological surveys, peculiarities of shaking intensity attenuation and changes in building stock and population distribution, in order to provide minimum error of damaging earthquakes loss estimations in "emergency" mode. The need for coordinated efforts and research at international level aimed at creation of distributed data base on past events consequences is mentioned if one wants to increase the reliability of loss estimation in "emergency" mode.

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ESC2018-S39-127

MACROSEISMIC DATA OF EARTHQUAKES OCCURED IN RUSSIA AND CIS: INFLUENCE OF INTENSITY ATTENUATION PECULIARITIES ON RELIABILITY OF NEAR REAL TIME CONSEQUENCES SIMULATION

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At present several systems exist at national and global levels which allow the potential impact of the earthquakes in terms of life and property

losses to be estimated. More than 15 years ago several packages have been developed and are now under continuous improvement: procedures are based on a chain of models tackling seismic hazard, vulnerability of elements at risk, impact on population and goods. The essential issues are uncertainties of the procedures' output and the delay in issuing the estimates. The paper addresses the uncertainties in potential impact simulation just after the earthquake dealt with shaking intensity simulation, as well as the ways to increase the quality of output (Larionov et al., 2003; Bonnin et al., 2010; Frolova et al., 2010; 2012). In order to identify the regional intensity attenuation peculiarities the results of simulation should be checked against available previous observed macroseismic data. Since 2013 Geophysical Survey of RAS develop and maintain the data base about strong and moderate earthquakes occurred in Russia and CIS. At present it includes catalog of events with MS=3.5 and more for the time period from 1988 up to 2013 and macroseismic data (event impact description for affected settlements; raster and digital isoseismal maps; macroseismic coordinates of epicenter and depth; references and original papers etc.) for about 100 events for the period from 1997 up to 2011. The analysis of collected macroseismic data allowed to update the existing intensity attenuation laws for the earthquake prone areas in Russia and CIS. For majority of earthquakes the relationships between shaking intensity and epicenter distance were approximated by log-linear equations, which allowed the regional coefficients of Shebalin macroseismic field equation (Shebalin, 1968; 1977; 2003) to be verified. The obtained data were used by the Institute of Environmental Geosciences of RAS and Ex treme Situations Research Center for Extremum system calibration in order to increase the reliability of near real time loss estimates (Frolova et al., 2017). Comparison of simulated shaking intensities according to different variants with observed values allowed regional characteristics of intensity attenuation to be identified: 1. Macroseismic field equation and its regional coefficients, 2. orientation and 3. ratio k of ellipse major and minor semi-axis. These three parameters are essential for reliable loss computations in near real time and should be identified for the areas under consideration in advance during the calibration. Experimental checking of calibration was fulfilled for some strong earthquakes in the North Caucasus, Central Asia and Siberia. The boundaries of zones with stable parameters of shaking intensity attenuation were identified for these prone areas. Information about past events consequences and zones characterized by stable parameters of simulation models will allow to increase the reliability of loss computations and to shorten time to take a decision about rescue operations. Comparison of observed macroseismic data for some earthquakes in Turkmenistan with estimated shaking intensities in USGS Atlas ShakeMaps did not give good agreement. The process of collecting macroseismic data and identification of geographical zone boundaries with stable parameters for calibration of shaking intensity simulation models is long. It is evident that international cooperation is extremely vital in this activity.

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ESC2018-S39-217

HOW TO COPE WITH EARTHQUAKES IN HIMALAYA

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Among the natural calamities, probably earthquakes are the worst. There are no advance warnings and losses are instantaneous as well as long term. We are in the 18th year of the 21st century. However, the human lives lost and economic losses due to earthquakes and the resultant tsunamis in the past 17 years have far exceeded similar losses in the entire 20th century. The Himalayan seismic belt, extending from Kashmir in the west to Arunachal Pradesh in the east of India has been seismically one of the most active intra-continental regions. The Gorkha earthquake in Nepal of Mw 7.8 on April 25, 2015 broke a long seismic quiescence in the central Himalayan region. Many studies indicate that enough strains have accumulated to generate Mw 8 and larger earthquakes in the region. It is also argued that the Gorkha earthquake may not have released the accumulated strains and larger earthquake(s) should occur sooner or later. As short time earthquake forecast is not possible (though there are some success in medium term forecasts), and earthquake shall continue to occur, we need to develop earthquake resilient society. Developing earthquake scenarios as what would happen if one of the earlier earthquakes repeats today, and sharing it with the concerned state governments and public is extremely helpful. A couple of very successful exercises were conducted by the National Disaster Management Authority, Government of India, for a repeat of the 1905 Kangra earthquake and the 1897 Shillong earthquake during the years 2013 and 2014. The 1905 Kangra earthquake had claimed ~ 19,000 human lives. For a hypothetical earthquake of Mw 8, occurring near Mandi in Himachal Pradesh, a scenario was developed taking into account the estimated intensities, population density, typology of the houses. It was inferred that the human lives lost would be several folds higher (~9,93,500) than ~19,000 lost during the 1905 Kangra earthquake. Detailed preparations were undertaken before the mock drill conducted on the 13th February 2013 involving the states of Punjab, Haryana, Himachal Pradesh and the Union Territory of Chandigarh. A similar exercise was conducted for the north-east Indian states for the repeat of the Shillong earthquake of 1897 during 2014. Several short- comings in preparedness were identified. The best part was public awareness generation. The salient features of these exercises are also presented in this talk.

ESC2018-S39-292

CHINAGEOSS INTERNATIONALE DISASTER DATA RESPONSE MECHANISM

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ChinaGEOSS Disaster Data Response Mechanism (CDDRM) is a new type mechanism of non-governmental disaster cooperation, which can be considered as a complement of the inter-governmental disaster reduction. The mechanism is responsible for coordinating Chinese satellite agencies and scientific research institutions to contribute high-resolution satellite data and analysis products for affected countries and regions. The response process includes data acquisition, data sharing, data application and data publishing. At the data acquisition stage, the operation office will call and harvest pre- and post-disaster high-resolution satellite images from the national satellite application centers and commercial satellite operators. At the data sharing stage, a disaster service portal is released to effectively query the metadata information by the technical department. The international users can access on-demand data from different regional mirror sites in Asia, Europe and America. At the data application stage, scientific research institutions will use these data rapidly map injuries, damages and indentify possible safe areas. At the data publishing stage, all of the sharing data are published in the form of a data journal to protect the data provider's intellectual

property right. The CDDRM has been successfully launched four times for major natural disaster events around the world (e.g. the New Zealand earthquake in Nov 2016, the Mexico earthquake in Sept 2017, the Iran-Iran earthquake in Nov 2017 and the Cyclone Gita in Feb 2018). More than 7 domestic agencies and 12 satellites in China have been involved in the past activities. These activities have been regarded as a best practice for the GEO-based emergency response under the Sendai framework, paralleling with the government level mechanisms.

ESC2018-S39-317

ADVANCEMENT OF EARTHQUAKE HAZARD AND CONSEQUENCE DATASETS FOR THE USGS SHAKEMAP AND PAGER SYSTEMS

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The complex patterns of earthquake shaking and the resulting consequences from past events form the basis of empirical hazard mapping, loss modeling, and earthquake scenario generation. They also provide critical information for calibrating mechanistic and numerical loss models. The systematic compilation of earthquake consequences is critical to the advancement of the U.S. Geological Survey's (USGS) ShakeMap and PAGER systems and other near-real-time earthquake products. We continue to compile, develop, and refine key openly-available datasets that contribute to such endeavors. Our goals are to improve the operational capability of the USGS National Earthquake Information Center (NEIC) as well as contribute and distribute data for wider use in earthquake shaking and impact studies by risk modeling communities and other interested parties. We report on several advancements on both the hazard and consequence modeling fronts. ShakeMap software improvements allow for more accurate interpolation both in space and in frequency. New maps around the globe will benefit from ongoing improvements to our global Vs30 site-condition map sourced from regional efforts that will replace our default topographically-based proxy map in these areas. The ShakeMap Atlas is being continuously updated with recent significant events, many of which have higher quality constraints than in years past. Improved internet-based macroseismic data, better coverage of strong motion networks, and detailed fault rupture geometries all contribute to many new well-constrained events. Landslides and liquefaction can contribute significantly to earthquake hazards, so we are in the process of developing a new product to estimate ground failure distributions (and ultimately, their consequences) in near-real-time. To this end, USGS and many colleagues have created an open repository of earthquake-triggered ground-failure inventories generated by the community, providing geospatial datasets for landslide and liquefaction model development and testing. On the loss modeling front, fatality and economic loss datasets (PAGER-CAT) are being updated in parallel to the ShakeMap Atlas. We are also adding aftershock loss data to these catalogues to inform loss model modifications specifically for aftershock sequences. This will likely take the form of modifications to exposure and vulnerability functions following the mainshock. Lastly, on a new front, we are developing a Bayesian updating framework with which we will be able to consider the incorporation of rapid and uncertain ground-truth loss observations to continually update the loss models in near-real-time following a major earthquake.

ESC2018-S39-431

ON SEISMIC HAZARD IN ARCTIC

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The Central Arctic region is located outside of modern estimates of seismic hazard due to its polar geographic location and because it is mainly a water space poorly studied in terms of the strong seismic movements parameters. Nevertheless, the Arctic is a promising area for the future production of hydrocarbons; therefore seismic hazard and risk assessment are necessary. The central part of the region, in particular, the Gakkel Range, is the most seismically active part of the region. The basis of the seismic hazard assessment studies is known to be the seismological data presented in a certain way, the process of their preparation is described in the

work. The catalog of earthquakes includes initially 2000 events that occurred in the region of the Gakkel Ridge in 1908 -2015. At that a number of earthquakes occurred in the early instrumental period was obtained from publications describing the events of the period, and the rest were registered after 1964 and the data is contained in the ISC catalog. The total catalog was cleaned, as well as it was subjected to manual declustering. The energy of events in the original sources is represented in the form of magnitudes of various types. Further, the earthquake magnitudes were reduced to the Mw moment magnitude using own developments. As a result, a homogeneous summary was obtained and an assessment of the representativeness of events of different energy levels at different time periods was carried out. The catalog of earthquakes is supplemented with information about earthquake focal mechanisms.
The next step of work is the construction of a map of the zones of possible earthquakes sources, both from known geological and tectonic data, and using the structural analysis technique of M.K Ovsov. Using original approaches, a map of tectonic segmentation of the area based on the moment magnitude was compiled. Particularly effective were the latest digital bathymetry and gravimetry in the reduction of Faya data. As a result of the analysis, the ridge rift zone was distinguished, which is not surprising, but transform faults also were revealed. The data obtained can be used to estimate the seismic risk of stationary and floating platforms for oil and gas production facilities in the region.

ESC2018-S39-523

CASUALTIES IN THE ITALIAN SEISMIC HISTORY

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The estimate of casualties due to earthquakes is increasingly requested to calculate risk scenarios for civil protection purposes or to estimate losses for the insurance market. The assessment of casualties is generally developed at a global scale, although being strongly dependent on local factors. The seismotectonic characteristics (i.e. features of the seismic sequence) of the territory, the vulnerability of the building stock, the time of occurrence of earthquake are as influential as the economic, politic and social elements. The interest in historical analogues of modern earthquakes in terms of casualties is hence high, but both the identification of such consequences in historical sources and their quantification in terms of modern ready-to-use data are not straightforward. With the aim of systematically investigating the casualties, either direct or indirect, due to past earthquakes in Italy we inspected all the seismological studies on the earthquakes occurred in more than 1000 years (from 1000 to 2014) as from the Italian earthquake catalogue CPTI15 (http://emidius.mi.ingv.it/CPTI15-DBMI15/). We considered the wealth of historical studies and datasets made accessible through the Italian Archive of Historical Earthquake Data ASMI (Archivio Storico Macrosismico Italiano http://emidius.mi.ingv.it/ASMI), the Italian node of the European Archive of Historical Earthquake Data AHEAD (http://www.emidius.eu/AHEAD). For each earthquake in CPTI15, ASMI stores and provides access to both the study used for the compilation of the catalogue, and the multiple, alternative studies that were collected, compared, and validated in order to select the most reliable one, upon which the catalogue entry is based. At present, ASMI gives direct access to more than 350 studies, either as PDF files or external links, related to more than 5800 earthquakes, including all the 4584 earthquakes in CPTI15, as well as nearly 1000 earthquakes below the threshold of the catalogue (intensity 5 and/or magnitude 4.0), traces of earthquakes occurred before the year 1000, and records of fake earthquakes. Starting from earthquakes with maximum intensity greater than or equal to 8 MCS (corresponding to heavy damage, including some collapses, to 25% of the total building stock) in CPTI15 we searched for evidences of casualties first in the supporting study, and then in all the alternative ones archived in ASMI. Such a strategy considers that seismological studies, even referred to the same earthquake and based on the same historical sources, usually treat casualties as a side information, interpret the information in different ways, or do not consider it at all. Actually, it is worth mentioning that historical seismological studies were generally not interested in the social impact of earthquakes. In addition, different historical sources might account for the same phenomenon in contrasting ways. We defined a

set of more than 500 records dealing with casualties related to more than 300 earthquakes, extracted from several studies. We considered also records explicitly mentioning the negative evidence of casualties. The information retrieved was also compared with data on casualties provided by global databases such as the NGDC/NOAA "Significant Earthquake Database" (https://data.nodc.noaa.gov/cgi-in/iso?id=gov.noaa.ngdc.mgg.hazards:G012153) and the "Catalog of Damaging Earthquakes in the World" (http://iisee.kenken.go.jp/utsu/index_eng.html). The analysis of such records resulted in a very wide range of cases, difficult to be unambiguously classified. Examples of such a variety are: i) well-defined numbers of casualties (though sometimes different from one source to the other), ii) precise descriptions of casualties on a place-by-place basis; iii) indications of casualties not directly related to the earthquake (consequences of landslides, emotional shock, panic and running away, etc) iv) rough quantifications of casualties (e.g. from… to…) or non-quantitative information (e.g. many/few/negligible), v) the simple information about the presence or absence of casualties without any further detail, and so on. To account for such a diversity, a standardized scheme was created to classify the retrieved information in the most synthetic and "parametric" way. Given the particular characteristics of the Italian seismicity and vulnerability of the building stock, we found clear evidence of casualties even for low intensity earthquakes. Indeed, in many situations, even for moderate earthquakes, casualties are due to the collapse of a single building rather than to diffuse heavy damage. For such a reason we will extend our analysis also to additional 475 earthquakes with intensity between 7 and 8 in CPTI15, and then, to even smaller ones. Although deriving quantitative conclusions from such a diversity of situations is difficult or sometimes impossible, our analysis results in the lack of any robust correlation between earthquake size and number of casualties, which seems to depend on many other factors, mainly if and how historical sources describe such effects, and how the same sources were later investigated in modern seismological studies. In addition, we verified the scarce reliability of the considered global databases, which sometimes report approximate and obsolete (and even fake) data about Italian earthquakes. In any case, extreme care and expertise should be adopted when using such kind of data, especially in decision-making processes.

ESC2018-S39-547

ANALYSIS ON OPEN DATA INTERCONNECTIVITY FOR EARTHQUAKE DISASTER RISK MANAGEMENT

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As stated in the Sendai Framework, disaster risk reduction requires a multidisciplinary approach and decisionmaking based on the open exchange and dissemination of disaggregated data. CODATA Task Group of Linked Open Data for Global Disaster has considered the needs for the data infrastructure proposed in the Sendai Framework and by partnership collaboration has provided conceptual building blocks to help realize the Sendai imperative. The issues around database development are complex and harmonizing data policies, improving data access and interoperability, and developing long term strategies for data stewardship are essential and can be applied for earthquakes and other disasters. At present the earthquake impact databases exist at global, regional and national levels. As a rule, impact databases are oriented for definite end-users and with increased understanding of the disaster trends and their impacts, better prevention, mitigation and preparedness measures can be planned to reduce the impact of disasters on the communities. Insurance companies were amongst the first to create and maintain the databases on natural hazard consequences, including earthquakes. A range of impact data bases with global, regional or even national coverage include:

• NatCatSERVICE is a database which collects information and assesses losses on natural disasters and cover a period from 79AD to the present; the post 1980 data are considered to be most reliable; the database is maintained by Munich Reinsurance Company (Munich);

• Sigma is global natural and man-made disaster database; it includes information on social and economic losses from 1970 to the present; the

database is maintained by Swiss Reinsurance Company (Zürich);

• EM-DAT provides information on the human impact of disasters - such as the number of people killed, injured or affected, number of homeless and estimated damage cost; this database is maintained since 1988 by the Centre for Research on the Epidemiology of Disasters (CRED, Université Catholique de Louvain, Brussels);

• Global Significant Earthquakes Database is a global listing of over 5,700 earthquakes from 2150 BC to the present and is maintained by National Centers for Environmental, NOAA;

• GLIDEnumber database is maintained by ADRC in collaboration with ISDR, CRED, UNDP, IFRC, FAO, World Bank, OFDA/USAID, La Red, OCHA/ReliefWed; is intended to facilitate linkages between records in diverse disaster databases;

• WHO. Global Outbreak Alert and Response Network pools human and technical resources for rapid identification, confirmation and response to outbreaks of international importance;

• DisInventar Sendai is a Disaster Information Management System, and UNISDR, the United Nations Office for Disaster Risk Reduction is promoting is promoting this as a tool that helps to analyze the disaster trends and their impacts in a systematic manner and is now used by over 80 countries worldwide;

• GEM Earthquake Consequences Database is a compilation of damage and loss data from over 80 major earthquakes designed to support development of earthquake risk models;

• Extremum knowledgebase is compilation of damage and loss data from over 1,700 significant earthquakes to support calibration of Extremum system models; maintained by Seismological Center of IGE, RAS and Extreme Situations Research Center;

• Spatial Hazard Events and Losses Database for the United States SHELDUS is a county-level hazard data set for the U.S. and covers natural hazards and is maintained by the Hazards & Vulnerability and Research Institute at the University of South Carolina.

The current state of earthquake impact data management and acquisition patterns indicates a great need for interconnection of dispersed scientific data in order to access, analyze vulnerability and mitigate seismic risk. The CODATA Task Group White Paper examines how such interconnection might be achieved, stating that “it is of utmost importance to promote and practice the collection, management, opening up and sharing of scientific data related to disaster risk research, as well as the employment of relevant technologies and applications, consistently and globally”. The disaster data landscape is a complex one, though information on loss data is rapidly growing. When human, monetary or environmental losses occur as a result of a disaster, such as an earthquake, extensive loss data are often collected and stored by different organizations, but the thoroughness and accuracy of the data vary from country to country and even among local entities. While many methods do exist, there is no standard that introduces a reasonable level of comparability into the resulting assessment results. This leads to gaps and overlaps in the data, and biases that ultimately affect the quality of research conducted and policies made on the basis of the data. This paper addresses these issues as part of a process to seek engagement and consensus building where practical and possible.

ESC2018-S39-626

THE GEM EARTHQUAKE CONSEQUENCES DATABASE (GEMECD) WITHIN THE RAPID LOSS ESTIMATION FRAMEWORK

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In the aftermath of an earthquake, governments and institutions directly concerned with disaster management, financing as well as insurance and public and private research institutions are confronted with the challenge of in real-time or rather rapidly (within few weeks) determining the overall economic impact of an event, in order to identify priority sectors for recovery and rehabilitation, understand differential geographic impacts, comprehend relative public versus private damages, mobilize financial resources, understand vulnerability and risk differentials etc. Existing approaches and tools used for rapid (or real-time) post-disaster damage assessment vary significantly in implementation time, the level of detail they deliver, and their level of accuracy but they all rely on past disaster experience to estimate present disaster impacts. To quantify damage and associated direct and indirect losses, disaster risk modeling techniques, in combination with historical damage data, census and

socioeconomic survey data, as well as damage surveys, satellite imagery, drone footage, and other media, are being used. Historical damage data play a central role in this process, as the life-span of buildings and other infrastructure is quite long while the exposure of existing assets is quite dynamic, consisting of old and new ones. Earthquake performance observations and surveys are thus of crucial importance for assessing the vulnerability of existing buildings and other assets. For best use to be made of historic consequences data it is essential to bring them together and make them accessible to the wider research and application community, to enable cross-event analysis to take place, and to determine to what extent lessons learnt in one country or region or asset or structure type can be applied elsewhere. The Global Earthquake Consequence Database (GEMECD) was developed under the auspices of GEM, the Global Earthquake Model in 2011-14, with the participation of partners in Latin America (ERN-AL), Oceania (GNS Science), the Far East (Kyoto University), the Middle East (Kandilli Observatory) and North America (SPA Risk) to make possible for the first time, an easy and open access to data that have been painstakingly collected by various authorities and researchers around the world over the past decades after important earthquakes. What sets GEMECD apart is its global outreach and its adherence to inventory and structural taxonomies developed in parallel within the GEM project. This ensures that GEMECD can be directly utilised for vulnerability assessments and loss model validations for many regions around the globe. The database has been designed in such a way as to be able to capture the full spectrum of earthquake consequences which can be visualised as a matrix of the interaction between the various inventory assets and the earthquake-related damage agents. The database assembles consequence data of five different categories (standard buildings, industrial installations, critical facilities, lifelines and transportation networks) and consists of data sets on ground shaking damage to standard buildings; human casualty studies and statistics; ground shaking consequences on non-standard buildings, critical facilities, important infrastructure and lifelines; consequences due to secondary, induced hazards (landslides, liquefaction, tsunami and fire following) to all types of inventory classes and lastly, socio-economic consequence and recovery data (provided by EM-DAT in CRED, Louvain University). Underlying each of the 70 events in the database that took place between 1967 and 2011 is a set of upgraded shake maps developed by the US Geological Survey which serves as a common hazard denominator for analyses. Central to GEMECD is the ability of carrying our analyses across events through a set of tools housed within GEM's OpenQuake Engine. For earthquake engineers, this would enable cross-event analyses to be derived for given building inventory classes, and levels of ground motion, leading to more robust empirical vulnerability relationships, but also enable layman users to learn about earthquakes of the past. This paper presents the GEMECD, its contents and capabilities. Housed within a public GIS platform, GEMECD serves to inform users on consequences from past events, as a benchmarking tool for analytical loss models and to support the development of tools to create vulnerability data appropriate to specific countries, structures, or building classes. By seeking out relationships linking past events and the environments they affect, it is hoped that our understanding of the potential regional consequences from earthquakes will improve, especially in parts of the world where there have been fewer documented events in the recent past.

ESC2018-S39-817

OBSERVATIONS ON THE BUILDING DAMAGES DURING THE JULY 20, 2017 BODRUM-KOS EARTHQUAKE

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The Mw 6.6 Bodrum-Kos earthquake occurred at 22:31 (UTC) on July 20, 2017 along the western section of the Gokova Gulf, between the Bodrum Peninsula and the island of Kos. The epicenter was located at latitude 36.96°N and longitude 27.41°E, with a focal depth of 6.0 km according to the Bogazici University, Kandilli Observatory and Earthquake Research Institute (KOERI). The epicenter is about 12 km E-NE of Kos, Greece and 10 km S-SW of Bodrum, Turkey. The maximum PGA among stations deployed in the Bodrum Peninsula was 295 cm/s2. This normal faulting earthquake was highly felt in the Aegean, especially on the island of Kos and in the Mugla

Province. No direct observation of the rupture zone could be made, as this was an off-shore event. However, a tsunami was observed which affected the coast of Bodrum Peninsula and the northeast coast of Kos island. The instrumental seismic intensity was disseminated as VII by KOERI. More than 100 injuries and 2 fatalities were reported by turkish and greek sources. The earthquake caused damage predominantly in masonry buildings. The building stock in the Bodrum peninsula consists of three main building types. Reinforced concrete, masonry and composite. The buildings classified as composite are originally built as a small masonry dwellings and enlarged by RC additions over the years. The so-called composite buildings and masonry buildings received significant damage during the earthquake. The RC building stock in Bodrum is relatively young, 2-3 stories high and with low-moderate level earthquake resistant design. They performed well during the earthquake. Sustained damages were limited to slight damage. The research for this paper is supported by Boğaziçi University Research Fund Grant Number 10260.

ESC2018-S39-840

USE OF GROUND MOTION SIMULATIONS OF A HISTORICAL EARTHQUAKE FOR THE ASSESSMENT OF PAST AND FUTURE URBAN RISKS

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Erzincan city located in the Eastern part of Turkey at the conjunction of three active faults is one of the most hazardous regions in the world. In addition to several historical events, this city has experienced one of the largest earthquakes during the last century: The 27 December 1939 (Ms=8.0) event. With limited knowledge of the tectonic structure by then, the city center was relocated to the North after the 1939 event by almost 5km, indeed closer to the existing major strike slip fault. This decision coupled with poor construction technologies, led to severe damage during a later event that occurred on 13 March 1992 (Mw=6.6). The 1939 earthquake occurred in the pre-instrumental era in the region with no available local seismograms whereas the 1992 event was only recorded by 3 nearby stations. There are empirical isoseismal maps from both events indicating indirectly the spatial distribution of the damage. In this study, we focus on this region and present a multidisciplinary approach to discuss the different components of uncertainties involved in the assessment and mitigation of seismic risk in urban areas. For this initial attempt, ground motion simulation of the 1939 event is performed to obtain the anticipated ground motions and shaking intensities. Using these quantified results along with the spatial distribution of the observed damage, the relocation decision is assessed and suggestions are provided for future large earthquakes to minimize potential earthquake risks.

KEYWORDS: Risk, Uncertainty, Historical Earthquake, The 1939 Erzincan, Ground motion simulation

ESC2018-S39-1080

IMPACTS OF PAST EARTHQUAKES UPON SOCIETIES: SPECIFIC EXAMPLES, TENDENCIES, APPLICATION TO KNOWLEDGE BASE

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The possible scale of consequences of strong seismic impact on society remains unclear. These consequences almost always strongly depend also on a particular political and military situation. In most cases, the impact of an earthquake does not lead to a dramatic change in the structure of society and in the character of nature management. A few alternative examples can be presented however. Below we present two examples when strong paleo-earthquakes were accompanied by a radical change in the structure of a land use, the change from the prosperous farming that existed on the basis of developed irrigation systems to more primitive nomadic type of nature management had occur. Most of population had left the previously well prosperous areas. In both these discussed cases the devastation caused by earthquakes was close to the time of the conquests of Genghis Khan and Tamerlane in Central Asia (present-day territory of Kyrgyzstan) and the conquest of Palestine by the Arabs. In this latter case, there was a complete collapse of the system of urban settlements, surrounded by complex irrigation systems that had existed before in the territory of the Negev desert (Israel). Concerning these earthquakes arises an important question of their localization.

Do they took place locally in the Negev desert currently characterized of a low seismic activity? Or the destruction were resulted from more remote events that occurred in the Dead Sea rift area. The character of the damages indicates the local nature of the earthquakes. With regard to the territory of modern Kyrgyzstan data on seismic destruction indicate the level of seismic activity of the southern coast and the Eastern part of Issyk-Kul essentially exceeding that estimated by recent instrumental data. It should be noted that in both cases, the radical decline in the level of economic activity can be explained, apparently, by the combined influence of the natural and military-political factor, and not by any one of them. Such examples, similar to other cases of parametrization of the ancient strongest earthquakes, provide important information for assessing the maximum possible seismic effects in the area under study and are important for calculating the long-term seismic hazard. They seems to be important also for historical science, since the scale of the consequences of strong natural (in particular seismic) catastrophes makes it possible to better understand the history of the development of this territory, as well as characterize the degree of resistance of ancient societies to strong negative impacts. We would like to emphasize also that the available data on the loss values from ancient earthquakes give grounds to suggest a tendency of decreasing of relative sensitivity of civilizations to strong negative natural impacts over time (because of technological development). It should also be noted that the cases of a stronger impact of seismic events on society are relatively more fully reflected in historical and archaeological sites, which creates prerequisites for their fuller study, which is important in the formation of the knowledge base on the impacts of natural disasters on ancient civilizations and for assessing the long-term seismic hazard of corresponding territories

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ESC2018-S40-258

A SEISMOMETER IN THE CLASSROOM: "LOOKING FOR EARTHQUAKES" WORKSHOP

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Earth sciences in general and seismology in particular have a small visibility in the secondary school system in Spain. To try to reduce this problem, we are carrying a workshop named "Looking for earthquakes", focused to introduce high school students to the world of seismology. This workshop includes two sessions. In the first one, a general presentation is made, which includes images and animations of faults and deformations due to earthquake activity. People is used to seeing images of destruction in the media after big earthquakes, but not to see scarps of faults, movements along transform faults or effects of liquefaction that give a real idea of the power of those events. Later on, the seismometer is installed in the classroom for a period of 3-4 weeks and the students are invited to follow the global seismic activity during this period and look for seismic waves arrivals in their instrument. If it is logistically feasible, the students participate in the installation and configuration of the seismometer. In the second session we review the data recorded by the instrument and we discuss the origin of the signals, which typically include the activity in the school and its surroundings, the energy variations related to the oceanic waves and, eventually, local and/or teleseismic records. Finally, we explain how the analysis of seismic records provides a powerful tool to investigate the structure of the Earth. This activity has been carried out using the SEP seismometer, specifically designed for educational purposes. This beautiful instrument allows to clearly visualize the physics concepts involved in seismometry (pendulum, electromagnetic induction) and it is sensitive to teleseismic arrivals, but can get blocked rather easily and therefore requires a periodic surveying, not always easy to perform onsite. To avoid this problem we have now acquired a RaspberryShake datalogger equipped with a 4.5 Hz geophone. This instrument is very robust and has been prepared to upload the recorded data to a global public repository that can be accessed in near-real time, providing an additional attraction for the students. However, its frequency response does not allow the recording of surface waves of large teleseismic events, often the most spectacular phases in absence of large local events. (this contribution is partially founded by the MISTERIOS project, CGL2013-48601-C2-1-R)

ESC2018-S40-330

VIRTUAL SEISMOLOGICAL NETWORK OF SOFIA UNIVERSITY

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Virtual Seismological Network of Sofia University (VSNSU) is operating since 2015 and it is supported by the Scientific Research Fund of Sofia University. The network consists of 16 seismic stations from 6 different countries in the Balkan Peninsula region - Albania, Bulgaria, Greece, Romania, Serbia and Turkey. The stations provide an open access to real time data. The amount of data is collected on a computer in sector Geophysics, Faculty of Physics, Sofia University "St. Kliment Ohridski" via software package SeisComP3. Additionally, in case of network interruptions, the missing data is requested by the seismic data centers IRIS and EIDA. Collected seismic data are converted from miniseed to necessary for analysis data formats. The data are analyzed by different computer software, studying varied parameters and properties of the seismic sources or the environment through which the seismic waves propagate. The seismograms are used to define seismic wave phases of teleseismic events, the different magnitudes of regional events as well as in cross-correlation of seismic noise. The measured magnitudes are used to define the specific statistical relations for the Balkan Peninsula to determine the respective magnitude depending on the amplitude of the respective wave and / or the epicenter (hypocenter) distance and / or the duration of the earthquake. The advantage of cross-correlation of seismic noise over the classical measurements is that the target area does not need to be seismically active, the resolution depends only on the density of the used stations. The data from VSNSU is used in student`s exercises, preparation of theses and research. Acknowledgment: TIDES COST Action 1401

ESC2018-S40-449

EARTHQUAKE INDUCED DISASTERS SYNERGY: A GAME THEORY APPROACH

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The probabilistic nature of seismic hazard process has always placed decision makers in an awkward position, as far as stages I (mitigation) and II (preparedness) of disaster management are concerned. For these stages, the deterministic approach of seismic scenarios or a successful earthquake prediction would be preferable. However, deterministic seismic scenarios are not necessarily realistic, as cost benefit analysis requires. In addition, earthquake prediction has not yet provided specific answers to the question "when, where and how big will be the earthquake". These questions pose a serious ethical problem to geoscientists, on how to use their scientific results in risk-communication (L'Aquila case). In practice, geoscientists and decision makers follow different approaches, deontology (right) and consequentialism (good for society), characterized by their dissenting views of the relation between right and good, according to the ethical theory. In natural disaster management research, game theory models consider government agencies and private companies interacting as players in a disaster relief game. Usually these models are two-player models, but when there is a multi-agency collaboration, the models become multi-player games. A two-player game between an attacker and a defender can be defined as: (1) sequential where attacker moves first, (2) sequential where defender moves first and (3) simultaneous (Seaberg et al, 2017). A destructive earthquake is considered as the 'attacker who moves first' and the decision makers as the 'defenders'. When the earthquake process is initiated, various automated mechanisms are activated as defense actions (e.g. real time Peak Ground Acceleration - Velocity distributions and Early Warning Systems, EWS). For responders, stage III (response) phase has begun. In the timeline of an earthquake-related disaster, the earthquake occurrence initiates stage III. Post-earthquake induced phenomena, such as large aftershocks, landslides and tsunami, which, in some cases, have proved more or less as disastrous as the mainshock itself, are still at stage II. In such cases, the attacker (earthquake) is not a stable 'dummy' player, attacking once and for good, but it has a more dynamic behavior, as it is able to activate the attack of its 'fellow players', thus causing worse repercussions. In this study, we seek to apply the model after the earthquake occurrence, also by incorporating earthquake induced phenomena. More specifically, we attempt to re-design the game tree suggested by Wu (2015) for "policy selection related to earthquake prediction" in the sense of policy selection related to the synergy of the above-mentioned earthquake related natural hazards. We apply this game tree in the cases of Atalanti (Greece) 1894, Brežice (Slovenia) 1917, Cephalonia (Greece) 1953, Tohoku (Japan) 2011 and Lefkada (Greece) 2014 earthquakes and compare the effects of the mainshocks and their induced phenomena.

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ESC2018-S40-588

DEMONSTRATION OF EARTHQUAKE ENGINEERING BASICS FOR HIGH SCHOOLS

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Earthquakes and plate tectonics are commonly taught at the under-graduate level since junior high or even earlier. However, the understanding

of how ground shaking affects buildings is seldom presented, if at all. Basic principles in earthquake engineering, like vibration, fundamental period, resonance and damping, are essential to understand seismic risk and its mitigation measures, the variable degrees of destruction due to an earthquake or the principles behind earthquake resistance building codes. Inspired by the experience of other researchers and outreach programs, IDL developed a set of experiments that can be easily reproduced by high-schools to illustrate earthquake engineering basic concepts, from the simplest single degree of freedom oscillator (SDoF) to a multi-storey building and to a tuned mass damper system. During an earthquake, buildings receive energy from the shaking ground. If the energy is not dissipated, it can accumulate and attain destructive levels. Even a small vibration, if properly synchronized with the building characteristics, can lead to its destruction. In fact, the simplest model for a building shaken by an earthquake is a vertical pendulum, that behaves like a rocking chair. Both are examples of single degree of freedom oscillators (SDoF). Both dissipate very little energy so that energy accumulates between swings till destructive levels. This is the concept of resonance, which occurs when the applied force has a similar frequency to the natural frequency of the oscillator. The SDoF is easily modelled by pieces of wood on top of metal rods of different lengths, like the BOSS model discussed extensively in "Seismic Sleuths" (FEMA/AGU, 364 pp., 1995). Our SDoF model is made of 4 rods connected to a skate that facilitates its manipulation. The model illustrates the concepts of resonance, natural frequency and damping. It can also be used to demonstrate the destructive effect of ponding, when two buildings of different height are vibrating side by side. More advanced students can estimate the natural period of the model by simple dynamometer measurements (knowing the mass of the system). These estimates can be compared to the measured periods. A relationship between natural frequency and height can be assessed. In fact, buildings are more complex than the simple vertical pendulum. Therefore, instead of a single resonance frequency, buildings will have several resonance frequencies associated with vibration in different directions but also under torsion. They are better described as multiple degrees of freedom oscillators (MDof). To illustrate this complexity, we built with simple materials a model of one 3 storey high building with greater flexibility in one direction, displaying 3 main resonance frequencies, corresponding to the three main vibration modes. To study experimentally the building dynamic response (as induced by ground shaking during earthquakes) the model is forced on the top storey by an eccentric motor whose frequency can be varied using a potentiometer. The oscillator will have 3 main resonance modes, that can be visually identified: i) all storeys swaying for the same side; ii) two storeys sway to one side; iii) all 3 storeys swaying opposite to each neighbour. The vibration and resonances can be inspected using a low-cost accelerograph connected to an Arduino. The data recorded can be analysed offline and its spectra computed to show the resonance frequencies. Like in true buildings, where the action of wind or natural ground noise will excite resonance modes in a non-destructive way, we can record on our model the simulated action of wind by giving gentle pushes to each of the storeys. The spectral analysis of the data will show the resonance frequencies. Ordinary wind is not an issue for typical-size buildings. However, for very high buildings, like the Taipei 101 with nearly 500 m height, even a gentle breeze will cause a large swaying on top floors rendering them very uncomfortable. To solve this problem, engineers designed the "tuned mass damper" system, which dissipates the energy transferred by the wind to a system that doesn't cause any harm to the building. This dissipating system also acts to reduce the building oscillations in case of earthquakes, which are common in Taiwan. Inspired on the video provided by the "Practical Engineering" website (https://www.youtube.com/user/gradyhillhouse/featured) IDL built its own system, representing one single high-rise building, designed to oscillate in one preferred direction. One pendulum, with a variable grip to control its damping, and variable length to control its natural period, is connected to the top storey. The success of the tuned mass damper in reducing the amplitude of the oscillations can be confirmed visually or by recording the movement with the same accelerograph and Arduino as used for the MDoF model. This model can also be used to illustrate the effect of the mass on the natural frequency of SDoF systems, by changing the weight of the building top adding masses. This publication is

supported by FCT- project UID/GEO/50019/2013 – IDL

ESC2018-S40-600

EDUCATING FOR EARTHQUAKE SCIENCE AND RISK IN PORTUGAL

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Instituto Dom Luis (IDL) has led the seismology awareness initiative Seismology@Schools in Portugal in recent years. (http://idl.campus.ciencias.ulisboa.pt/sismologianaescola/). Through this initiative we aim to teach students and teachers alike about seismology and its crucial role in civil engineering.The following activities are carried out towards this goal. We have a room at Faculdade de Ciências da Universidade de Lisboa with simple experiments that showcase several topics related to seismology, including a tsunami tank, a simulator of buildings resonance, several types of seismometers and a shaketable. During the school year we receive groups of students ranging between 12 to 18 years old and researchers from IDL guide them on a tour. Each of these experiments is used to describe physical principles that the students learned in school, thus strengthening their knowledge. The shaketable is used to train the visitors on the adequate behaviour in case you are caught inside during an earthquake, drop, cover and hold on! They also learn on the differences between the concepts of magnitude and macroseismic intensity. Another activity that we organize is pro actively visiting schools and delivering workshops related to seismology. In this case, we transport these experiments to the schools or the schools build them with the students, depending on time and available resources. The third activity that we conduct is to set up a network of seismometers in schools, which currently counts with 5 schools. Through this project schools get a sense that they are contributing to science. This is especially the case when we show them a screenshot of their seismometers recording a local earthquake. Seismology@Schools is a volunteer-based project, organized by seismologists during their spare time. This is both our greatest strength and our achilles heel: on the plus side we guarantee the most accurate knowledge but on the negative side we lack the time that this project deserves to expand further. What distinguishes our project from other citizen science project is that we are an institution facilitating the involvement of the citizen, usually it is either a group of citizen that create the initiative or a private company. Another key difference is that we involve everyone from the school, from the kids, teachers and the parents. This permits a broad scale dissemination of important safety measures in the advent of an earthquake. This work is supported by FCT-Portugal (UID/GEO/50019/2013 – IDL; PTDC/GEO-FIQ/2590/2014 - SPIDER).

ESC2018-S40-617

OBSERVATORI FABRA RASPBERRY BASED SEISMIC SYSTEMS

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Observatori Fabra has been operating in Barcelona since 1904. It was created and maintained by the Reial Acadèmia de Ciències i Arts de Barcelona (RACAB), an association of investigators of science and its applications stablished in 1764. It has always been devoted to astronomical, meteorological and seismological observations and studies. This observatory is a relatively small and independent institution with a limited budget and personnel but with a significant historical scientific patrimony and a remarkable interest to use it for both scientific and divulgation purposes. Seismic observations started regularly in 1906 and have been maintained active since then. We think that affordable high quality seismic instruments are crucial to allow small institutions such as ourselves and even amateurs to continue working on many interesting low-cost projects and to encourage educational or citizen seismology. The progress in electronics and specially the development of embedded computers of high performance and low power and price, allow to design instruments seismic monitoring with very low finance. In this poster we detail how we have modernized our short-period instruments Geotech S-13 at Fontmartina seismic station (in the Parc Natural i Reserva de la Biosfera del Montseny, 50km away

from Observatori Fabra) with new systems based in Raspberry technologies to digitize, send, store, analyze and show their seismic observations. This new data from Fontmartina station coexists with the traditional Teledyne systems for radio transmission of the same amplified signal tobe recorded with ink on paper seismograms at Observatory Fabra, in operation since 1988. And also with the data generated by the broadband instrument Güralp CMG40T placed in the same hole and operated by Institut Cartogràfic i Geològic de Catalunya (ICGC) since 1999. We also show briefly how we are digitizing with similar technologies several old instruments in Observatori Fabra (from smoked paper pendulums to short-periods Mark-L4C) and other educational instruments. We plan these for absolutely different purposes, even more focused to historic, educational and citizen seismology. There are more types of embedded computers (i.e. ACME Arietta, BeagleBone, Banana Pi, Intel Edison, NanoPC-T3, Parallella Board, Arduino, etc), most of them using Debian, or a modified version, so the software here presented can be easily adapted to them. Today the price is very similar for all Raspberry Pi models, so the choice is commonly focused on Zero model by its lower power consumption and the B3+ module by its high performance. Sometimes the data transmission system (WIFI links or similar technologies) increase both the power consumption and the performance in the remote unit, so it could be a better solution to chose a high performance Raspberry Pi. The choice of digital analog converter is the factor that conditions the quality of the system. The AD7710 has been chosen with a resolution of 16/24 bits and sampling frequencies up to 250Hz. It has differential input and anti-aliasing filter, gain x1-x128. At 24 bits the resolution decreases with increasing gain. It presents great stability in temperature, which allows it to operate in extreme environmental conditions. A ATmega328 microcontroller is used as an interface between the AD7710 and the RASPBERRY. For the development of the firmware for ATmega328 the ARDUINO-UNO platform is used, with a low price of the development system, whose easy programming in C facilitates its use in educational activities. Multiple modules can be synchronized and operate as a seismic array. We present this contribution to detail to a potentially interested audience these diverse examples mentioned above of technologies and projects easily doable with limited resources.

ESC2018-S40-833

"AS IF YOUNG PEOPLE MATTERED": AN EXPERIMENT IN RESILIENCE-NURTURING AFTER THE 2016-2017 CENTRAL ITALY EARTHQUAKES

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The INGV Edurisk group (set up in 2008) develops educational projects aimed at improving individual and collective awareness of natural risks and resilience from grass-roots level. The latest one was carried out after the 2016-2017 Central Italy seismic sequence in Ascoli Piceno, a municipality with a population of above 100.000 and the capital town of one of the Provinces most affected by the earthquakes. The project was funded by the National Dept. of Civil Protection and the Ascoli Town Council to provide teenagers and adults from Ascoli with an opportunity to take stock of the short- and long-term effects of the earthquake on their lives, examining its likely social, economic and cultural consequences and finding how to meet them in a conscious and proactive way. The activity included several educational and informational actions carried out from May 2017 to February 2018. In May 2017 the interactive exhibition Tutti giù per terra (We all fall down) was set up in Ascoli and was visited by local students from schools of all grades and vocations. This allowed to establish connections with their teachers and paving the way for the next stage of the project, that took place in November-December 2017 and involved a selected class or students group from each of the eight secondary schools of Ascoli and teachers from school of all grades (kindergartens, elementary and secondary schools). The teenagers took part to three workshops led by ConUnGioco Onlus operators and INGV researchers. They were encouraged to discuss their personal experience of the 2016-2017 earthquakes and ponder on the reconstruction-to-be, particularly considering in which way different possible formulas adopted for the reconstruction could influence their personal future and the future of the Ascoli territory.

Several interesting (and disturbing) considerations became evident during the workshops: most teenagers claimed at first to be indifferent to the subject or tended to deny that the earthquakes had affected/changed their lives very much or at all. The students also showed a widespread inability to think of their home territory as a united whole and a strong inclination to trust any kind of rumours and unreliable or even fake news implicitly and uncritically. Finally, they did not seem aware that post-earthquake reconstruction could be planned in several different ways, and not only as a mere return to the status quo. In parallel with the students workshops, training courses were held for the teachers. The participants worked on the same issues proposed to the students, showing more awareness than, but basically the same doubts, misgivings and sense of helplessness as the teenagers. For them too the reconstruction seemed to be a course set by someone else, without much space for their active involvement. At the end of this stage of the project, the students participated to the creation of a new interactive exhibition, focused on two main themes ("earthquake" and "reconstruction") and structured to serve as a place in which to show their points of view and expectations, as a receptacle in which to collect the views, experiences and proposals of the Ascolani people on the same issues and as a public space in which citizens of all ages could improve their knowledge of earthquakes (as a physical and historical feature of their territory) and find simple tools which which to build up a basic but sound "culture of risk". In the third phase of the project (January-February 2018) the Palazzo dei Capitani, one of Ascoli's two town halls hosted the exhibition "Facciamo noi!" (Let's do it by ourselves!), for which the secondary school students, under the coaching of ConUnGioco Onlus operators, had created part of the objects on display. The same teenagers then took on the role of guides for the schoolchildren and adult visitors, showing increased competence and self-reliance in this peer-to-peer experience, as well as in an "outgoing" side-experience that took them in the streets to interview passersby and collect their opinions on the exhibition's main themes of earthquake and reconstruction. The teenagers also acted as mentors for the youngest visitors in creative workshops during which children were encouraged to express their own concept of "earthquake-proof houses" in drawing and collage. The vivid imagination shown by the children's artwork helped the teenagers to understand that looking to the future can also mean expecting that something different and better than the obvious can happen. The project involved about 80 teachers, 240 secondary school students, 500 schoolchildren, and above 500 adult citizens. We hope to have helped them all to grew more capable to face the complex future adventure of the reconstruction of their common home.

ESC2018-S40-842

CLASSROOM SEISMOMETERS BUILT FROM "LEGO" BRICKS THAT REALLY WORK

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Since 2006 the British Geological Survey have been developing seismology resources for schools in order to raise the profile of geosciences in UK school education and encourage students to consider geoscience options at University level. Despite the UK not being a tectonically active region the country has a long history of observational seismology, from the early days of horizontal pendulum seismometers designed by Milne and Gray, through the development of broadband seismometers from Guralp and pioneers of array seismology with the Blacknest nuclear test monitoring group. The first school seismometers used in the UK in 2006 were essentially the same as the 1905 Gray-Milne horizontal pendulum seismometer, a 15-20 second natural period horizontal pendulum with magnetic eddy-current damping, updated for the digital age with a coil and magnet velocity transducer and digital computer recording. These instruments have just the right frequency response to pick up clear P, S and Surface wave signals from large teleseismic events. They were an instant hit with teachers, both geography and geology subject teachers who loved the connection to current earthquake events and also physics subject teachers who liked the open and visually accessible design. From 2006-2016 over 600 such instruments were installed in schools across the UK and Europe. However the design has some flaws as a classroom instrument, it is

expensive (over 600 Euros to purchase) and requires a very stable ground floor location to install. When the manufacturer ceased production in 2017 it was decided that a simpler and cheaper design was required. The result is a simple vertical sensor design with a natural frequency of 1-2hz. The geometry of the design is a simple hinged armature suspended by a flat spring bent to a C shape. This design retains the visual simplicity that physic teachers like, and can be used as a demonstrator for electromagnetic induction and basic physics lessons. However the true beauty of the design is that it can be built with “lego” bricks (with the addition of non-lego components for the spring, coil and hinge). The result is an instrument with a similar response to a 2hz vertical geophone that can be made by students and teachers alike for a cost of less than 50 euros (or even less if you can supply your own “lego” bricks) Such a sensor is not ideally suited to pick up the low frequency signals from teleseismic events however trials with schools have proven the sensors capable of detecting the P wave arrivals from distant events and it has the advantage of being very compact and insensitive to ground tilt. In several of the schools the sensor is tested in P wave signals have even been detected even when the sensor is located on the windowsill of an upper storey classroom. Earthquakes are not however the only signals that produce detectable vibrations. Classroom experiments can be carried out by connecting the sensor to the microphone soundcard input of a PC and recording the high frequency vibrations caused by students jumping up and down or dropping small weights from different heights onto a table near the sensor. More exotic local signals can be detected from freight trains passing nearby (up to a km from the school), quarry blasts or even “football-quakes” if the school is within a km of a football stadium and the home team scores a goal, in Leicester these are called #vardyquakes or in Barcelona #messiquakes.

ESC2018-S40-845

IN A FREE DIGITAL SOCIETY, LEGAL INSTRUMENTS HAVE TO BE UNDERSTOOD

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The GNU General Public Licenses pioneered by Richard Stallman and Eben Moglen, have also directed substantial adversarial attention by the richest and most powerful monopolies and institutions in the history of information technology. As example, I cite the current legal case Oracle America, Inc. v. Google, Inc. within the United States related to the nature of computer code and copyright law. Sun Microsystems, Inc. had three important Free Software projects that have put users of technology in control of their own computing - OpenOffice.org, Java, and MySQL. After acquiring Sun Microsystems in 2010, Oracle had come into ownership of the Java Application Programming Interfaces (APIs) packages developed by Sun in the 1990s, and since 2006 is covered by the GNU General Public License GPL. The United States Court of Appeals for the Federal Circuit found that Google's reuse of the APIs had violated copyright law, ruling in favor of Oracle. The position of the Federal Circuit is particularly important for its decisions on patent law as it is the only appellate-level court with the jurisdiction to hear patent case appeals in the United States. Many educational institutions assume that participating in a digital society is good. However, the assumption is not necessarily true. The reality is that today, even though we live in a more inclusive society, the internet and technology have become a danger to us. As a society, we need to understand the technological trends and discuss their implications. If we ignore these problems, leaving it to the market, the state, or other groups to influence and decide, we'll all find that we have no freedom, no privacy and nothing to protect populations from undue government interference, tracking of our movements and from baseless interrogation about our identities and activities. It will be our own fault because we decided not to participate.

The first instance of a court addressing GPLv3 occurred in a decision by the Regional Court of Halle, Germany, in July 2015. The Halle case is extremely important for educational institutions. The legal judgement offers affirmation that free software licenses must be respected worldwide, as documented in several court cases in European countries (e.g., in Slovenia, the Netherlands, Sweden, France, Austria, and the UK), as well as outside Europe (e.g., Taiwan, Korea, the US, and China). Consequently, the legal judgements affirm that the terms of the GNU GPL must be observed exactly, just like the clauses of every

other contract. Inaccuracies in the observance of free software license terms are violations of the law and make it illegal to use the software. In this talk I will start by discussing the completely disparate areas of law - copyrights, patents, trademarks, and tradesecrets. I then describe the way laws are being misused to make software development a dangerous activity. The legal problems will be discussed and supported by an analysis of court opinions rather than lectures and textbooks.

ESC2018-S40-870

IMPROVING THE AWARENESS OF NEXT-GENERATION ON SEISMIC RISK

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The project “Alternanza Scuola Lavoro” (ASL) was instituted in Italy by the law 107/2015 and it is an innovative teaching method based on the “learning by doing” strategy. By means of practical experiences, students are helped to consolidate and expand their knowledge acquired at school, to test their attitudes, to orientate their field of study and future career and to acquire basic skills that can be used in their future work. The ASL project carried out by the geophysical group of the CNR-IMAA institute was aimed at raising the awareness of students on seismic risk throughout interactive lessons, practical experience, and field activities, which lead the students to independently make actions for risk mitigation both as citizens and as future experts. Two schools with a different basic education, the Scientific high school Galileo Galilei and the Surveying technical institute Einstein - De Lorenzo, were involved in the project for a total of about 80 guys. The training activity started in 2017 with some classroom lessons and has continued the following year with field activities giving basic knowledge about: i) the seismic hazard and geological settings of the sites to be visited; ii) the physical principles underlying the relevant geophysical methods to be used in such contexts and iii) the seismic vulnerability and damage assessment of existing buildings based on the AeDES form used in Italy for damage survey after seismic events. The field camp was organized in three sites of Central Italy (Amatrice, Arquata del Tronto and Norcia) struck in 2016 by a seismic sequence characterized by two main events occurred on August 24 (Mw 6.0) and October 30 (Mw 6.5). Amatrice and Arquata del Tronto were mainly affected by the event of the 24th of October since they were at about 9 km distance from its epicentre. Norcia, on the other hand, was mainly affected by the strongest event, with an epicentral distance of about 5 km. Furthermore, the degree of damage which involved the chosen sites was greatly different. In particular, the impact of the seismic event of the 24th of August on the municipalities of Amatrice and Arquata del Tronto was highly destructive, with many building collapses (partial and total, mainly in the historical centres). On the other hand, buildings of historical centre of Norcia municipality, which suffered moderate-to-strong earthquakes in the recent past (1979, ML 5.9; 1997, ML 6.0), were already reinforced. These interventions caused therefore a global reduction of seismic vulnerability, even if differences on the degree of damage of buildings were observed in different areas of the town. The field activities carried out by the students were aimed to a better comprehension of the three fundamental elements of the seismic risk. The urban seismic hazard was estimated in terms of subsoil geophysical characterization evaluating site amplification effects and near surface electrical resistivity properties. Students were guided to the execution of 30 ambient seismic noise measurements and 2 Electrical Resistivity Tomographies (ERT) for Norcia subsoil characterization. The students familiarized themselves with the vulnerability and damage concepts by means of the compilation of AeDES form. Further, the direct listening to the stories and the experiences of local people helped students to understand, even from the point of view of a "learning related to the emotional sphere”, how exposure to the seismic phenomenon play a crucial role in the risk assessment. The final step of this activity consisted in data processing and preliminary interpretation of the results. Students also prepared reports and multimedial products presented during their final exam.

ESC2018-S40-876

EDUCATIONAL AND CITIZEN SEISMOLOGY ACROSS EUROPE AS PART OF SERA

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In 2017 six educational seismology networks from across Europe (UK, France, Switzerland, Portugal, Greece and Romania) joined forces under the banner of an EU Horizon 2020 project SERA http://www.sera-eu.org. Seismo@school programmes using observational seismology as an educational tool in schools and non-formal educational settings like museums or citizen-seismology projects are effective methods to bring people in touch with complex scientific concepts and to increase their understanding of earthquake hazards and risk. The group are holding a series of educational workshops for teachers (in Romania 2017, Portugal 2018 and Greece 2019) together with discussion workshops school seismology network operators and scientist working on citizen seismology projects (in UK 2018, France 2019 and Switzerland 2020) Results from these collaborations and meetings are being disseminated widely through websites and social media as well as connections to existing EU structures like SCIENTIX

ESC2018-S40-962

LESSON LEARNED FROM EDUCATIONAL SEISMOLOGY PROJECTS IN ROMANIA AND HOW TO STEP UP FROM SEISMOLOGY@SCHOOL TO CITIZEN SEISMOLOGY

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The Seismology@school concept was already validated globally through the success and impact of several projects and networking activities developed especially in the last decade. The main objectives of the initiatives were to increase the level of knowledge of teachers and pupils on earthquake phenomena, earthquake effects, preparedness measures and also promoting the role of education and schools in disaster risk reduction. At the core of the initiatives are educational seismographs installed in schools, operated by teachers and students, acting as a trigger for the initiation of a full range of in class or out-of-school formal and informal activities. The model was also introduced in Romania in the framework of ROEDUSEIS project (2012-2016 - Romanian Educational Seismic Network) and gave project initiators (a research & education partnership) the opportunity to draw a wealth of conclusions and to define the best ways to continue this initiative, as well as to focus on actions that offer sustainability and maximize the impact. Many of the conclusions are common to all similar projects and identify the need for continuous training and technical support for schools as well as finding the best way of introducing resources as complementary educational materials and not, as much as possible, supplementary work for both teacher and student. However, increasingly a fact is underlined in the users' feedback as well as identified in SWOT analysis: mutual benefits and the sense of ownership as an engine for authentic and long lasting engagement. This statement leads us to the idea of citizen seismology as a next step, consisting in a broader approach that involves multiple benefits but also multiple challenges. Even though most seismology@school programs have set as objective the acquisition of qualitative earthquake recordings by the schools' networks, these data tend not to be quantitative or scientifically rigorous. This may be due either to the educational instrument performance limitation or to the operating environment and the equipment decalibration (as a result of their use for educational purposes), or even the failure to keep the seismometer in operation. Although the above reasons can be considered as purely objective and operational, an indirect but linked reason is the lack of proper user understanding of how research tools works and how data are used by researchers. This could also be translated as a lack of involvement and motivation. To overcome this limitation and to motivate users to participate, each targeted stakeholder category should be properly addressed, a role should be assigned to them, particular tools should be made

available and dedicated actions need to be planned. To be mentioned that by users we do not only mean teachers and students, but look at a broader concept in which schools and seismology are gateways to community access (open schooling). More pragmatically, if the most valuable feedback, in the case of citizen seismology, is the quick data provided in the aftermath of an earthquake, especially from an area poorly seismic monitorized, then easy access to particular applications should be facilitated and promoted. This led us to another project findings pointing out that request for feedback should not be based solely on a scientific altruism and the public good, but rather linked to providing access to a service. For example, requesting feedback after an earthquake notification and returning the result (estimated intensity) back to the user. In this way, the importance and usefulness of the feedback will be fully understood by the user. In conclusion, we envisage the model of citizen seismology as a development and continuation of seismology@school concept, also allowing to approach more sensitive but mandatory open data policy and legal issues, exploring the current legislative environment and the ways in which it both enables and constrains citizen seismology efforts.

ESC2018-S40-1048

STUDENT EXPERIENCES IN PERFORMING AMBIENT NOISE SEISMOLOGY

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Nowadays non-specialists are becoming increasingly involved in seismological studies. Ambient noise tomography is a recent subsurface mapping technique that utilises the common surface wave signals propagating through two stations. We give an analysis of student experience in performing the standard processing pipeline for ambient noise and the road ahead.

ESC2018-S40-1051

THE «SCHOOL STUDY EARTHQUAKES» PROJECT RESULTS AND FUTURE PLANS

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South Eastern Europe and Turkey exhibit the highest seismicity in the Mediterranean Basin and the North Anatolian Fault System. In order to stimulate the interest of young students in seismology in this earthquake prone region, a consortium of research centers from 5 countries developed the "Students Study Earthquakes" (SSE) project network, under the European Union-Erasmus+ framework, in 2015. The SSE network of schools monitor and study real-time earthquake data from 18 seismographic stations that are mostly located in schools in Bulgaria, Cyprus, Greece, Italy and Turkey. The network employs the TC1 vertical seismometer, especially designed for educational purposes and easily assembled by teachers and children. At each seismographic station, the real time earthquake waveforms are collected with the Jamaseis educational seismology software on a local PC that is part of the distributed school network operated by the Institute of Geodynamics, National Observatory of Athens. This data is shared amongst the network of schools and teachers play a key role in developing and applying innovative educational tools. The results of the SSE project concerning the recent seismicity (2015-2017) in South Eastern Europe and Turkey, will be demonstrated in this presentation and student-teacher interaction and network sustainability will be discussed.

ESC2018-S40-1066

MEDIA COVERAGE OF SCIENTIFIC ISSUES IN THE AFTERMATH OF EARTHQUAKES: A COMPARATIVE RESEARCH ON EMILIA 2012 AND AMATRICE 2016

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After a large earthquake, broadcast and traditional media play a crucial role, fulfilling complex social and psychological functions, which can alternatively foster or hinder the return to normality of both exposed communities and society at large. Media are a relevant resource for citizens to cope with disasters. Especially in the first days after the first big shake, scientists are asked by the media to provide scientific assessments of seismic phenomena, to explain both what is happened and what is purported to happen in a next future. As a consequence, geo-scientists visibility and voice across the media is doomed to rise till to become central in media narratives of disasters, providing an unprecedented window of opportunity to disseminate relevant messages about hazard, risk mitigation and resilience. The urge to make sense of the event thus results in a genuine appetite for scientific knowledge (Wein et al. 2010), stressing the role of journalistic mediation along the whole risk / science communication process, as well as the ability of the media to provide public with steady and authoritative point of references to anchor their understanding of seismic phenomena. The here presented research considered the media coverage of scientific issues during the Emilia 2012 and Amatrice 2016 seismic crisis, to the extent they were covered by the four most circulating Italian national newspapers: 'Corriere della Sera', 'la Repubblica', 'La Stampa' and 'Il Messaggero' within the 31 days following the first earthquake shock. The research considered 248 editions of the mentioned newspapers, and collected and processed data by using content analysis, an empirical methodology that allows analysing media messages as well as other types of communicative texts, in order to formulate statistical inferences on their explicit meaning (Neuendorf 2002). The comparative analysis of news media coverage of Emilia (2012) and Central Italy's earthquakes (2016) highlights the relationship between physical events and media representation of expert knowledge, highlighting key trends and some significant signs of change in the news frames used to assess and communicate seismic risk. The newsworthiness of scientific advice is everything but taken for grant: in fact, analysis made emerge two relevant points. First, media coverage of geo-science follows a 'typical' life cycle, broadly compatible with hype media theory (Vasterman, 2005). Most of the articles are indeed concentrated in the very first days, rapidly decreasing in the following days till to disappear at the end of the month. Second, the daily amount of news story is significantly defined by three variables: the maximum magnitude of aftershocks in the previous day, the number of days after the 'zero event' and the degree of controversy / conflict that arises from scientific evaluation of the ongoing phenomena. The research has been partially published by the Italian journal 'Problemidell'Informazione', but will be deepened still further in order to give geo-scientists a more comprehensive description of data and of their related implications on their own work.

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ESC2018-S41-53

LASTQUAKE: A MULTI-CHANNEL INFORMATION SYSTEM FOR GLOBAL SEISMIC RISK REDUCTION

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The EMSC, one of the top global earthquake information centers, has been empirically developing a multichannel rapid information system comprising websites, a Twitter quakebot and a smartphone app for global earthquake eyewitnesses. At the intersection between seismology, citizen science, and digital communication, its aim is twofold: to offer timely, appropriate information in regions where an earthquake is felt and to collect high numbers of eyewitnesses' direct and indirect observations to improve rapid situation awareness. Engagement with eyewitnesses is based on the rapid provision of tremor detection (between few tens of seconds to a couple of minutes) which is derived from the analysis of indirect information, i.e., Internet and social media searches by eyewitnesses eager to find out the cause of the tremor. Eyewitness' behavior is comparable to real-time seismic sensors when using EMSC websites or LastQuake smartphone app. Crowdsourced data is then fed back into the ongoing information product improvement and situation awareness which, in turn, attracts more eyewitnesses through a viral spread. The use of visual communication for felt report collection has proven to be fast and efficient on a global scale with, on average, 50% of felt reports being collected within 10 minutes. The LastQuake app now includes timely geo-targeted safety checks and safety tips to describe behaviors to be encouraged or avoided after violent tremors. We argue that this simple, affordable sy

ESC2018-S41-108

MODELLING THE CHANGES OF CUMULATIVE RESILIENCE TO EARTHQUAKE HAZARDS FOR ADAPTING TO METROPOLITAN SEISMIC RISK USING A GIS-BASED MULTICRITERIA EVALUATION APPROACH

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1.Background

Asia-Pacific region is one of the most vulnerable areas of the world to the devastating earthquake hazards. Particularly, metropolitan areas are chronically vulnerable and risky to earthquake hazards in parallel with high agglomeration of population, economic activities and improper urban developments encroaching onto hazard-prone areas. Recently international efforts, such as the Sendai Framework for Disaster Risk Reduction 2015-2030, identified ways to reduce disaster risk by concerning more on building resilience for the particularly vulnerable areas. In Taiwan, approximately 70% of the population and economic activities are concentrated in metropolitan areas. However, local authorities rarely use resilience approach to link earthquake risk management with emergency and land use planning, because they lack instruments and financial resources to assess resilience and implement risk management to tackle earthquake impacts. Resilience assessment can help decision-makers encompass various stakeholders' local knowledge and their engagement into conceptualizing resilience and communicating land use policies to the public. However, a challenge for decision-makers is how to develop the metrics that can adequately measure the resilience within the context of risk reduction in its full complexity. Especially, these metrics should involve the cumulative effects of multiple resilience factors and their dynamics faced by metropolitan communities. This study, thus, proposes a novel methodology to assess the cumulative earthquake resilience and its evolution, and to examine the relationships between the attraction factors relevant to the general process of urbanization, land use changes and resilience variability with a focus on the local levels.

2.Methods and data

Combining the resilience concept of United Nations International Strategy for Disaster Reduction, focus group meetings and literature review, an indicator-based framework for resilience assessment is developed. This framework conceptualizes resilience as a complex interaction between the capacity of inherent conditions and the process of earthquake hazard impacts at the local levels. The procedure of our investigation includes three steps. First, we created a resilience metric entitled the Cumulative Resilience Indicators to Earthquake Hazards for

Metropolis (CRIEHM) that can serve as a proxy for the communities' inherent conditions and their various capacities contributing to earthquake resilience. The CRIEHM is built with a goal to characterize and compare the resilience to earthquake hazards within metropolitan regions based on a composition of multiple indicators. We organize these indicator metrics into four categories: (1) hazard exposure; (2) inherent socioeconomic conditions; (3) land use plans and infrastructural capacity, and (4) adaptive capacity and social learning. Second, using Taipei Metropolis in the northern Taiwan as the case-study area, the CRIEHM is combined with a participatory geographical information system (PGIS)-based multicriteria evaluation analysis (MEA) and spatial statistical techniques into the selection of indicators, comparative assessments and mapping of the changes in the cumulative resilience of Taipei Metropolis between 1996, 2006 and 2016. Third, to examine the affecting factors of cumulative resilience changes, we develop a Cumulative Earthquake Resilience Change Model for Metropolises (CERCMM), using four urbanization attraction factors to reflect how they influence the process of land use planning and urban sprawl that could lead to the resilience change. The attraction factors consist of urban infrastructures, transport networks, land use changes, manufacturing and service industry developments. We then conduct a spatial-based regression analysis to test the CERCMM. To illustrate the proposed methodology, the data are collected from the National Science and Technology Center for Disaster Reduction, Taiwan, as well as from the National Land Use Investigation, Taipei Municipal census and Directorate-General of Budgets' Accounting Statistics.

3.Results and policy implications

The results of the CRIEHM analysis demonstrate highly heterogeneous distribution patterns of the cumulative resilience across Taipei Metropolis, and highlight the trends of their long-term changes. The least resilience areas unfold as clustered patterns and spatial analogues across the metropolitan regions, rather than randomly distributed. The spatial distributions of the least cumulative resilience areas have only slight changes. Most of them are concentrated in the suburbs and numerous densely populated and historical downtown areas (such as Taipei City center), as well as in some villages on the north coastline in the three study periods. When examining the CERCMM, it indicates that most of the areas with new developments and inferior socioeconomic contexts were getting worse in resilience in the past twenty years. This is mainly due to land use intensification and compaction in the historical downtown center, and rapid urban sprawling by residential, industrial and road infrastructure stretching into hazard-prone areas. These findings suggest that land use planning should consider the socioeconomic progression and infrastructure investment factors that contribute to urban compaction, dispersal, and address current as well as future urban developments resilient to hazard risk transmission. Policy-makers should make some trade-offs between building resilience and reducing urban development and density in hazard-prone areas. The methods presented here can be applied elsewhere in the world to highlight priority areas for further investigation and contribute towards improving metropolitan earthquake resilience and risk management.

ESC2018-S41-112

BUILDING URBAN MODIFIERS CLASSIFICATION ACCORDING TO THEIR HABITABILITY AFTER AN EARTHQUAKE.

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The seismic vulnerability of a building refers to its predisposition to suffer damage after an earthquake. Today there are many studies that classify buildings by taking into account their seismic vulnerability (ATC-13, EMS-98, RISK-UE, HAZUS, SYNER-G, WHE, GEM, PAGER) and there are also numerous methodologies that use these typologies or add new ones to obtain the damage of the buildings after an event of this type (RISK-UE, HAZUS). The aim of this research was to find out whether the urban modifiers were related to habitability. To this end, it has developed a classification of the urban modifiers that increased the damage after an earthquake and later, after a statistical study and the modifier grouping, it has classified the typologies of buildings that could remain uninhabited after an

earthquake. This information would be very useful for councils and regions that are located in seismic risk areas since it would allow them to catalog their park estate as well as for civil protection that could predict which buildings would remain inhabitable. In order to determine the link between the urban modifiers and the damage was carried out an exploratory study of such modifiers in the city of Lorca with the aim of establishing their correlation with the damage caused by the 2011 earthquake 3 km from the city. It has been selected three areas of study in the city with a total of 816 buildings and conducted an exhaustive fieldwork to assess the seismic vulnerability. The buildings were classified according to their structure (concrete or masonry) and their urban modifiers. Besides, have been taken into account the ground on which the buildings were located and the type of damage to homogeneously compare the data and carry out a statistical study. As a result, an extensive and complete database with information about the constructions of Lorca was obtained and it was implemented in a Geographic information system. Later, have been conducted a correlation analysis to find out the link between the urban modifiers and the habitability and defined an index of discrimination. Having this first analysis, it has been calibrated the urban modifiers for each type of ground and each structural typology. This first graduation of the urban modifiers in relation to the damage will allow us to initially influence on the urban regulation in the city of Lorca and give recommendations for urban planning and reduce the damage of possible future earthquakes. Finally, have been studied their contingency table to assess the link between the dependence between two qualitative nominal or ordinal variables. Therefore, from this contingency table, we can assess the urban modifiers and habitability. With the obtained results, have been carried out a scale of habitability and added the levels with the associated probability to the damage greater than or equal to 70% on each constructive typology (concrete and masonry) and for each type of ground (hard and soft). As a result, have been obtained diverse building typologies that would give the habitability cartography with at least 70% matching, in other words, we could say with 70% reliability which buildings would be uninhabitable in Lorca if an earthquake with the same characteristics occurred in Lorca as it happened in May 2011.

Using this method, we can perform mapping analysis of the habitability of buildings that can provide an approach of great interest for mitigation tasks and early response planning. It is essential to transfer the results to the organisms responsible for city planning and management of civil protection and emergency in order to develop cities with less seismic risk.

ESC2018-S41-293

ALTER PROJECT: AN ALLIANCE FOR DISASTER RISK REDUCTION IN ARMENIA

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Disaster risk reduction initiatives –such as the globally agreed Sendai Framework 2015 – 2030- call for cooperation among all key stakeholders: Public and private sectors, local communities, NGOs, volunteers, and media etc. The ALTER project focuses on creating and testing such an alliance in Armenia for floods originating from dams' failures due to the occurrence of large earthquakes. Even though major progress has been done in disaster risk reduction in Armenia through UNISDR and World Bank projects, many things have to be done to optimize resilience through cooperation among all major players. The role of ALTER project is to bring experience from European Union Joint Civil Protection Mechanism area to Armenian partners (Armenian Government and key stakeholders) and through certain activities to build long term sustainable coalitions. This alliance will be based on transfer of methods, tools, knowhow and experience to serve specific objectives: 1) Identification and analysis of three (3) pilot areas. According to the special characteristics of each area, a specific set of activities on resilience will be elaborated. 2) Design and implementation of an activities

package that will increase resilience at the selected areas, underlining the importance of local communities and the cooperation between public and private sectors. 3) Improvement of risk management capabilities at local and regional levels. 4) Transfer of methods, tools, knowhow and experience for risk management planning and implementation of modern procedures at the selected areas. 5) Design, implementation and evaluation of risk awareness and dissemination campaigns to sensitize entities, stakeholders, local communities and general public. Focus will be at pilot territories and key decision makers that can also enable fast transfer of paradigm to other areas of Armenia and neighboring countries (cross border dimension, especially in the case of Georgia). 6) Integration, evaluation and continuation of activities through training workshops and small scale exercises. All activities, already in place by other initiatives, that can serve the aim of disaster risk reduction through broad alliances will be used and synergies will be sought and exploited. Furthermore, national and regional policies will be followed to mainstream ALTER project results and ensure their sustainability.

ESC2018-S41-331

NEW APPROACH TO THE GENERAL SEISMIC ZONING PROBLEM BASED ON THE THEORY OF EXTREME VALUES

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The most general approach to study of the recurrence law of the rare largest events is associated with the use of the limit theorems of the theory of extreme values. We use both these limit theorems and distribution laws - the Generalized Pareto Distribution (GPD) and the General Extreme Value Distribution (GEV). The unknown GPD and GEV parameters are typically determined from the available empirical data with the use of the maximal likelihood method (ML). However, the ML estimation is optimal only for the case of fairly large samples (number of events N>200–300), whereas in many practical important cases, there are only dozens of large events. We have used numerical modelling to examine the situation. It was shown that in the case of a small number of events, the highest accuracy in the case of using the GPD approach is provided by the method of quantiles (MQ). For the case of the use of the GEV approach it was found that the method of statistical moments (SM) works more effciently over other methods (ML and MQ). We applied these results to the seismic risk assessment problem. We have formed the aggregated data sets containing rare strongest earthquakes in subduction zones, regions of intracontinental seismicity, and zones of midoceanic (MO) ridges. In result we found quite accurate estimates of the GPD- and GEV-parameters for these three aggregated zones. These results confirmed the difference between character of the tail distributions typical of these three seismotectonic regimes. Factually, MO differs considerably from the other two, and the difference between subduction zones and intracontinental areas is smaller. The obtained results give possibility of correct estimation of recurrence periods of rare strongest events oc-curring in the subduction zones, in the midoceanic ridges, and in the intracontinental areas. However, their spatial resolution is too coarse for the general seismic zoning problem. In order to overcome this shortage we have elaborated the “Stabilizer” procedure of the parameter estimation. This procedure provides much more detailed spatial resolution, and thus is more suitable for the general seismic zoning problem. The prelimi-nary results of realization of such procedure are presented and discussed. The work was supported by the Russian Foundation for Basic Research (project no. 17-05-00351).

ESC2018-S41-400

HOW LIDAR AND IMAGE ANALYSIS CONTRIBUTE TO EXPOSURE AND VULNERABILITY ASSESSMENT?

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Earthquakes and their associated effects have catastrophic impacts on the societies from the economic, social and environmental point of view. Major earthquakes have the potential to not only cause significant damage to the built environment and infrastructure and lead to social losses (casualties and injuries), but also to disrupt the

social and economic life of the nations for years to come more than any other natural hazard. The most efficient way to prevent earthquake disasters is through creating built environment and societies that are resilient to the seismic risk, which is the ultimate goal of seismic risk studies. Two main components are responsible for seismic risk: earthquake hazard and exposure&vulnerability of built environment. Given that earthquakes are impossible to avoid, reducing the vulnerability of the exposed elements becomes the most appropriate mechanism to reduce the negative consequences of this kind of events. Thus, exposure and vulnerability have to be estimated in order to propose adequate, realistic and effective risk reduction measures. Structural vulnerability of buildings depends on particular architectonic features, such as construction materials, height (or number of stories), area, regularity and simplicity (in plan and elevation), state of preservation, etc. Generally, gathering all these data is not an easy task. Cadastral databases are a valuable source of information; however, either not all countries have an updated cadastre (especially developing countries) or there is not a data distribution policy available that allows users access the data. A further difficulty for the cities to update the building stock information is the high urbanization rate they are experiencing nowadays. In addition, this rapid urban growth is generally unsupervised and not planned, therefore not included in official records such as cadastral databases. All of this leads to deficient construction methods that increase the vulnerability of buildings to earthquakes. Field campaigns to make an inventory of the building stock carried out by experts in civil engineering and/or architecture is another option to estimate the vulnerability of a city's built environment. Nevertheless, it is an expensive, arduous, and time-consuming task. Given this, here is a major problem that scientists, administrations and companies have to face when estimating the exposure and seismic vulnerability for earthquake risk studies. As exposed before, commonly used methodologies to estimate exposure and vulnerability are usually highly time- and cost-intensive and cannot adequately cope with the increasingly high spatio-temporal variability in many present day cities. As a result, novel methodologies and techniques for exposure and vulnerability assessment need to be developed as a supplement to existing approaches: they have to be quick and easy to apply, and yield a positive benefit /cost rate. The scientific community have been researching in this relatively new field for the last decade (e.g. Ricci et al. 2011; Wieland at al. 2012). That is the motivation of the present research. Here we present a new procedure aimed at compiling exposure and seismic vulnerability databases. It is based on the combination of remotely-sensed data (LiDAR, satellite images and aerial orthophotos) and machine learning techniques. Expert knowledge of the local construction practices is also needed. The city of study is Port-au-Prince, capital city of Haiti, which was devastated by a magnitude 7.0 earthquake in 2010. The data we use are distributed free-of-charge by the Rochester Institute of Technology.

The procedure designed consists of three main phases. (1) First, we prepare and analyse the data. In this step, the LiDAR is classified to get the 3D-points belonging to the building roofs; and an OBIA is applied to the orthophotos in order to delineate the building footprints. (2) Second, we integrate both results to create a Digital Surface Model (DSM) of the city where buildings are the objects of interest. Each building is given some of the architectonic features mentioned above: area, height and roof materials. These are vulnerability-related attributes. In this second step, the exposure database is created. (3) Third, to complete the database, each building is allocated a vulnerability reference, i.e., the building typology. This is done through machine learning algorithms, such as Support Vector Machines, Random Forests or Bayesian Networks. Finally, we validate the exposure and vulnerability database by comparing with a ground truth set of samples. Approaches based on new technologies like the one presented here are powerful tools for risk assessment, in which to base prevention policies in the frame of disaster governance.

ESC2018-S41-401

AN HISTORICAL FLIGHT AND SOME OPEN QUESTIONS TOWARDS A PLURALISTIC BUT HOLISTIC VIEW OF RESILIENCE

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The term "resilience", found for the first time in several Latin authors, then passed through medieval culture until intellectuals who strongly

contributed to the birth of the modern scientific method (as Francis Bacon), 19th century encyclopedists, the Rankine's definition in engineering, and finally to psychology, anthropology, and ecology, with the fundamental Holling's contribution in 1973. In the last decades, the concept expanded quickly into social-ecological systems, disaster/risk assessment, sustainability, and adaptive capacity to cope catastrophic scenarios. Nowadays, "resilience" is largely used by multi-disciplinary scientists and representatives of public/private organizations, but with increasing ambiguity about its properties and attributes. This work wants to present an excursus through the ages and a brief (not exhaustive, of course) "state-of-the-art" regarding "resilience", pointing out some open questions of the current debate among researchers of different disciplines, working in the fields of hazard mitigation, sustainability, risk assessment, heritage preservation, and so on. Increasing popularity but still scarce unification depict the situation, where resilience still necessitates a robust effort of further multi-, inter-, trans-disciplinary research, going beyond the current fragmentation. Impressive tools supplied by Geomatics/Big Data management and extraordinary potentialities available from complex mathematical models give us now the opportunity to create 'a network of networks'; but the fast run of technology cannot be separated by a slower and shared 'Peripatetiké Scholé', exploring philosophical and scientific theories with a pluralistic but holistic view. Finally, a suggestion of some nuclei of future research is presented, that might be exploited in future studies.

ESC2018-S41-529

SEISMIC-INDUCED EFFECTS OF THE 2016 CENTRAL ITALY SEISMIC SEQUENCE REVEALED BY INSAR DATA

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The 2016 central Italy seismic sequence has been a ~3 months long sequence that produced several damages in the areas surrounding the epicenters of the earthquakes and caused hundreds of victims. The surface displacement fields due to the main events on August and October were effectively constrained by X-, C- and L-band InSAR data. They revealed significant deformation patterns close to the Amatrice, Visso and Norcia towns measuring more than 20 cm of ground displacement. However, many local surface deformations not directly ascribable to the main tectonic patterns together with several seismic-induced "secondary" effects as landslides, avalanches, subsidence, etc. have been detected and constrained by InSAR data. Such seismic-induced phenomena could severely impact the environment and the population in the surroundings of the hit areas. Therefore, our goal is to highlight the usefulness of multi-band InSAR analysis for Hazard assessment and Rapid Mapping purposes when in-situ investigations are difficult or dangerous to be performed. The retrieved InSAR-based information can support the Scientific Community and the Institutions in the management of crisis emergencies. We focused on four areas, named Monte Vettore, Podalla, Bolognola and Cicconi, where X-band Cosmo-SkyMed and C-band Sentinel-1 InSAR data revealed how the main seismic events of the sequence (re)activated several landslides and secondary faults interested by deformation up to ~2–3 cm along the satellite Line-of-Sight (LoS). In particular, thanks to COSMO-SkyMed data, we detected a clear local signal along the Mount Vettore, the highest mountainous relief of the Sibillini chain, following the Mw 6.0 Amatrice/Accumuli earthquake. In addition, a deformation pattern was also observed along the Deep-Seated Gravitational Slope Deformations (DGSD) of Podalla, in the proximity of the Fiastra Lake Dam. Furthermore, the seismic events occurred in the month of October produced some interferometric fringes along the Northern sector of the Sibillini chain, close to the Bolognola and Cicconi villages. Geomorphological and geological analysis allow us ascribing such patterns to ground displacement due to reactivation of gravitative and karst phenomena.

ESC2018-S41-554

POCRISC: TOWARD A COMMON CULTURE OF SEISMIC RISK IN THE PYRENEES

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POCRISC EFA158/16 project is 65% financed by the European Regional Development Fund (ERDF) through the Interreg V-A Spain France Andorra program (POCTEFA 2014-2020). POCTEFA aims to reinforce the economic and social integration of the French–Spanish–Andorran border. Its support is focused on developing economic, social and environmental cross-border activities through joint strategies favoring sustainable territorial development. The project started in January 2018 and lasts 3 years (2018-2020). The main objective of the POCRISC project is to encourage a common culture of seismic risk in the Pyrenees, developing harmonized approximations of the seismic vulnerability and risk, thereby promoting the dissemination of common and shared information to local authorities and the public, and providing decision-making tools useful for seismic crisis managers. All of this is focused on a cross-border area covering the regions of Catalonia in Spain, Occitania in France and Andorra. The expected results of the project include, at municipal level, an automatic estimation of the expected earthquake damage targeted to risk management actors for the benefit of the population. In addition, we will develop smartphones applications for assessing vulnerability and for post-seismic damage survey useful for seismic emergency management services. The practical guidelines for seismic vulnerability directed at construction technicians and risk managers will be of great added value. All these results will be implemented by the collaboration of cross-border emergency services during the seismic crisis exercises. This project exploits the results of previous European projects related to seismic risk, such as RISK-UE FP5 (Advanced methods for the assessment of seismic risk), ISARD INTERREG (Regional Automatic Seismic Information), SISPyr POCTEFA (Seismic Information System for Pyrenees) or NERIES FP6 or TOPO-IBERIA. From these projects POCRISC takes advantage of, among others, methodologies for vulnerability and seismic damage assessment at the regional level, and the ShakeMap tool which automatically generates maps of ground motion. The results of POCRISC are intended to be implemented in other border areas or at a Euro-Mediterranean level. The tools and guides that will be developed are transferable to other areas exposed to seismic risk. These tools should support emergency management in these areas promoting decision help for post-seismic interventions. The development of the smartphone application for damage assessment can be used anywhere in the participating countries. In addition, extensive scientific dissemination is foreseen through publications, international conferences and post-earthquake intervention workshops.

ESC2018-S41-757

UNCONVENTIONAL APPROACH IN COMMUNICATING RISK PREVENTION

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The concept of public health is most commonly linked to the feared occurrence of epidemics and contagion, which have a great impact on the collective imagination and are part of society's cultural baggage, experiential and virtual. However, it also includes other problems not as immediately apparent such as environmental, hydro-geological, and seismic risk. From an examination of some of the dramatic events that have occurred in Italy related to the geo-environmental setting of the country and to the effects of the interaction with anthropic pressure, there emerges the need to provide the general public with correct and clear information on the complex scenario characterizing Italian country.
The traditional approach used in Italy up until now in addressing these themes, has not come up with results worthy of mention. To turn disasters into a show in the media as often happens in "peace time", has the effect of distancing the audience from possible future situations. To talk about them immediately following a catastrophic event instead induces an effect of surreality that can lead to anger and bewilderment. Neither of these

two communicative styles provides effective training for adopting measures of prevention and self-preservation. Some natural events are considered catastrophic for their damaging effects on society, however many of these effects are more due to an inappropriate management of the environment rather than the event itself. In order to prevent the continuation of the occurrence of such pernicious situations, it is necessary to spread the knowledge of natural mechanisms so that the general public becomes aware of the dynamics that characterize our planet's balance. To this aim, we argue it is indispensable to test new methods of communication in order to reach a wide audience in an understandable way. Experience teaches us that tackling the subject of the prevention of risk and protection from danger (the avoidance of exposure) is very difficult. Instead, what is neededis a communicative strategy that informs the public of the characteristics of a territory (understood as a natural and cultural environment) and the relative operative dynamics, just as one should understand the anatomy and physiology of one's own body in order to manage and protect it in the best possible way. A series of initiatives carried out in Italy over the last three years based on the integration of outdoor sports that take place in the landscape and the environmental sciences. The theoretical underpinning from which this study begins, is the role of knowledge in cognitive-behavioral processes that are activated during physical activity performed in a natural setting. This concept will be applied in various situations and with various target audiences. In this case, the attention is focused on television audiences, using sport events in transmitting information about the territory in which the event is taking place, providing public with those notices that are essential in promoting preventative behaviour in regards to environmental risk and that of self-protection in the eventuality of highly dangerous natural events. In this study, integrating environmental sciences, public health and outdoor sports, we have considered cycling to be the sport that best lend themselves to our project. Analogous possibilities could be made for skiing hiking, orienteering, climbing, and last but not least, sailing, which, especially in Italy, is a necessity and an instrument of sustenance as well as a sporting discipline, and one that is too often carried out only by the elite of society. Cycling was a natural choice both for its widespread popularity and for its close ties with the landscape. Cycling is an excellent sport, mostly performed in the environment "en plain air", loved and practiced universally, and is increasingly becoming a means of providing independence and integration for disabled people. It represents a transport solution with zero environmental impact and thus is a fundamental resource for making smart cities possible. Moreover, as a sport that enjoys a large following at the competitive level, cycling favors the processes of identification and thus has high potential for spreading scientific information to the general public. A wide open point of view is the first step in performing research following a holistic approach: it gets closer to the natural aptitude to observation. In this sense the study of landscape contrasts with the fragmentation of knowledge: it requires a collective action, in which everyone is aware of putting their discipline in the service of a cognitive strategy. Moreover, such kind of approach, offers new perspectives in the transmission of knowledge, while opening a dialogue between teachers and students, as well as between technicians, decision makers/ politicians/citizens.

ESC2018-S41-880

WEB-BASED TOOL FOR ASSESSMENT AND DISPLAY OF SCENARIO-BASED SEISMIC RISK

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We present a web-based tool for the development of seismic risk scenarios. The design of the back-end of the tool presents three databases required for the calculations and a set of automated processes. The databases include a fault database to select earthquake source, a soil condition shapefile to compute site-specific ground motions and a buildings shapefile including building data, as contour geometry, number of stories and vulnerability class. The most important sequence of programmed processes is the estimation of seismic damage given the user-defined earthquake rupture and the building database (see below). The front-end contains three different parts. The first part is an informative page on the key aspects of the tool. Importantly, it gives the user three different options to display the final results, in terms of the probability level

associated with the seismic scenario. These are high-probability, low-probability-high-impact or very-low-probability-very-high-impact. This high-probability scenario considers the median estimate of the ground motion at each site and the modal damage degree for each building site. The low-probability-high-impact level takes into account the median-plus-one-sigma ground motion and the modal damage degree for each site and, finally, the very-low-probability-very-high-impact level displays the results corresponding to the median-plus-one-sigma ground motion and the percentile 75 of the damage distribution for each site. The second part of the front-end allows the user to input the data required to specify the seismic source. Two input modes, manual and automatic, are available. The automatic mode refers to the seismic scenario corresponding to the maximum rupture that can occur in a given fault segment (according to the data contained in the fault database). This mode is supplemented with tools for the selection of faults matching specific criteria about the style-of-faulting, maximum expected magnitude and distance to a specific site. It is intended for the design of extreme earthquake scenarios. By contrast, the manual mode does not restrict the rupture to a specific fault segment nor a maximum magnitude scenario. It allows selecting any point of the study area and defining the geometry of the fault plane and slip motion, assuming a magnitude-dependent rupture area and a uniform slip distribution within it. The validation of the seismic source automatically starts a chain of processes for damage estimation consisting of several stages (programmed in the back-end). The first one is the computation of the distance from the source to all sites. The second one is the computation of the site-specific response spectrum at each building site using a ground motion prediction equation. The third stage is the identification of the performance point of the building, according to its vulnerability class and the site-specific response spectra demand. This is the input required to estimate the damage distribution of each building at the subsequent stage. The next and final stage is the estimation of the debris produced in each building and its accumulation and distribution in open spaces (sidewalks, roads, etc.). The third sage consists of the visualization of results. The parameters represented in choropleths for every building of the database are: vulnerability class, peak ground acceleration, spectral acceleration (for the fundamental period of the structure), expected damage degree and volume of debris allocated in each 1-meter wide contour band (counting from the façade contour). The present tool will be useful for different purposes. It can help civil defense officials, risk managers and decision makers to evaluate different scenarios and probabilities in a relatively easy way. It will be also useful for outreach and education, raising awareness in the population about the exposure to earthquake risks. In this regard, the information provided is not restricted to primary damage to buildings, but also to secondary damage to elements exposed in open spaces. Risk aggravating effects such as streets blockage and open space covered by debris will be also portrayed. The tool is prepared to be applied in different target areas providing the appropriate input databases.

ESC2018-S41-967

UNDERSTANDING PEOPLE MENTALITY REGARDING SEISMIC RISK THROUGH A NEW FORM OF QUESTIONNAIRES

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Communication and mitigation strategies related to earthquake risk must always consider, in order to be effective, the social profile of targeted people; we believe that it's not enough to address perception, but mentality towards the seismic phenomenon - which reflects openness and impact potential. Various seismic risk perception studies are available, and many types of questionnaires were developed. However we find that many are limited in design and interpretation, not taking advantage of double-purpose capabilities (with simple but also complex and not respondent-obvious social-profiling intentions) or highly important aspects such as respondent location in correlation with analyzed risk. Romania is one of Europe's countries with the greatest seismic hazard (mainly due to the intermediate-depth Vrancea earthquakes at depths between 60 and 180 km, with magnitudes higher than 7) and risk. As the National Institute for Earth Physics,

official institution in charge of seismic monitoring in Romania, is in the process of developing it's strategy for educational seismology outreach, two separate questionnaires addressed to all categories of people were created: "You and earthquakes" and "How prepared are you in case on an earthquake?". The straight-forward goal for these was to reveal the knowledge, preparedness and perception of Romanian population to earthquakes, but the secret goal was to enable us, though statistical pivot analysis, to understand the mentality of the population and assist us in designing strategies to have a more consistent impact on seismic risk mitigation. We considered that in order for questionnaires to be appealing, they had be short, having a maximum of 14 easy-to-respond earthquake-related questions. We also collected location data (county and locality of residents), with the specific goal of revealing correlations with seismic hazard levels. Questions in the first questionnaire were designed to be joined in result analysis, enabling first of all to remove response sets that provide fake answers (automatic correlations can be done to highlight a non-serious respondent behavior), and then to aid in a more insightful profiling of respondents. For example, when joining responses to questions such as "How much are you afraid of earthquakes?", "How soon you think that a next major earthquake could happen?", "How much you know about earthquakes?" and residence location, a more significant profile is drawn, revealing correlations between earthquake education and fear justification or not. Some questions such as "How much you know about earthquakes?", "What is earthquake magnitude?" and "In which areas are there earthquakes with damage potential?" act as a quiz, but also reveal perceptual aspects. Two sets of questions, important in the Romanian context, relate to the evaluation of Earthquake Early Warning System effectiveness (correlate with knowledge): participants are asked to fill in what would they do if they had 20 seconds between receiving an SMS indicating a major earthquake and feeling the shake, in case of being inside a building at different floors, and how much time would it take. In this way we test (at least in terms of intention and not impulse) the hypothesis that people on lower floors would try to exit the buildings. Through the questionnaire we also identify which sources for earthquake information people use and would use. Most answers refer to official websites of research and disaster management institutions and YouTube videos, and not so many to museums or TV news. Another important question refers to what would make people have an instant initiative to minimizing seismic risk; as expected, most people think that a major earthquake felt by them would mobilize them. Again, when linking these answer with answers to "Which is the hazard you most fear in your area?", a mentality profile arise, in concordance with the process of forgetting how damaging earthquakes can be (since 1977, 1986 and 1990, no major earthquakes with destructive potential have occurred in Vrancea Area). The second questionnaire, which comes in the form of a test, has the particularity that it asks respondents firstly to auto-evaluate themselves in terms of how prepared to an earthquake they think they are; the fit with the test results is good, and maximum grades are almost never given. The test acts also as a tool for passing knowledge and insights on effective preparedness measures. The analyzed questionnaires reveal that the overall mentality of Romanian people toward earthquakes has highly contradictory aspects: on one side people perceive earthquakes as imminent and disastrous natural events, with potentially severe effects on them and in their locality, think they know what to do (although do not understand in reality the phenomenon very well) and don't consider that it is necessary to protect themselves better as a priority.

ESC2018-S41-973

CHILDREN'S EARTHQUAKE RISK PERCEPTION: SOME CASE STUDIES IN CALABRIA, SOUTHERN ITALY

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This work is a synthesis of research on the perception of seismic risk in Calabria, southern Italy, considering some case studies done through several Learning Units carried out at school. Some questionnaires and educational materials were administered to the students of primary and secondary education in some Calabrian cities and villages, in order to bring out the knowledge actually possessed and tied to age, experience, areas of origin and the perceptions that learners

show that they have in relation to seismic phenomenon. The last few years have seen the debate on the geoethics of environmental and climatic protection growing to include resilience as a central idea within this new discipline, which holds many similarities with geography. Resilience analysis often looks at the capacity to re-establish conditions of equilibrium within a system which has been hit by a serious shock, e.g. a natural or man-made disaster. Geoethics works, in tandem with geological analyses and the geography of risk, to inform a population and develop integrated risk management in such a way as to strengthen a community's resilience. In fact, the risk must be considered in its territorial nature, as a complex phenomenon which involves all aspects of the relations between man and environment. Assuming that the rupture of the dynamic equilibrium among population, environment and resources is the increasingly frequent causes of the outbreak of disasters, in the academic increasing attention has been paid to the concept of resilience, for its potential to evaluate a system in a state of equilibrium and adaptation in response to a shock. Therefore, the aim of this work is to study some people's capacity to overcome what was potentially a disastrous event and, through a process of reconstruction, turn it into an occasion for growth. The experiment, carried out in some primary and middle schools in Calabria (southern Italy), was conducted on the basis of the belief that there is a close relationship between a population's having a realistic understanding of the risk of such an event, e.g. an earthquake, and high levels of resilience. We also tried to gain an insight into the relationship that may exist between resilience in primary and secondary school children and methods of coping which give an appropriate management of seismic risk. To be more precise, we try to discover whether there is a link between good/appropriate resilience and good/appropriate risk management. The data and opinions collected will be useful to design and build new Disaster Risk Reduction tools, more adapted to the needs of all citizens, compared to natural hazards such as earthquake, boosting the community's resilience. Finally, these case studies can be treated as an exercise related to a 'geography' of the Anthropocene because the anthropic factors i.e., the vulnerability due to the absence of education and risk communication, the presence of buildings realised without any anti-seismic norms, the communication's absence of the Civil Protection plan, could contribute to transform a natural extreme event, i.e., an earthquake, in a disaster. Therefore, it is necessary to recognize the responsibilities of man in creating the conditions of vulnerability to natural processes; in fact, according to some scholars (Alexander, 1991; Furedi, 2007), disasters derive from acts of society.

ESC2018-S41-975

A NEW APPROACH TO COMPARING EARTHQUAKES DISCUSSED USING THE EXAMPLE OF CHILE AND HAITI 2010

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The comparison of different earthquakes with each other is a popular tool to highlight particular aspects of one or several events. This is common in basically any form of public discourse on earthquake risk and communication from news articles to academic publications. The objective is most often to highlight differences in the social conditions and how those affect the outcome of earthquake impacts. Such comparisons usually contrast earthquake magnitude and different types of impacts until venturing into discussions about building codes, preparation, response, corruption etc. While differences in earthquake shaking are sometimes mentioned or even extensively discussed, they are usually presented in a form that makes it hard - at least for a lay-person - to grasp the relevance of these differences. Here, I present an approach to visually represent the quantitative data on shaking and population exposure for several events that facilitates an easy comparison of the relevant information. The objective is to foster comprehensive discussions on the connection between particular social aspects and earthquake impacts based on examples. For such discussions it is crucial that the relevant apects of the natural hazard of earthquake shaking are first sufficiently presented and compared before entering more complex discussions on the social dimensions. Providing simple visualizations of large amounts of data can help to facilitate a better understanding of the given events and thus foster and inmprove discussions on the role of particular social components. The suggested approach can be

applied to any ground motion parameter. The first step is to provide maps of shaking for the events to be compared next to each other with the same geographic scale as well as color scale. The second step simplifies the interpretation of the shaking profiles by removing the spatial component and plotting "exposure curves", which provide the area exposed to each shaking level or higher. Finally, to allow not only a comparison of area exposed but also population, a similar plot but for "population exposure curves" is done, which represent the population exposed to each shaking level or higher. In some cases the exposure curves allow for a clear ranking of events in terms of shaking strength or population exposure. The approach is applied to the example of notable earthquakes from 2010 that have often been compared to each other. Comparing the exposure curves for the Chile 2010 and Haiti 2010 events reveals a much more complicated picture than just comparing magnitudes. While Chile had a magnitude of 8.8 and Haiti only 7, Haiti still experienced a stronger average shaking over space even when an area as large as the strongest 1000 square km is considered. Nevertheless, the area exposed to a PGA of 50%g or greater was in Chile more than three times as large than in Haiti, but Haiti had more than twice as many people living in that area. It is therefore not entirely puzzling why the Haiti event might have caused more impacts. The fact that it resulted in significantly greater impacts, however, is very likely due to the fact that Chile has better building codes, less corruption, better preparation, and is generally a higher-income country than Haiti. When different events are compared in terms of their social impacts it is crucial to provide a discussion of the differences in their shaking profiles and not just a comparison of magnitude.

ESC2018-S41-1001

IN ALL SHAPES AND COLOURS: A RESEARCH ON TSUNAMI RISK PERCEPTION: EVIDENCE FROM THE CAT-INGV PILOT STUDY

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In order to better address tsunami risk perception and understanding by people living in coastal areas, the CAT – INGV; the Tsunami Alert Centre of the Italian National Institute of Geophysics and Volcanology, promoted and carried out a pilot survey on a stratified sample of >1000 residents in coastal municipalities across two regions of southern Italy, historically threatened by seismogenic tsunami risk: Calabria and Apulia. The aforementioned general objective of this pilot study may be splitted into four strategic goals: 1) to get data on citizens knowledge and characterization of tsunamis; 2) to assess how they perceive the risk posed by tsunami both in the Mediterranean and in their areas; 3) to identify the most appropriate channels and techniques to effectively spread alert messages; 4) to improve the strategic planning of scientific communication, risk communication and mitigation strategies of CAT-INGV, as well provide helpful insight to develop a dedicated website. According to a deeply-held belief, tsunamis in the Mediterranean Sea are purported to be very rare. Unfortunately, this belief is definitely untrue: as reported by optimistic sources, at least 2,000 of the 80,000 victims of the great earthquake in Messina (1908) have been killed by the tsunami that followed earthquake (Boschi et al. 1995). More recently, in 1956, a 7.7 magnitude earthquake that occurred close to the Cycladic island of Amorgos (Greece) triggered large waves that also hit coasts of Amorgos, Astypalaia and Folegandros, with run-up values of respectively 30, 20, and 10 mt. (Okal et al., 2009). More recently, a relatively small tsunami caused by a 6.9 magnitude earthquake occurred in 2003 in Boumerdes (Algeria) hit the Western Mediterranean coast causing damage properties in at least eight harbours in Balearic Islands, in addition to the over 2500 casualties due to building collapses along Algerian coasts (Velaet al. 2011). In 2017 two smaller tsunamis occurred in Dodecanese, creating minor damages to vessels and small boat at berth in the ports and vehicles closer to the shore. Since such events are just a little part of the over 290 historically known events occurred in the Mediterranean (Maramai, Brizuela & Graziani, 2014) geo-scientists should recall citizens that tsunamis are everything but impossible and that tsunami may come in all shapes and colours, so that even a small event can result in serious damages and loss of life (such as dragging into the sea both childrens and adult persons). In such a scenario, risk communication about Mediterranean Tsunami may represent a challenging enterprise. According to previous

research people have little knowledge about tsunamis, and they are also likely to underestimate both probability and consequences of such events. Moreover, their understanding of tsunami dynamic is significantly affected by media coverage (and social imagery) of big events such as the 2004 Sumatra Tsunami and the 2011 Tohoku Tsunami (Astarte, 2014). Other research demonstrated that despite the relevance of tsunami in Japanese history and culture, the alleged preparedness of Japanese people is frequently affected by serious misunderstanding and underestimation of catastrophic potential (Oki and Nakayachi, 2012). Given these premises, the very first data of the research, which is actually in progress, provide very interesting insights about the way people face with tsunami risk, their idea of event possible impacts and their expectation about Civil Protection and Scientific Institutions, both in terms of risk communication and mitigation measures. Data from such a research may provide a relevant framework for geo-scientists' approach to public engagement, since scientists and research institutions must carefully shape their messages, relying on well-researched principled practices rather than on good intuition (Bostrom, & Löfstedt, 2003). The questionnaire is organized into six main sections: socio-demographic data and information on respondents' territory; knowledge and sources of information on tsunami risk; contextual perception of risk posed by tsunamis; social representations of tsunami; role of cultural attitudes and worldviews; messages and channels to be used for tsunami early warning. Interviews have been administered between April and May 2018. During the ESC session in Malta, a complete account of most relevant data will be presented and discussed, in order to provide a comprehensive framework of methods, techniques and empirical evidence.

ESC2018-S41-1004

THE PERCEPTION OF SEISMIC RISK IN ITALY FROM 2013 UP TO DAY: WHICH CHANGES OCCUR AFTER SOME MAJOR EARTHQUAKES IN RECENT YEARS

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Studies of risk perception examine the judgments that people make when they are asked to characterize and evaluate hazardous activities and technologies (Slovic, 1987). Risk perception is a cognitive process involved in several daily activities that orients people's behaviors on the impact of uncertain events. This process is both individual and collective; it selects and interprets signals related to direct observations or information received from others. Some researches highlighted that in many cases there is a difference between subjective risk perception and objective evaluation (Slovic, 1992, 2000). To understand risk perception it is necessary to consider a number of social, psychological and cultural ambits, as well as interaction among them (Wachinger & Renn, 2010). In our opinion, in agreement with the constructivist approach, seismic risk perception does not depend on the actual value of the seismic risk but there are others factors influencing it. In the specific case of seismic risk, the role of people perception is very important, especially in the absence of clear communication strategies. The clarity of the language used by mass media, scientists and decision-makers in communicating seismic risk to people is essential for a proper knowledge and awareness.

This paper presents the results of the research on seismic risk perception in Italy, started by INGV researchers on funding by the DPC 2012-2015. In 2013, we built a questionnaire to assess seismic risk perception, with a particular attention to compare hazard assessed by scientific data and methodology, then translated into a national law. The Seismic Risk Perception Questionnaire (SRP-Q) is designed by semantic differential method, using opposite terms on a Likert scale to seven points. The questionnaire allows to obtain scores for five risk indicators: Hazard, Exposure, Vulnerability, People and Community, Earthquake Phenomenon. In 2015, a CATI survey was conducted on a statistical sample of the Italian population (N=4,012), its results represent a benchmark for the seismic risk perception in Italy. At the same time, from 2013 to today, we have gathered on the web more than 9,800 responses to the SRP-Q (www.terremototest.it) and these data allow us to make comparisons for year and for different reference periods, also on the basis of the seismic phenomena that have occurred. The questionnaire is given by web on a random sample since 2013, January 21th, to April 2018, collecting over 9,800 answers. In this contribution we compare and discuss data collected during the last

six years (2013-2018) trying to investigate if and how the occurrence of strong and damaging earthquakes (in particular those occurred in Central Italy in 2016) has changed the seismic risk perception in some regions of Italy. We hope that the analysis of risk perception data is able to produce useful indications to design seismic risk reduction activities and address risk communication strategies.

ESC2018-S41-1015

COMPARISON OF PGA AND PGV BASED EARTHQUAKE DAMAGE ASSESSMENTS FOR PUBLIC SCHOOL BUILDINGS IN ISTANBUL

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Damage assessment for public schools which were designed and constructed on the basis of a standardized project in Istanbul is presented under different scenario earthquakes. Analytical fragility functions in terms of peak ground acceleration and velocity (i.e. PGA and PGV) are used for the computation of likelihoods of reaching various states of damage. For this purpose, spatial distributions of PGA and PGV values for each scenario event are computed with ground motion predictive models. Local soil information in terms of shear wave propagation velocities (Vs,30) is also taken into account in the computation of ground motion. Mean damage ratios estimated for each case are compared and effects of the selected ground motion intensity measures on the results are discussed.

ESC2018-S41-1019

URBAN SEISMIC RISK REDUCTION AND MITIGATION STRATEGIES IN TURKEY

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It is a well-known fact that Turkey is located on one of the most seismically active region. Recent earthquakes revealed that the building stock is quite vulnerable. In addition to the high number of casualties, the level of economical loss is a big thread on Turkish economy. As one of the major actions to mitigate the vulnerability of the building stock in Turkey, Turkish Government has issued a law titled as "The Law of Transformation of Areas under the Disaster Risks (Law No. 6306)" entered into force in 2012 (published in the Official Gazette of 31.5.2012, no.28309). The scope of the law is to determine the procedures and principles regarding the rehabilitation, clearance, and renovations of areas and buildings at disaster risks in accordance with relevant standards with a view to create healthier and safes living environment in the urbanized areas. The number of the expected building renewal is 6.5 million in all over Turkey. This is the largest housing project in the world as a part of seismic hazard mitigation. After 5 years of the law publicized, the preliminary goals were fulfilled, and the social awareness has significantly increased in short period. The basics of the procedure defined in the relevant law has been evaluated and a pilot project has been accomplished for the Turkish Ministry to provide the philosophy of the proposed methodology. Additionally, "a peer review board" has been established that is composed of academicians from earthquake engineering field to solve the problems revealed in the application process. As one of the biggest urban renewal projects in the world, a huge and valuable experience has been accumulated through these process which could act as a useful example for the countries with similar seismic risk.

ESC2018-S41-1025

REVISITING THE EMPIRICAL FRAGILITY FUNCTIONS DERIVED AFTER THE 2010 HAITI EARTHQUAKE

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Empirical fragility functions can be derived by statistical processing of observational damage data, i.e. inventory of damaged and undamaged buildings, and ground motion intensity values at the buildings' locations that represent the earthquake demand of which each building exposed to. Shortly after the Mw=7.0 earthquake that struck Haiti on January 12, 2010, the USGS published shaking intensity maps produced by ShakeMap software. These maps in combination with the damage data collected through field surveys as well as the data obtained from remote

sensing based damage assessments were used for deriving fragility functions (Hancilar et al., 2013). ShakeMap generates maps of the spatial distribution of recorded peak ground motion parameters (acceleration, velocity, and spectral response) and of instrumentally derived seismic intensities. For regions where there are insufficient strong motion recording stations as it was the case for Haiti earthquake, observed macroseismic intensities are combined with region-specific empirical ground motion estimations which utilize earthquake source and local geology information. When intensity data are used directly, the peak ground motion parameters are inferred from the macroseismic observations using empirical predictive equations. This is opposite to the standard ShakeMap procedure and causes large uncertainty in the estimated ground motion distributions. The USGS lastly updated the Haiti earthquake shake maps in 2017 by incorporating more data collected via the USGS "Did You Feel It?" Community Internet Intensity Map system and there are considerable differences when compared with the earlier maps. In this study, the fragility functions are derived again using the new ground shaking maps. Both versions of the developed fragilitycurves are compared.

ESC2018-S41-1029

ESTIMATED HUMAN LOSSES DUE TO EARTHQUAKES IN THE AZORES ISLANDS: PRELIMINARY RESULTS

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QLARM (Quake Loss Assessment for Response and Mitigation) is a software tool and a worldwide database which allow to estimate building damage and losses anywhere in the world. QLARM estimates strong ground motion from ground motion prediction equations (GMPE), or intensity relationships and calculates losses using regional collapse models and casualty matrix. More than 1.9 million settlements are documented with 2013 population, building distributions into EMS98 vulnerability classes and related population distribution into these classes and when available soil conditions. QLARM is used in real time (24/7 alert service since 2002) or for scenario of likely rupture sources. The QLARM code is used to estimate losses in future earthquakes in Faial Island, a small and volcanic island in the Azores. Historically, heavy damage and casualties have been reported for two earthquakes. The first earthquake (Mb 5.6) occurred in August 1926, and strongly affect Horta city and surrounding villages, killing 8 persons, causing tens of injuries and homeless. The other earthquake (Mw6.2) occurred in July 1998, causing 8 death, around 150 injuries, and 1700 homeless. QLARM capabilities are used to assess the likely impacts of future earthquakes, given the current population and building stock of the Azores. Data and hazard model are first validated by comparing calculations and observations for the 1980 M7.1 and 1998 M6.2 earthquakes. For that, the performance of the GMPE proposed by Munson and Thurber (1997), specifically developed for volcanic island context, is compared to the intensity relation from Shebalin (1985) after applying several PGA-intensity converters. The residuals between observed and calculated intensities reveal to be much better with the Shebalin (1985) when tuning the distance attenuation factor of the relation. The building stock and population for each settlement in Faial are then distributed into EMS-98 vulnerability classes using data from 2001 and 2011 census. An additional intensity amplification factor is also assigned to each settlement where observations from prior earthquakes allow it. Calculation of losses are performed using line sources corresponding to the most probable rupture of the 1980 and 1998 earthquakes. Observed fatalities are within the range of the calculated ones for both earthquakes. The upper limit of the calculated range of injuries fits the observed ones. Based on these results, one can accept that both hazard and building models are validated and could be used to perform losse estimates in cases of future earthquakes. Two earthquake scenarios are proposed, based on the knowledge of active tectonics and the potential length of faults, which may rupture. The first one scenario, is assumed to occur offshore with an estimated magnitude of 6, while the second is assumed to occur inland with magnitude 6.9. The selected hypocenter depth for both is 5km. For the offshore scenario, the death toll ranges from 50 to 200, and the inland earthquake may cause from 600 to 700 fatalities.

Variability of the results for both killed and injured people will be further investigated as well as the site amplification caused by large lateral heterogeneities commonly observed in volcanic islands. At this preliminary stage, QLARM is providing reliable first order of magnitude losse estimates, which could help to mitigate future earthquakes in this region of the world.

ESC2018-S41-1038

DISASTER PREPAREDNESS IN MODERATE SEISMIC ZONES – CHALLENGES PRESENTED ON A CASE STUDY

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Session could be either the indicated or S36: Cultural Heritage and Earthquakes: case studies, issues and challanges. The vulnerability of societies in medium hazardous areas were clearly demonstrated in case of recent earthquakes like L'Aquila (2009) and Amatrice (2016). Communities in seismically moderate hazardous areas with no collective memories about past earthquakes are exposed to a hazard that they are not prepared for. Trying to instill a continuing sense of seismic disaster preparedness is often difficult when the population has not witnessed such an event. As past seismic events move out of collective consciousness, even those professionals responsible for preparedness may lose their focus. Experiencing other near-disasters, such as floods, without sustaining damage, may create a false sense of security or shift focus from needed vulnerability evaluations and rehabilitation efforts. The seismic hazard, vulnerability, and earthquake risk may be underestimated by both engineers and authorities or may not be properly quantified in moderately hazardous areas. Past buildings and other infrastructure elements might not have been designed against earthquake loads. Even recent changes in the seismic codes are often not accepted by many engineers, hindering the abilities to take the proper mitigation measures. The process of earthquake risk assessment of a town can provide important data for authorities and disaster management to better understand risks to many buildings rather than a single building. This is even more important in case of moderate seismic areas where any mitigation measures to be taken should be justified by seismic risk determination. Moderate seismicity does not necessarily equate to moderate damage from earthquakes. Vulnerability to earthquakes even increase with extending urban areas. Seismicity in the Pannonian Basin is moderate compared to seismicity of surrounding areas, nonetheless reports of major earthquakes in Hungary often refer to heavy building damage and liquefaction (e.g. 1763 Komarom eq.). Gyor was chosen to be the examined area for seismic risk analysis because it is the most important city of northwest Hungary with a large number of monumental buildings and a complex geological and geographical settings. In order to make the best use of limited resources usually characteristic to moderate seismic zones; the presented method used existing soil data, rapid visual screening of buildings, a limited number of field tests and free, but sophisticated software. This research focuses on the results of vulnerability analysis of buildings however considers the results of seismic hazard and local site effects based on response analysis with more than 6000 realizations. Vulnerability of the buildings with different structural types were evaluated based on rapid visual screening of 5000 building. As one would expect, since the hazards and vulnerabilities were not uniformly distributed in the city districts of Gyor, there were zones of higher and lower risk. These results can then serve as useful tools for decision makers, and can be applied directly to risk management plans. By projecting recent hazard events onto our community, we are trying to rebuild professional and public recognition of disaster preparedness. Events are chosen to be similar to what is expected for our region. Detailing the damage, response (or lack of response), difficulties with recovery, economic and social upheaval, we attempt to bring a message to professionals and the general public that we should be better prepared to handle such an event. Presenting the findings about the earthquake risk assessment of such areas and comparing them to real-life events can draw the attention of decision makers to initiate mitigation measures.

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SESSION 42

ESC2018-S42-62

SOFT-SEDIMENT DEFORMATION STRUCTURES INDUCED BY GLACIO-ISOSTATICALLY TRIGGERED FAULTING IN FRONT OF AN ADVANCING PLEISTOCENE ICE SHEET (RüGEN ISLAND, NE GERMANY)

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The decrease in crustal ice loading during ice-sheet retreat is widely considered to have been more rapid than the load increase during ice-sheet advance, resulting in a faster glacio-isostatic crustal rebound during deglaciation than crustal flexuring during increasing loading associated with ice advance (Grollimund and Zoback, 2001). This suggests that crustal faulting during ice advance must be related to local re-activation of pre-existing faults. To our knowledge, no earlier studies suggest that ice-load-induced earthquakes have occurred while the Scandinavian Ice Sheet (SIS) was advancing, and no soft-sediment deformation structures (SSDS) have been described so far from seismites within sediments that accumulated during ice-sheet advance. Recent investigations that we carried out show, however, that the idea of gradual flexural loading of the crust during ice advance versus a more stepwise fault-accentuated rebound during deglaciation must be revised. We documented two layers with abundant SSDS in a glaciolacustrine silty-sandy succession in a coastal cliff on Rügen Island (Jasmund Peninsula) in northern Germany. Most deformations are relatively simple load casts and pseudonodules, with genetically related flame and fluid-escape structures. A critical feature is that the two deformed levels are interbedded between undeformed layers. This excludes an origin of the deformations as a direct result of endogenic tectonics, periglacial processes or glacitectonics. An origin of the SSDS as earthquakes-related seismically induced is therefore the only feasible explanation. Based on their stratigraphic position and optically stimulated luminescence (OSL) dating, the two deformed sediment levels (seismites) were formed in front of the Pleistocene SIS during the Brandenburgian phase of the Weichselian glaciation (Heine et al., 2009; Kenzler et al., 2015, 2017). The succession with the two seismites was deposited between 22.7±1.9 ka and 19.0±1.8 ka (Kenzler et al., 2015, 2017; Pisarska-Jamroly et al. in review). This time roughly coincides with the maximum extent of the SIS in the south-western Baltic Sea area (Houmark-Nielsen, 2010; Toucanne et al., 2015; Hughes et al., 2016). Kenzler et al. (2017) concluded that the first late Weichselian ice advance reached the Jasmund Peninsula at 22±2 ka. The study area is situated in a low-seismicity intraplate setting, so it seems only appropriate to discuss here what faulting may have been involved. The Baltic Sea area north of Rügen is characterized by numerous faults activated and reactivated during late Palaeozoic and Mesozoic tectonic phases. Inversion tectonics during the Late Cretaceous and Early Cenozoic caused reversal of faults and anticline formation. Recent vertical movements along offshore subsurface faults caused by glacial isostasy are postulated but are difficult to detect and to verify (Al Hseinat and Hübscher, 2017). It could well be, however, that such faulting took place, and these faults may have resulted in the earthquakes that caused the formation of the seismites in the cliff section. This support the idea of discrete vertical blocks movements, both in front of the advancing ice sheet causing down-faulting, and during subsequent ice retreat. The study has been financially supported by a grant for the GREBAL project (No. 2015/19/B/ST10/00661) from the National Science Centre Poland.

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ESC2018-S42-94

A MODEL FOR LARGE EARTHQUAKES RECURRENCE IN SOUTH AMERICA BASED ON MARKOV PROCESS

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The stochastic model of the Markov chains is applied in South America in order to search for a pattern of large earthquakes (M>7.8) recurrence. The model defines a process in which successive state occupancies are governed by the transition probabilities (pij) of the Markov model and are presented as a transition matrix (say P), having NxN dimension. In order to enrich our data set the use of the Monte Carlo simulation process was also used. The predefined seismic zones in South America considered as states here. If these visits from one zone to another considered to be earthquake occurrences, the migration of events from one zone (state) to another can be inspect. Transition probabilities computed, reveals a migration of these large earthquakes from south towards north.

ESC2018-S42-116

MOHO DEPTH DETERMINATION FROM P RECEIVER FUNCTION ANALYSIS IN THE CARPATHIAN BASIN

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We perform receiver function analysis to determine a detailed map of the crust-mantle boundary and the crustal velocity structure of the transition zone between the Eastern Alps and the Carpathian Basin. We use data from the AlpArray temporary seismic network, the permanent stations of the Hungarian National Seismological network, stations of a private network operated by Georisk Ltd., temporary stations of the Carpathian Basin and South Carpathian Basin Projects, as well as permanent seismological stations in the neighbouring countries for the time period between 2002 and 2017. Altogether about 200 seismological stations are used in the analysis. Owing to the dense station coverage we can achieve so far unprecedented resolution, thus extending our previous work on the region. We apply three different quality assurance procedures for the waveforms and the obtained receiver functions. Receiver functions are calculated by the iterative time domain deconvolution approach. We present the quality controlled P receiver functions (radial and transversal component) and we will investigate the transverse components for back-azimuthal patterns that may point to anisotropy or dipping interfaces. We show some cross-sections beneath the Eastern Alps – Pannonian Basin transition zone, and concentrate on major structural elements of the area such as Mid-Hungarian Zone and Balaton Line. Finally, we present results on the Moho map obtained by H-K analysis. We also compare our results to previous active and passive seismological images in terms of Moho depth and crustal velocities.

ESC2018-S42-128

UNDERSTANDING PAMIR-HINDUKUSH SEISMICITY

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Located on the northeastern part of the Asia-India continental collision zone, Afghanistan is one of the seismically most active countries in the world. Destructive earthquakes occur frequently, mostly beneath the Afghan Hindu Kush mountains at crustal and sub-crustal levels, and pose a large threat to the Afghan community. Sub-crustal seismicity forms a worldwide unique zone of intense intermediate depth seismicity, which has been interpreted as intracontinental subduction with different polarity beneath the Tajik Pamir and the Afghan Hindu Kush mountains. The lithospheric slab currently subducting beneath the Hindu Kush seems to be in the state of breaking-off as all large sub-crustal Mw>7 earthquakes within the last century occurred exclusively beneath the Hindu Kush. It is unclear how and if earth's surface reacts to these deep lithospheric processes. Observations on crustal seismicity are sparse, as earthquake occurrence in NE Afghanistan is neither consistently monitored nor comprehensively studied. Since September 2017, 14 temporary deployed seismic stations are operating within the Hindu Kush Mountains within a joint project between GFZ and NAC, forming the largest seismic network in Afghanistan, since digital seismic data became available. The network is situated on top of the nest of intermediate depth seismicity and further west in the Afghan platform, aiming to resolve the crustal structure and seismicity within this remote region. Most of the stations are deployed within infrastructural units of the NAC and different local universities and institutions. The stations are equipped with short period Mark seismometers and Cube data recorders. The current temporary network is planned to operate until January 2019. Here, we present the purpose of the project, goals and station description alongside with the first results on seismicity distribution.

ESC2018-S42-134

FROM INDIVIDUAL STATION MAGNITUDES TO EVENT AVERAGE: WHAT IS AVERAGE AND DO SITE CORRECTIONS MATTER?

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Regardless of which magnitude scale is used to define the size of an earthquake, the value, with rare exceptions, is an average of magnitude values calculated at many individual stations. There are, however, many ways to define average. Using data from over 4100 earthquakes in eastern Canada, each with magnitude (MN) values determined from at least five stations, the effects of how these data are combined were examined. To highlight small differences, magnitudes were recalculated to an additional decimal place. First, how the definition of average (mean, median, 20% trimmed mean and 40% trimmed mean) affects the final magnitude value was explored. When the data set as a whole is considered, the difference between the various averages is negligible, with the mean difference between any two definitions of average being less than 0.02 magnitude units when the exact difference is considered and higher, but less than 0.06 magnitude units if the sign is ignored and only the absolute value considered. These results suggest that there is no significant difference in how average is calculated and that combining and using catalogs based on different definitions of average should not cause any adverse effects as long as the underlying station magnitudes were calculated the same way. Previous research has shown that the seemingly minor differences in how a magnitude is calculated can have significant effects. Calculating two different averages, such as mean and median, would be one way by which to flag events with suspicious individual station magnitudes. If the two differ by more than a predefined value, the event magnitude would merit further investigation. Next, station site corrections defined as mean residuals were determined for all stations from which magnitudes were recorded in the earthquake catalog. The corrections were then applied to the raw station magnitudes and the event magnitudes recalculated. The corrections for most stations in eastern Canada, which are primarily located on hard rock, are lower than 0.2 magnitude units and, thus, the application of station corrections has little effect

on the event magnitude of the bulk data set. The difference between the original and site-corrected magnitudes for some individual events, however, is in excess of 0.5 magnitude units indicating that there is some value in applying the corrections. The impact tends to be greatest when the number of station magnitudes is small and/or some of the stations used have large corrections. Finally, source and path effects as well as station distribution can impact the event magnitude. For example, oversampling at some azimuths could bias the final value. Residuals at eastern Canadian stations over a wide geographic range show a very similar distance bias, suggesting that the problem lies within the magnitude equation itself. Azimuthal bias does not appear to be significant in general but further study exploring the effects of azimuthal averaging is ongoing as the data used to determine the site corrections show clear azimuthal variations for some regions and stations.

ESC2018-S42-214

COMPARISONS OF ALTERNATIVE SEISMIC INTENSITY PARAMETERS FOR SELECTED SETS OF REAL AND SIMULATED GROUND MOTION RECORDS

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In areas where inadequate number of regional real ground motion records are available, seismic vulnerability of structural systems can be assessed alternatively using simulated records generated for potential scenario events at the region of interest. However, the main question of interest herein is the accuracy of these simulated records. Thus, this study aims to obtain and compare alternative seismic ground motion intensity measures for the selected sets of real and simulated ground motion records. For this purpose, simulated records corresponding to two alternative study areas; Erzincan and Duzce which are located in the Eastern and Western parts of Turkey, are utilized. For ground motion simulations at the selected study areas, the stochastic finite-fault technique is used. On the other hand, real records are chosen from the available global databases corresponding to previous earthquakes with the intention of obtaining a ground motion dataset regionally compatible for each study area. In the selection process, parameters such as the fault mechanism, earthquake magnitude, soil condition, source to site distance are taken into account. After formation of the real and simulated record sets for the selected regions, Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Housner Intensity (HI), Cumulative Absolute Velocity (CAV), Velocity Spectrum Intensity (VSI), Arias Intensity (Ia), a modified version of Acceleration Spectrum Intensity (ASI*), and Significant Duration (td) are calculated for each record as selected ground motion intensity measures. To assess the degree of compatibility between the intensity parameters of the real and simulated records, statistical tests are performed and comparisons are graphically displayed as well. Results reveal that in most cases there is consistency among the ground motion intensities calculated for the selected real and simulated record datasets.

ESC2018-S42-282

PRELIMINARY STUDY OF SEISMIC ACTIVITY CHANGES IN THE CARPATHIANS ARC BETWEEN 1976 AND 2016

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The Carpathian Mountains arc is a part of the Alpine Mediterranean Belt and it is the seismically most active area in Central Europe. The Carpathians are divided into Western, Eastern and Southern Carpathians. Distribution of the earthquakes epicenters shows that there are significant differences between the seismic activity of the inner part of the Carpathians arch and the surrounding mountain chains. However, tremors in this region are mostly observed in the Vrancea zone in Romania (the Southern end of Eastern Carpathians). The earthquakes are located in a restricted area in the bending zone between the Eastern and Southern Carpathians where at least three tectonic units are in contact: the East European plate, Intra-Alpine and Moesian subplates (Marmureanu et al., 2011). In most cases the seismic events are immediately related to the movements on existing fault surfaces (Kovac et al., 2002). Until now, the Central European seismologist community has been

focused predominantly on analyzing the seismicity of individual regions and countries within the Carpathian arc. Presented study were focused on the seismic activity of strong seismic shocks (ML ≥ 2,0) occurred in the Carpathian Mountains arch area since 1976 to 2016. The aim of the study was to trace temporal changes of seismic activity in the whole the research area. The research was based on the data from unified earthquake catalogue compiled by us from individual national seismic catalogues. The preliminary study pointed out significant changes of seismic activity in Carpathian Mountains region, especially a sudden increase of activity after 2004 coming after a strong shock on magnitude ML 6. The results showed that this sudden increase of seismic activity manifested by a significant enhancement of the number of seismic phenomena with local magnitude and ML , while the number of earthquakes with ML > 3 remained practically at the level from before 2004.

ESC2018-S42-285

ATTENUATION DIFFERENCES ACROSS THE CANADIAN SHIELD- APPALACHIAN OROGENY BOUNDARY IN EASTERN CANADA

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Seismic attenuation provides insight into the tectonic history and underlying geophysical processes of a region. Spatially varying attenuation across tectonic zones has implications for hazard at regional scales as it affects the level of shaking from an earthquake at a given distance. While not at a plate boundary, eastern Canada is a tectonically complex region with the Canadian Shield and Appalachians comprising two of the major geological provinces. The boundary between the zones is marked largely by the St. Lawrence River where several of the most active seismic zones in eastern Canada are found. Although current seismic hazard models treat all of eastern Canada as one region in terms of crustal structure and attenuation, an increasing body of evidence from several different data sets indicates that there are attenuation differences between the Shield and Appalachians with higher attenuation in the latter. The evidence is based largely on magnitude residuals and regional Lg amplitude variations. The St. Lawrence River provides a natural boundary that allows both stations and earthquakes to be characterized as either Appalachian or Shield. Through careful sorting of seismic stations into Shield and Appalachian groups, we study the regional trend of attenuation, as well as its azimuthal variability. Data from St. Lawrence earthquakes recorded at regional stations and a second data set consisting of regional earthquakes recorded at St. Lawrence stations, provides us with a large data set of pure Shield and pure Appalachian paths from the same earthquakes for analysis and comparison. Magnitude residuals for earthquakes occurring along the Shield-Appalachian boundary show that magnitudes are lower at stations on Appalachian crust at both local and regional distances suggesting higher attenuation. Station site corrections based on these residuals from earthquakes occurring over a wider geographic range also indicate underestimation of magnitudes at Appalachian stations. Predicted ground motions from peak amplitudes of Lg arrivals exhibit a similar trend, indicating higher attenuation in the Appalachians compared to the Shield. Finally, while less quantitative, consistently lower felt intensities reported from communities on the southern side of the St. Lawrence relative to the north also point to higher attenuation in the Appalachians.

ESC2018-S42-320

PERFORMANCE TESTING OF TRILLIUM 360 VERSION 2 SEISMOMETER

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There is a need for a new generation seismometer able to measure the smallest existing ground motion, in a form factor suitable for borehole, posthole, and portable deployment as well as traditional surface vaults. This is an active area of research with recently released products such as Trillium 360 (Version 1) pushing the boundaries of borehole sensor performance. This paper presents the latest test results for an improved Trillium 360 Version 2 product with even lower self-noise. Tests were conducted at a new facility in Ottawa, Canada with multiple closely spaced boreholes drilled into hard rock to allow for side-

by-side coherence testing in a down-hole environment.

ESC2018-S42-354

THE COURSE OF ANALYSIS AT THE ISC, AND REBUILDING THE HISTORICAL BULLETIN

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The Bulletin of the International Seismological Centre (ISC) is widely regarded as the most comprehensive record of Earth's seismicity, and has been in production for over 54 years. With the support and cooperation of over 148 agencies worldwide we are able to integrate and combine data from many sources, from global agencies with permanent networks to local temporary deployments. Our position as a not-for-profit and non-governmental entity thus allows us to create a unique product that is then freely provided to the global community. From initial contact with an agency and the following data collection and preparation, through careful analysis and publication, our routine operations will be described in the first part of this presentation. In order to further improve the value of the ISC Bulletin, we have undertaken the ISC Rebuild project. The goal is to bring the earlier period of the Bulletin (1964-2010) into line with the more recent years, and thus homogenize our methods across more than four decades of data. This allows us to add new data sets, stations, and magnitude readings to the Bulletin, and then to relocate using modern velocity models and inversion methods. Examples of some of the improvements we are able to make include: 1. Until 2001, only P phases were used in relocation. We now use all available ak135 phases. 2. Relocation takes place with the latest ISC locator (Bondar and Storchak, 2011). 3. Quality checks are now part of the operational routine, such as checking for duplicate readings, bogus events, etc. 4. Recomputed magnitudes are now more robust; we use an alpha trimmed median and a minimum of 3 station readings for all ISC magnitudes. Results from the now publicly available first sixteen data years (1964-1979) of the Rebuild project will be shown in the second part of this presentation, and show a marked improvement in clarity.

ESC2018-S42-364

DETERMINATION OF THE EARTHQUAKE LOCATION WITH PARTICLE SWARM OPTIMIZATION

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Metaheuristic algorithms are begin to be used in optimization methods in recent years. A metaheuristic is aim to find a good solution to a difficult optimization problem. Many metaheuristic algorithms created by observing natural life. This observation such as; the organisms (a population or a swarm) have optimized and adapted themselves to survive nature. Many metaheuristic algorithms exist in literature, which are particle swarm optimization, genetic algorithms, artificial bee colony, simulated annealing.. etc. Particle swarm optimization (PSO) was developed by Kennedy and Eberhart in 1995, based on swarm behavior observed in nature such as fish and bird schooling. PSO searches according to the space of an objective (fitness) function by individual agents, called particles. Each particle traces a piecewise path which can be modelled as a time-dependent positional vector. Each particle is attracted toward the position of the current global best (g) and its own best known location (x), while exhibiting at the same time a tendency to move randomly. When a particle finds a location that is better than any previously found locations, then it updates this location as the new current best for particle i . There is a current best for all particles at any time t at each iteration. The aim is to find the global best among all the current best solutions until the objective no longer improves or after a certain number of iterations. In this study, a particle swarm algorithm which is one of the meta-heuristic algorithms, has been applied a problem in seismology. It has been determined earthquake location (epicenter) by using this algorithm, in addition to various methods for determination of earthquake location. The PSO algorithm places firstly the particles randomly in its solution space. Each particle determines its location and distances relative to the stations, which records the earthquake and improves its position to find the best epicenter point. Also it is the objective (fitness) function of the PSO algorithm. A simulation has been developed that determines the earthquake location according to

the PSO algorithm by using the MATLAB programming language. Algorithm have been tested with synthetic data and occurred earthquakes according to different station numbers. It has been determined that the results are consistent with small error rates. Also the estimation of earthquake location will try to develop by applying different meta-heuristic algorithms.

ESC2018-S42-365

SEISMICITY AND SEISMIC HAZARD ASSESSMENT IN MACEDONIA (NORTHWESTERN PART OF GREECE) AND THW SURROUNDING AREA

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The area under investigation is generally characterized as a zone of low to intermediate seismicity. The earthquake of 1995 between Kozani-Grevena having a magnitude of M6.6 was a surprising event. Searching further (historical era) the area experienced 13 large earthquakes with magnitude M>6.0, since 552 A.D. The data applied cover the time span 552-2015. Two procedures applied then order compute some seismicity parameters. The first method concerns the 1) time independent seismicity based on Poisson distribution, while the second one is 2) the time predictable model. The parameters of FMD for the first procedure calculated as at = 7.03 and b=1.03, while the reflected at value in one year is a1=4.74. Based on these outputs the probability of earthquake occurrences for magnitudes 6.0, 6.5 and 6.6 during a time period of 100 years, is calculated. The results show probabilities of 69%, 31% and 25% which are in accord to the aforementioned magnitudes. The second method reflects on long term foreshadow of magnitudes based on Gaussian distribution. The results was depicted occurrence of events with magnitudes M>6.0 for the next 10 and 20 years probabilities of 46% and 59%, respectively. Seismic hazard for the whole area applied based on the modified model of Ebel-Kafka. Synthetic catalogs of 1000 and 100000 years constructed via Monte Carlo technique and used for the seismic hazard estimation. The obtained results reveal PGA-values around 0.20g.

ESC2018-S42-399

A SEISMOLOGICAL AND KINEMATIC STUDY OF TAORMINA FAULT (EASTERN SICILY, ITALY)

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Offshore Eastern Sicily is among the most seismically active regions of Italy. The historical Italian earthquake catalogue, reports that some of the last millennium's most destructive earthquakes were located along the southernmost part of the Calabro–Peloritan Arc (1908, Mw=7.2; 1932, Mw = 5.1) and in south-eastern Sicily (1169, Mw=6.6; 1542, Mw=6.6; 1693, Mw=7.4; 1990, Mw = 5.7). We focus our attention on a tectonic structure bordering the Ionian coast offshore area from the Mts. Peloritani, the Taormina Fault (TF). The TF extends parallel to the eastern coast of Sicily from Messina to Taormina, and it is suggested to be the source of strong paleoseismic events. In order to better characterize the seismic activity of this structural line, a seismological study of TF is carried out by means of locations and computing of focal mechanisms. We collected about 200 earthquakes recorded in the period 2000-2016 by the seismic network managed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV). These earthquakes occurred in the offshore area surrounding the TF and were preliminary located using a 1D crustal velocity model proposed for the volcanic area of Mt. Etna. Hypocenters are mainly located at depth between 1 and 35 km. In the considered period, the study area was affected by a seismicity with a low-to-moderate energy release, ranging the local magnitude (ML) of earthquakes between 1.0 and 3.8. In order to improve the earthquakes location and calculate the fault plane solutions of most energetic events, we enlarged the seismic stations coverage, collecting recordings from stations placed in more distal area of Calabria, central-western Sicily and Aeolian Islands. In the two periods 2002 October - 2003 February and 2012 June - 2013 June, the NEMO-SN1 seafloor observatory was deployed about 25 km offshore from the eastern coast of Sicily, at a depth of 2100 m. We checked the

analyzed earthquakes on seismograms recorded by NEMO-SN1 and picked the P- and S- phases of the events of our dataset. A joint database has been created, collecting data recorded by both land and marine seismic stations. Therefore, we used a new 1D crustal velocity model, specifically calculated for the Western Ionian Sea from the inversion of seismological data recorded by NEMO-SN1, to locate our dataset. Then, the integrated locations have been performed, allowing the improvement of the earthquake hypocentral parameters. To highlight the prevalent kinematic of the TF, the fault plane solutions of 50 earthquakes, which were the most powerful events (ML ? 2.0), were computed. Although our results are preliminary, they will allow us to improve the seismotectonic knowledge of this important active seismogenic structure.

ESC2018-S42-404

ENHANCING ROUTINE SEISMICITY MONITORING BY USING A SMALL APERTURE SEISMIC ARRAY, RESULTS FROM THE EXPERIMENTAL STAGE OF THE PYLOS ARRAY (WESTERN PELOPONNESE, GREECE).

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The National Observatory of Athens (NOA), in the frame of the RADONS project, deployed a small aperture seismic array to assist a multi-parameter earthquake forecasting lab in the Southwestern Peloponnese. The study area was the broader region of the seismically very active western segment of the Hellenic Subduction Zone. Although the region is seismically very active, the correlation of seismicity with tectonic structures offshore to the west of Peloponnese is still weak and spatially and/or temporally restricted to the duration and to the location of local seismic experiments. In fact, hypocentral solutions routinely provided by NOA in the study area, esecially those offshore, are poor because of the low station density and poor event detectability capabilities, low azimuthal coverage (<180°), and a velocity structure hardly resembled by a simple 1D velocity model. For the first time will be presented the first 3 months of seismicity (April-July 2016) recorded during the experimental stage of the Pylos array (April-October 2016). The array consisting of 5 seismic stations, was deployed to test its benefits in terms of seismicity monitoring capabilities and the suitability of the site before the final 9 stations design. It was deployed within the Kynigos solar farm close to Pylos (western Peloponnese), had an aperture of about 750 m and consisted of 4 stations (Trimble REF TEK 130S-01 broadband seismometers) disposed in half-circle around a central station (Guralp CMG-40T intermediate period seismometer). The average inter-station distance was about 360 m. The Array Transfer Function shows a good azimuthal dependence but a wide main lobe which makes it impossible to distinguish the plane wave characteristics for seismic signals with small wave number differences. To enable high quality in the hypocentral solutions contained in the seismic catalogue strict criteria were applied to perform earthquake locations. Events were manually detected and picked, and only those which had clear P and S onsets at the central station of the array and at least at an additional station of the permanent Hellenic Unified Seismic Network (HUSN), and that showed a clear backazimuth and slowness for the first arrival were located. P and S backazimuths and slownesses were estimated by performing F-k analysis and visually checked by performing beamforming of the traces. Earthquake locations were obtained by using HYPOSAT, an algorithm which allows to use array parameters in combination with P and S phase onsets at additional stations. A new 1D velocity model was built by combining results from previous active and passive seismic studies and used for earthquake locations. The use of the seismic array allowed to lower the magnitude of completeness from Ml~2.0-2.1, in the case of routine NOA locations, to Ml~1.3-1.5 up to 100 km from the array. Moreover it helped to better constrain the hypocentral solutions, especially offshore with respecto to those included into the revisited NOA catalogue. The lowering of the magnitude of completeness together with the improvement of the hypocentral solutions, especially offshore to the west of Peloponnese, enabled the detection of clusters of earthquakes and the imaging of seismogenic structures (e.g., interpolate seismogenic zone) otherwise not visible with the routine NOA locations. The first 3

months of data have provided promising results clearly showing the benefit derived by the use of a seismic array in the monitoring of local seismicity especially in the outer part of the Hellenic Sedimentary Arc. The benefits of using a small aperture seismic array jointly with permanent stations of the UHSN are visible up to 100 km of distance from it. This research is a contribution to the FP7-PEOPLE- 2013-ITN research project ZIP (Zooming In between Plates), grant agreement no: 604713, and to the RADONS project (project of the National Observatory of Athens) who has allowed the deployment and maintenance of the array.

ESC2018-S42-405

LOCAL SEISMIC NETWORK REYKJANET

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REYKJANET local seismic network is situated in Reykjanes peninsula on Southwest Iceland. The area is the onshore part of the mid-Atlantic plate boundary between the North America and Eurasia Plates. The seismic activity of Reykjanes peninsula is represented by typical main-shock after-shock sequences as well as earthquake swarms. The REYKJANET network was built in 2013 and it consists of 15 stations placed around epicentral area. Since the beginning all stations are off-line with continuous data recording with sample rate of 250Hz. The State Of Health of all stations is monitored by SMS each two days. We use mainly broadband seismometers Guralp CMG-40T of several various sensitivities which makes the network heterogeneous (one station is equipped with Lennartz LE-3DLite). Five stations are also equipped with infra-sound sensors. All stations use ecological powering exploiting renewable natural resources - wind and sun. During 2018 we will upgrade our network with complete new instrumentation and with on-line data streaming where possible. The seismometers will be replaced with Guralp CMG-3ESPC with uniform sensitivity, more suitable for expected amplitudes. The data recorders will be replaced with Nanometrics Centaurs which among other advantages enable on-line streaming via Seedlink.

ESC2018-S42-463

ANNUAL MOMENT RATE ESTIMATION FOR MARS USING INSIGHT DATA

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Geological maps of Mars show thousands of normal and reverse faults. The former concentrate in grabens around Mars' largest volcanic center, the Tharsis plateau, while the latter are distributed more diffusely across the planet. Most faults occur on very old surfaces and thus witness a tectonically active past. The mean annual seismic moment release associated with their formation was estimated by Golombek et al. (1992) and Golombek (2002), and extrapolated to a current value between 10^18 Nm/yr and 10^19 Nm/yr. Thermal evolution and stress modeling suggests moment rates between 3×10^16 Nm/yr and 4×10^19 Nm/yr. All these values fall between the moment rate inferred for the Moon from Apollo data, and that of the Earth, as was also suggested by the Viking seismic experiment in the late 1970s. One of the science objectives of the InSight mission to Mars, to be launched in May 2018, is to determine the actual moment rate from very broad band recordings of martian seismicity. InSight will carry a triaxial very broad band seismometer and a triaxial short period seismometer to Elysium Planitia, where InSight will land on the 26th of November 2018. Seismic monitoring activities will begin in January 2019 and continue for at least two years, until the nominal mission end in November 2020. Compared with the time interval covered by the GCMT, InSight's mission life time is relatively short, and monitoring an entire planet with a single seismometer also poses some obstacles to the completeness of a seismicity catalog. Small events will be recorded only from a relatively nearby the station, whereas larger, globally detectable events will be overrepresented, thus pretending a reduced slope of the size frequency distribution. It is likely that the first recorded events will be small local or regional ones. After some time, large events strong enough to be globally detectable, will be representative of the global seismicity. This will apply especially to the largest event that is observed during the entire mission. We use the Tapered Gutenberg-Richter

distribution model of seismic moments to derive a scaling between the largest event and the annual moment rate, and simulate a large number of synthetic catalogs to assess the statistical properties of the annual moment rate based on the largest recorded event. We find an approximately 90 % probability that the estimated moment rate is within ±2 orders of moment magnitude of the correct value after two years of registration, and a probability of 50 % or better (depending on distribution slope) that it is within one order of moment magnitude of the correct value.

ESC2018-S42-471

STUDY OF OBSERVED MICROEARTHQUAKES AT MASADA DEEP BOREHOLE

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Seismological measurements, conducted at great depths of several hundred of meters or even a few km, can provide useful information that one cannot get while conducting the measurements on the surface. We take advantage of Masada Deep borehole (MDBI), an abandoned oil well, for the installation of a seismometer at a large depth of 1,256 m (1,516 bsl). The station is located in the near vicinity of the East Masada fault, part of the Western Boundary Fault of the Dead Sea basin. We present seismic observations of microearthquakes which occurred along the Dead Sea fault (DSF). Many of them were not recorded by the Israel Seismic Network (ISN). The quiet site of the station has an obvious advantage in detection and identification of earthquakes and explosions. For example, the station detects about 30% more quarry explosions as compared to observations of the ISN. We demonstrate that borehole seismograms are clearer than the on-surface observations of nearby seismometer. We lowered the magnitude scale of observed events down to about M-3. Many of the earthquakes, sometimes clusters, occurred underneath the MDBI at depths of 10-25 km, having special signature. Using the cross-correlation technique we present several series of seismic activity either underneath the station or along the DSF. Frequency-magnitude relationship, known also as Gutenberg-Richter relationship, is somewhat higher than the determined value for the whole Dead Sea Fault.

ESC2018-S42-475

SETTING UP AN INTERNATIONAL DAY FOR SEISMOLOGY

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In recent months, a steering committee made up of seismologists have teamed up to promote the idea of a “World Seismology Day”. The initiative is driven to counter for the lack of public awareness about the work done by seismologists. Traditionally, seismologists are seen as focusing on studying earthquake sources and seismic hazard. However, seismology is not only limited to earthquake studies: for example, much of our knowledge of the deep interior of our planet is thanks to seismology. New branches in seismology are using different types of sources other than earthquakes: natural (e.g., ambient noise, weather storm monitoring, volcanic tremors, mass-wasting events), and man-made (e.g., controlled sources for geophysical studies and nuclear explosions), the latter playing a crucial role in the nuclear test-ban treaty monitoring. Seismologists are not only studying Earth but are also exploring other planets and moons. In addition, engineering seismology is making our society safer. Unfortunately, much of this cutting-edge research is less known to the public resulting in many seismologists, specialising in one of the above-mentioned fields, left unappreciated. Several areas of science have been assigned a UN-recognised day for the field (e.g., World Meteorological Day, World Tsunami Awareness Day, World Oceans Day); however, such a day is

presently lacking for seismology. In preparation for a "Seismology Day", we would like to gauge the degree of support within the seismology community and increase momentum behind the idea. A World Seismology Day will not only provide a focal point every year for outreach and public engagement activities but furthermore, gives researchers a higher chance of success with funding that supports such activities. We believe that the profile of seismologists and the vast array of studies associated with their work can be raised through a celebration of an international seismology day. Currently, non-UN-recognised days associated with earthquakes (e.g., ShakeOut, Vancouver Earthquake Day) are scattered on different days across various countries around the world. A single global day will have a stronger impact on community outreach and international policy; will not only be limited to earthquakes and hazard preparation but will also be representative of a wider scientific community; will help encourage young scientists to pursue a career in Earth sciences; will help attract research funds locally and internationally; and, will have long-term benefits for the global community in general. The steering committee will oversee the process of proposing a list of possible seismology days and to run a poll to select a single day. The seismology day will ultimately have to be endorsed by IASPEI. An informative website is currently being set up, and financial funds to help maintain the website are being sought. We are keen to receive feedback from seismologists and other interested people on our plans for the seismological community. People interested in joining the steering committee are invited to contact us.

ESC2018-S42-486

INFLUENCE OF THE STATION GEOMETRY, PICKING ERRORS AND CHOICE OF EARTH MODEL ON EARTHQUAKE LOCATIONS USING THE SOURCE-SPECIFIC STATION CORRECTIONS IN THE KVARNER-VELEBIT REGION, CROATIA

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Most of Croatian seismicity occurs in the Adria–Europe contact zone along the NE Adriatic coastal region. The Croatian Earthquake Catalogue lists today over 100.000 events which broadly outline the most active areas, but details are often blurred due to: a) insufficient density of local seismic stations, b) unfavourable station spatial distribution; c) inadequate velocity models for the region; d) onset-times picking errors; and e) a complicated tectonic setting with many overlapping active faults. Here, we concentrate on the greater region of the Kvarner bay and Mt. Velebit (North-Eastern Adriatic), and investigate the influence of the first four parameters listed above. We use about 22000 events that occurred there since 1995, with over 250000 read phase onset times recorded by the local and regional networks, to create synthetic 'ground-truth' (GT) datasets with computed theoretical travel times for the phases actually observed for each event, assuming a simple realistic GT earth model and a range of picking-error normal distributions. These datasets are then used to locate the GT 'events' assuming a range of initial models, and utilizing standard location procedures that include several iterations of locations with source-specific station corrections and model adjustments. Such an approach allows us to statistically evaluate differences of each resulting set of locations from the GT-locations, and eventually draw conclusions about the systematic errors present in the catalogue due to each of the factors enumerated above. This study has been fully supported by the Croatian Science Foundation, grant IP-2014-09-9666.

ESC2018-S42-489

A GLOBAL NETWORK FOR UNDERWATER EARTHQUAKE DETECTION USING THE EXISTING SUBMARINE OPTICAL FIBRE NETWORK

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Whilst underwater earthquakes are crucial for understanding the interior of the Earth, a limited number of permanent ocean bottom seismometers exist today because of their prohibitive installation cost. Here we show that the existing underwater telecommunication cable

network could be used to detect seismic events at the bottom of seas and oceans by using state-of-the-art frequency metrology techniques. We have detected earthquakes on terrestrial and submarine optical fibre links located in the UK, Italy and Malta and of length up to 535 km. Local and tele-seismic events were detected, with epicentre distance ranging from 25 to 18,500 km. These include earthquakes in New Zealand, Japan, Iraq and Mexico. The high sensitivity to seismic noise of our fibre-based measurements is achieved by state-of-the-art optical frequency references based on telecommunications lasers frequency locked to ultra-low expansion glass Fabry-Perot cavities. In contrast with existing distributed acoustic sensing techniques, which are limited to a few tens of kilometres and require dedicated optical fibre, our technique can be used over thousands of kilometres and require only a single telecommunication channel on ordinary data-carrying optical links. This paves the way to implementing a global seismic monitoring network using the existing submarine telecommunication cable network, with no changes required to the underwater infrastructure. Experimental results will be presented at the conference followed by discussions on the implementation of a global network for the detection of submarine earthquakes based on the existing telecommunications underwater infrastructure.

ESC2018-S42-569

THE RELATION BETWEEN ME, ML AND MW IN THEORY AND PRACTICE

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How do moment magnitude, MW, local magnitude, ML, and energy magnitude, ME, of small to moderate earthquakes scale with each other in theory, and why do they scale differently in practice? It turns out that ML, in the way it is commonly determined, is a poor and inconsistent measure of earthquake size. MW is robust and can in principle be determined in a consistent way over the entire imaginable magnitude range, but it accounts only for the static component of the earthquake source. Could ME be an alternative?
A simple conceptual analysis reveals the relation between radiated seismic energy, seismic moment, static stress drop, apparent stress, radiation efficiency and rupture velocity. It can be shown that, when we claim to derive static stress drop from the analysis of observed seismograms, we actually obtain the product of the static stress drop times the radiation efficiency. This product, which is proportional to the apparent stress and which is a function of rupture velocity, contributes the dynamic component to the radiated energy.
Numerical simulations based on an extended-source model show that, to estimate the radiated seismic energy (and thus also ME), one needs to take into account not only the radiation pattern, but also rupture velocity and directivity. Whereas the seismic moment of an earthquake, and thus MW, can in principle be determined exactly from a single observation, the total radiated seismic energy, being the integral of the energy flux at every point on the focal sphere, can not be determined exactly even from an average of multiple observations. At best, we obtain approximate estimates of the seismic energy that can differ significantly from each other depending on the available data. This is the principal reason why energy estimates scatter more strongly than moment estimates. It is a common observation that, with decreasing magnitudes, observed pulse durations, or equivalently observed spectral corner frequencies, approach a constant value. Both theory and simulations show that anelastic attenuation and the bandwidth of the recording instrument determine the magnitude threshold below which observed pulse widths and corner frequencies remain nearly constant. Below this limit, all information about the dynamics of the source is lost, and attempts to correct for this in the presence of noise and aleatory signal variability, even with well-calibrated attenuation models, are probably futile. We thus have to accept the fact that ME (just as ML) is a different measure of earthquake size for small earthquakes than for moderate to large earthquakes. Ignoring this fact in attempts to estimate the seismic hazard from frequency-magnitude relations based on ML or ME of small earthquakes is like counting apples on an apple tree to predict the number of pears on a pear tree.

ESC2018-S42-581

EVALUATION OF SIMULATED GROUND MOTION RECORDS CONSIDERING BOTH SEISMOLOGICAL AND ENGINEERING RESPONSE MISFITS

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With the recent advances in scientific computing, ground motion simulations have become more common. Since different characteristics of waveforms are expected to influence alternative structural response parameters, evaluation of simulated ground motions from not only seismological but also engineering point of view is the subject of debate. In this study, first, simulated motions are evaluated through definition of different seismological misfits including peak ground motion values, duration as well as frequency and energy content of records. Then, the simulated motions are investigated in different aspects of earthquake engineering practice for structural response estimation (e.g.: displacement, acceleration and seismic energy evaluation). To investigate the suitability of simulated motions in various accepts of earthquake engineering, 4 recent earthquakes which occurred in different geological areas are considered. The 1992 Erzincan (Turkey) (Mw=6.6), the 1999 Duzce (Turkey) (Mw=7.1), the 2009 L'Aquila (Italy) (Mw=6.3), and the 2011 Van (Turkey) (Mw=7.1) earthquakes. For ground motion simulation the stochastic finite-fault method based on a corner frequency approach is implemented. Then, misfits in terms of both seismological and engineering measures are calculated. Results of this study reveal that depending on the study area and geological conditions, different levels of seismological and engineering demand misfits are obtained. The proposed evaluation methodology herein is a step forward in paving the road for use of simulated ground motion records for engineers.

ESC2018-S42-629

SEISMIC EVENT IDENTIFICATION USING DIFFUSION MAPS

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In this work, an advanced machine learning technique named diffusion maps is applied for automatic identification of repeating seismic event clusters such as an aftershock sequence. In previous work, we applied the diffusion maps approach for earthquake-explosion discrimination and for characterizing explosions by their origin quarries. Diffusion maps construct a geometric representation of the seismograms that capture the intrinsic structure of the signal at each channel. As a pre-processing step, the seismograms are converted to normalized sonograms. We demonstrate our approach on an aftershock sequence of the February 2004 Dead Sea earthquake with magnitude ML=5.2 and its aftershocks. In the first stage the STA/LTA detector is applied and then the diffusion maps based identification is performed. Alternatively, a cross-correlation detector can be applied in the first stage. The obtained results are validated by the analyst and they are also compared with the dataset recorded by a portable sparse array deployed at an epicentral distance of 15 km from the earthquake. Our results demonstrate the potential and strength of the diffusion maps based approach, as the identification process can be carried out in an unsupervised mode with no need of "master patterns".

ESC2018-S42-665

SURFACE WAVE DISPERSION MEASUREMENT IN THE DINARIDES

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The Dinarides are the orogeny located in the central Mediterranean collision zone that formed due to the interaction between Adria microplate and the European mainland. Along with the creation of the Dinarides, the north-east movement of Adria and its interaction with Europe induced the formation of several other mountain chains, namely the Alps, Apennines and Carpathians. Furthermore, this interaction also triggered many complex tectonic processes such as eastward extrusion in the Eastern Alps and an opening of the Pannonian basin due to the subduction and slab rollback in the Carpathians. Considering all the aforementioned processes, in order to piece together a tectonic history of the Central Mediterranean, it is essential to fully explore each of these processes. In comparison with the surrounding areas, the Dinarides are

relatively poorly explored and tectonic processes that led to their formation are not well understood. Therefore, in order to bring some new insights, we provide a first detailed study of surface wave dispersion in the Dinarides. Using regional-to-teleseismic Rayleigh waves, we created 2-D phase-velocity models at discrete periods in the range from 20 s to 160 s. We used a two-station method with an inter-station path length larger that one wavelength. For a total of 74 seismic stations, we calculated the dispersion curves and cross-correlated them with an acceptable great-circle pair. Our preliminary results show negative velocity anomaly under the central area of Dinarides and positive anomaly beneath Pannonian basin and Adriatic sea, clearly supporting the results of the previous studies.

ESC2018-S42-668

THE INVESTIGATION OF EARTHQUAKES RECURRENCES AND SWARMS OF MUGLA-ULA REGION

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Mugla region located the drift system of the Aegean, where intensive observation of seismic activity in Turkey. Gökova, Mugla-Milas and Yatagan fault zones are important tectonic sources occurred earthquakes in the region. Earthquakes that occurred during the instrumental period are the 1926 (M = 7.7) Twelve Islands, 1957 Fethiye Gulf (M = 6.8 and M = 7.1), which located in Mediterranean. Near the southern Aegean - Crete island arc trench system and the Twelve Islands are region where earthquake activity is most intense. Especially 05.02. 1984 M = 5.0, 22.11. 2017 M = 5.0 and 24.11. 2017 M = 5.1 earthquakes, which located in the vicinity of the Mugla-Ula region, indicated that the probability of recurrence of earthquakes with M > 5.0 is high. Earthquake recurrences have been observed when the instrumental records of the region have been examined. Also, the main shock of 22.11. 2017 M=5.0 earthquake, which is occurred 50 aftershocks (magnitude intervals 1.0 < M < 3.9). These earthquakes were swarm character and continued long-term seismicity. These earthquakes have been increased the earthquake hazard of Mugla province, which is a historical and touristic region. In this study the active seismicity near Mugla-Ula has been examined in detail. The earthquake locations have been recalculated with using the HypoDD program with double differences over the travel times of the P and S waves by earthquakes (M > 3) occurred in the region. The relocation results have been mapped and the earthquake clusters have been investigated according to the tectonic structure of the region. It is thought that this detailed seismicity study will significantly contribute to the earthquake hazard studies of the region because of the high earthquake (M > 5.0) probability.

ESC2018-S42-675

COULD WE EXPECT SEISMIC ACTIVITY IN THE OHRID LAKE EPICENTRAL AREA AS STRONG AS 1911 M6.7 EARTHQUAKE

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The complex seismotectonics of the Ohrid epicentral region, Republic of Macedonia, resulted in series of strong earthquakes 5.9<M<6.7 that occurred between 1911-1912. Ever since that period, not such seismic activity has been observed in that region. However, in the period of June till September 2017, the Ohrid epicentral region exhibited increased seismic activity as a swarm of small size earthquakes with the biggest one of ML 5.0. The distribution of epicenters show faults' activity in the northern parts of the epicentral region, with absence of activity in its southern parts. The mechanisms of the strongest earthquakes of this series show faults' activity with orthogonal orientation in respect to the main N-S extension of the predominant faults. The analysis of the latest events will help prove correlation with the past seismic activity as deducted from the historical records.

ESC2018-S42-678

SEISMIC ACTIVITY IN SKOPJE EPICENTRAL AREA: PAST, PRESENT AND FUTURE

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Seismicity of the Skopje seismic zone is a result of the subduction of the Skopje Valley and the differential vertical and horizontal displacements of the surrounding mountains expressed in the regional tectonic compression. Those processes initiate movements on the faults in Skopje Valley and the surrounding terrain, causing frequently earthquakes of magnitude 6 or more. Many written documents exist about seismicity of his area which dated since 518y. Comparison of the locations and the macrosesmic effect of the earlier earthquakes of the 518y and 1555y with the earthquakes from 1963y and 2016y, show that all four of them are generated along the same fault, that is Skopje-Kustendil fault. The discussion in this study is based upon four events of 518y, 1555y, 1963y and 2016y, for which many historical (prior to 1963) and current instrumental data are available. These data are valuable for evaluating of historic and recent seismicity in the area under investigation, as well as the building codes and the safety standards that will further help in the planning for emergency strategies for Republic of Macedonia.

ESC2018-S42-697

IMPROVED EARTHQUAKE DETECTION FROM A NEWLY EXTENDED LOCAL SEISMOLOGICAL NETWORK OF THE MALTESE ISLANDS – CENTRAL MEDITERRANEAN

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Appropriate planning and deployment of seismic stations of a local network is a prerequisite to efficiently monitor seismic activity, determine the seismic source, and eventually contribute to seismotectonic interpretation and natural hazard assessment. The effectiveness of a recently extended local network in the Maltese Islands and applications of various methodologies are presented and further discussed. The Maltese islands have been affected by a number of earthquakes in the historical past, with the majority of their hypocenters concentrated in the Sicily Channel (bordered by the Tunisian, Libyan and Sicilian coastlines), in eastern Sicily, and as far away as the Hellenic arc. Some of these earthquakes have also caused considerable damage to buildings. The Malta Seismic Network (ML) in the recent years was extended and currently comprises six broadband stations, installed over all the Maltese archipelago. Since June 2017 and in collaboration with Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) in the frame of the premiale project FASTMIT, to further improve the network abilities and also test new sites as permanent station locations, 6 short period new stations have been installed in key positions across the islands. The developments on the network have improved the detectability threshold and allowed the identification of activity that would have been misclassified or overlooked. The earthquakes detected by all stations since June 2017 are manually repicked and relocated applying several location techniques. Initially the events are located using the manual P and S arrivals and Hypoinverse algorithm with a 1D velocity model that is used in the daily analysis. To further improve the results several velocity models are tested and NonLinLoc is implemented to relocate the events. The results are evaluated examining the spatial errors, the form of the density scatterplots per event, and also the difference between maximum likelihood and expectation locations is taken into account. As an additional procedure, the travel-time residuals are examined separately for each station as a function of the epicentral distance. To optimize the final velocity model, seismic profiles are created in certain azimuths with satisfactory station coverage. Phases identified on the waveforms of the stations are compared with the theoretical travel times of the best velocity model. The model is modified to minimise the differences between the observed and theoretical travel times. Moment tensor solutions, for the strongest events, are computed by using the CAP method. Synthetic seismograms are created following a spectral element approach and are compared with the observed. The relocation procedure is repeated and the results are re-evaluated and compared with the initial. Finally, several cross sections are constructed in various azimuths and the spatial distribution of the earthquakes is evaluated and compared with the active fault structures. Extending the Malta Seismic Network, besides improving regional earthquake determination is also revealing the activity of local faults. Furthermore, the development of a near real-time earthquake monitoring system, that additionally incorporates

data from regional networks, allows a rapid alert not only for local, but for regional earthquakes. Such studies emphasize the importance of identifying local and regional fault zones activation, and their impact on the seismic hazard of the Maltese islands. Moreover, they lead to an understanding of the local and regional geodynamics, shedding light on the mechanisms that contribute to both the crustal deformation and the tectonics of the central Mediterranean.

ESC2018-S42-698

SOUNDS OF EARTHQUAKES IN ICELAND AND WEST BOHEMIA

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Earthquake sounds are usually observed during the occurrence of small earthquakes. The observations of audible manifestations of earthquakes date back to the ancient age and have been recently analyzed in more detail based both on macroseismic observations and audio recordings. In most cases the earthquake sounds resemble low-frequency underground thundering that is generated by seismic-acoustic conversion of P and SV waves at the earth surface. This is also supported by the fact that earthquake sounds usually precede shaking caused by S-waves. The less frequent are explosion or clap-type sounds whose origin remains unclear. We installed microbarographs on 9 selected broadband stations of the seismic networks in Iceland and West Bohemia in order to detect various types of sounds reported in the literature. Our recordings of pressure waves generated by swarm earthquakes in epicentral distances up to 25 km cover the frequency range 0.1 -40 Hz. All infrasound recordings correspond to the thunder type of sound with waveform, which is very similar to the waveform of the vertical component of seismogram. This is consistent with direct conversion of seismic to pressure waves at the earth surface. However, all records of the West-Bohemia swarms show later arrival of sound wave, whose arrival time is consistent with its generation in the area of epicenter. This would imply invalidity of the Huyghens principle and we discuss the possible sources of this phenomenon. We also compared the frequency spectra of seismic and sonic records of all the M>3 events with a sufficient signal-to-noise ratio. In most cases, the resulting transfer spectrum shows an increase with frequency, which results in preponderance of high frequencies in sonic records compared to seismograms. With the exception of a single station, the absolute level of the seismic-acoustic transfer function exceeds significantly the theoretical prediction and in all cases it shows several local maxima. This points most probably to local geological effects and complex morphology of the volcanic landscape causing various types of resonances.

ESC2018-S42-699

CRUSTAL STRUCTURE INVESTIGATION OF CORINTH GULF BROADER REGION, USING DATA FROM THE HELLENIC UNIFIED SEISMOLOGICAL NETWORK

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Corinth Gulf, Greece, is one of the most active extensional continental regions in the world. The long history of repeated large earthquakes and the existence of high level background seismicity led to the installation of several digital three-component seismic stations around the Gulf. The dense station coverage allows the precise and accurate hypocentral determination of the occurring earthquakes, using the weighted P- and S-wave arrival times, also providing a large waveform dataset. The spatial distribution of the earthquakes allows velocity model determination, using several reflection and refraction phases through raytracing. For that purpose, a large amount of earthquakes were manually analyzed. The seismicity covers approximately the study area, with depth distribution varying from surface to 12 km. Ray-tracing and inversion techniques are applied to determine the velocity structure. Selection of the manual events is performed, fulfilling the following minimum criteria: 8 P- and 4 S-wave arrival times for each event, good quality of traces (high signal to noise ratio), azimuthal coverage, variety in both depth distribution and in range of epicentral distances. Due to the high density of hypocenters in certain areas, a

supplementary selection was performed, yielding 850 earthquakes with the best possible spatial distribution (minimum inter-event distance required). Seismic profiles, using these events, are created in certain azimuths with satisfactory station coverage. The procedure requires the selection of events where, apart from the direct Pand S-waves, reflected and refracted phases can clearly be identified. Theoretical traveltime curves and observed traces are plotted in different azimuths. The differences between the observed and calculated travel times, common between the profiles in certain locations and azimuths, indicate the needed modifications of the velocity model. As a final verification of the resulting model, synthetic waveforms are calculated adopting a spectral element approach and correlated with the observed seismograms. The final velocity model is also used to relocate the selected events in the study area and the errors are compared with the results of the initial 1D velocity model. Moreover, the form of density scatterplots and the difference between maximum likelihood and expectation locations is taken into account. As an additional procedure, the travel-time residuals are examined separately for each station as a function of the epicentral distance. Finally, several cross sections are created in various azimuths and the spatial distribution of the earthquakes is evaluated and compared with the active fault structures.

ESC2018-S42-714

SINGLE LAYER RECURRENT NEURAL NETWORK FOR DETECTION OF SWARM-LIKE EARTHQUAKES IN WEST BOHEMIA AND SOUTH-WEST ICELAND

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We present a new method of local event detection based on neural networks. The proposed algorithm uses a unique neural network architecture. It combines features used in other neural network concepts like Real Time Recurrent Network and Nonlinear Autoregressive Neural Network to achieve a good detection performance. We use the recurrence combined with various delays applied to recurrent inputs to make the network remember history of many samples - the Single Layer Recurrent Neural Network (SLRNN). The network was first trained and tested on data from local seismic network in West Bohemia (Webnet). Then we applied the trained network to different dataset from local seismic network in South-west Iceland (Reykjanet). Both networks monitor earthquake swarm areas, both networks have similar number of stations used for detection and both cover roughly equal areas. We show that the neural network trained on Webnet data could be used on Reykjanet data with very good results.

ESC2018-S42-777

ROMANIAN SEISMIC NETWORK: CRITERIA FOR THE ACCURACY OF VRANCEA EARTHQUAKE LOCATIONS

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Accurate event locations are essential for seismic hazard studies and for developing and testing three-dimensional velocity models of the Earth. The seismic activity in Romania is dominated by the intermediate-depth earthquakes occurring in Vrancea region. Presently, the Romanian Seismic Network has more than 120 real time seismic stations and is designed mainly to detect record and locate the seismic events in Romania. The common practice of seismic location accuracy analysis is to calculate the formal uncertainties (error ellipses, elapsed time and unreliability of depth) which are dominated by three factors (Pavlis, 1986): measurement errors of the seismic arrival times, modelling errors of the calculated traveltimes and non-linearity of the earthquake location problem. We developed simple criteria for estimating the accuracy of Vrancea earthquake locations, based on parameters which are commonly reported in earthquake bulletins: at least 10 stations, all within 150 km epicentral distances, azimuthal gap of less than 100°, at least one station within 30-50 km from the epicenter. For the evaluation of the developed criteria we used intermediate-depth earthquakes from Vrancea area with magnitude ML > 3 occurred since 2017 to present. These criteria will improve the earthquake catalog and minimize the time for manual earthquake location.

ESC2018-S42-787

REGIONAL BODY-WAVE MAGNITUDE SCALE MB(PN/SN) FOR EARTHQUAKES IN THE NORTH ATLANTIC REGION

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The mid-ocean ridge system is one of the most prominent features on the surface of the Earth, and it plays a key role in creating new oceanic crust. Hence, characterizing the earthquakes that occur along the mid-ocean ridge is important in understanding ongoing tectonic process. The magnitude is a key parameter to assign relative size of the earthquakes. However, until this study, no reliable magnitude scale was available to be used for small earthquakes along the mid-ocean ridges. The magnitude scale used for mainland Norway is based on Lg-wave amplitude measurements and does not work for the oceanic crust in the North Atlantic region. We obtained a robust magnitude scale for earthquakes along the northern mid-Atlantic ridges by using Pn and Sn waves that propagated through oceanic crust and uppermost mantle, then are recorded at seismic stations on land in the Northern Atlantic region. The new magnitude scales are called mb(Pn) for Pn and mb(Sn) for Sn measurements, respectively. Attenuation parameters in the magnitude scales were computed for earthquakes that are included in the global CMT catalogue by tying the new magnitudes to MW. We inverted for station and event specific correction terms and found that the earthquakes that occurred along the spreading ridges of the mid-Atlantic ridges showed strong long-period waves but poor high-frequency signals, which required about +0.1 magnitude units of compensation, whereas earthquakes that occurred along fracture zones and transform faults showed relatively strong high-frequency waves that lead to a negative adjustment of ≈0.2 magnitude units. The mb(Pn) and mb(Sn) magnitude calculations have been incorporated into the Norwegian National Seismic Network processing system and have been applied retrospectively to earthquakes in the catalogue. On average, the new magnitudes are almost 1.5 magnitude units larger than previously calculated ML values. The new catalogue magnitudes are used to compute b-values for the different segments of the mid-Atlantic ridge.

ESC2018-S42-801

THE ARRAIOLOS - PORTUGAL - MODERATE-SIZED 2018 (M = 4.9) EARTHQUAKE OF JANUARY 15 AND AFTERSHOCKS: PRELIMINARY RESULTS

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On 15 January 2018 at 11:51 UTC, an earthquake of 4.9 ML occurred in the Northeast of Arraiolos region near Aldeia da Serra village. The hypocentral location, determined by Instituto Português do Mar e da Atmosfera (IPMA), has coordinates 38.79 N, 7.93 W at 11 km depth. The focal mechanisms determined by P-wave first motion polarities and waveforms inversion indicate a dominance of strike-slip events with nodal plans near NS (left lateral) and EW (right lateral) directions. Due to the lower magnitude, the earthquake didn't cause damage but was widely felt in the Centre and South of Portugal mainland. In the vicinity of the epicentre, at the Aldeia da Serra village, it reached a maximum intensity VI, having been felt with intensity IV/V in the city of Évora, about 20 km from the epicentre. The event was also felt with intensity III in Lisbon at more than 100 km from the epicentre. This event caused alarm in the population that haven't felt an earthquake for several decades. It also raised the media attention with many reports and interviews on TV and newspapers. The main earthquake was immediately followed by a sequence of aftershocks of which the largest one, with ML=3.1, occurred the 1st February, fifteen days after the main shock and was largely felt by the population in the region of Arraiolos. Two hours after the occurrence of the main shock the Institute of Earth Sciences (ICT) and the Instituto Dom Luiz (IDL) started the installation of a seismic network for aftershock monitoring. The network is composed of 14 Broadband (CMG 6TD, 30 s) and

21 short period (CDJ, 2.0 Hz) portable seismic stations located around the epicentral area, with interstation distances varying between 2 to 15 km. Thus, the coupling of the 35 temporary stations with IPMA's permanent network allowed the collection of a high-quality dataset of events with good azimuthal coverage, well controlled hypocentre depth and focal mechanisms. This temporary network allowed the detection of several low magnitude events not detected by the permanent network, lowering significantly the magnitude detection threshold. The fine azimuthal coverage allowed also a good precision on the determination of the hypocenter parameters. The preliminary results obtained by the Arraiolos temporary network will be presented, namely the relocation of the mainshock, the aftershocks distribution, seismic source studies and macroseismic map. Arraiolos Field Team: Alexandra Afilhado, António Martins, Susana Gonçalves, Noel Moreira; Afonso Loureiro, Paulo Alves, Jorge Cruz, Joana Araújo; Miguel Maia, Sandro Vicente; Catarina Matos, José Luis Duarte, Paula Afonso, Duarte Espanhol (IDL,ICT and IPMA).

Acknowledgments:
This work was partially supported by the European Union through the European Regional Development Fund, included in the COMPETE 2020 (Operational Program Competitiveness ad Internationalization) through the ICT project (UID/GEO/04683/2013), with the reference POCI-01-0145-FEDER-007690, by the project PT-DZ/0003/2015, and by Portugal2020 Program, under contract 22151/01/SAICT/2016 (C4G-Collaboratory for Geosciences). We also acknowledge the contribution of CERU (Centro Europeu de Riscos Urbanos) to the field work.

ESC2018-S42-802

LOCATION AND DEPTH ESTIMATION OF THE NORTH SEA EARTHQUAKE 30 JUNE 2017

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30 June 2017 a magnitude 4.5 mb earthquake occurred in the Viking Graben of the North Sea. When recorded, the event was the largest in the area for several decades. This is an area with several offshore platforms related to oil and gas production, and an accurate location and depth estimate of this event is therefore important for risk assessment. However, applying standard location procedures to P- and S-phase arrival times observed at station network surrounding the North Sea leaves the event depth rather unconstrained, and we are seeking alternatives for constraining the location and depth estimate. Different from most other events in the North Sea, this relatively large event has been recorded by stations at both regional and teleseismic distances, with depth phases observed at several of the far field stations. Depth phases like pP and sP are phases which are reflected at the surface from below in the source region, and the difference in arrival time between the first arriving P and the depth phase can be used to better constrain the depth of the event. We localized the event using different methods: The HYPOSAT algorithm, a grid search algorithm using the LLNL-3D velocity model and a grid search using the global ak135 1D velocity model. For calculation of more accurate pP and sP travel times, the HYPOSAT algorithm was extended to accommodate the use of local velocity models for the source region, combined with global models (as ak135). In the HYPOSAT algorithm we included P, S and depth phases (at various distances and azimuths) and tested three different local and regional 1D velocity models. The local model most representative for the source region included local low velocity sedimentary layers. This resulted in a depth estimate of approximately 4 km. Secondly, the event was localized using a standard grid search with the LLNL-3D velocity model. For this localization only P and depth phases at teleseismic distances were included. However, this resulted in a depth of approximately 8 km. A new grid search was done using the ak135 velocity model with the same phases as for the previous grid search. This gave a depth of 15 km. The grid search using the LLNL 3D velocity model gave a 20% lower residual than for the ak135 1D velocity model. Thus, from this study it is concluded that depth estimation is challenging. The estimation strongly depends on choice of method, velocity models and phases used for localization. However, we reckon that the HYPOSAT algorithm which includes a local model provides the best solution, since this estimation includes the velocity model that best represents the source region.

ESC2018-S42-829

RE-ANALYSING THE ONNA SITE EFFECT AS A COLD CASE: NEW HINTS ON THE LOCAL VELOCITY STRUCTURE FROM AFTERSHOCK SEISMOGRAMS

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The village of Onna, settled on the soft sediments of the Middle Aterno river Valley, was destroyed by the 6th April 2009 L'Aquila earthquake, attaining an MCS intensity of 9.5. Explanations were given in terms of building vulnerability as well as source and site effects; however, none of these factors, if considered alone, is fully convincing. Monticchio, a village with similar age and constructive typology located less than 2 km from Onna but settled on more competent rocks, attained an MCS intensity of 6. This suggests that the different geologic setting played a major role on the severe damage of Onna. However, the deepest borehole available in the study area (120 m) did not reach the bedrock beneath Onna and the shallower (< 80 m) geophysical and geotechnical measurements do not show a significant near-surface impedance contrast that could explain the large ground motion amplitude observed during the mainshock. In this study, we have analysed hundreds high-quality seismograms of 125 aftershocks recorded in Onna and Monticchio from July to December 2009, to estimate a reliable empirical transfer function. We built a velocity model extending the shear wave velocity of sediments at 80 m down to a bedrock at 200 m of depth. The best fit is obtained with an impedance contrast of 2 at the bedrock top. This model yields a satisfactory match of the weak motion amplification. A significant amplification is also reproduced in nonlinear simulations of the mainshock shaking.

ESC2018-S42-850

HYPODD RELOCATION OF COASTAL EARTHQUAKES IN MEDIUM-ADRIATIC REGION: THE USE OF A NEW 3D VELOCITY MODEL

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The Apennines/Adriatic foredeep between Porto Sant' Elpidio and Riccione (medium-Adriatic region) reach thicknesses of more than 5000 m of Plio-Pleistocene terrigenous sediments. The Meso-Cenozoic foreland fold-and-thrust belt dissects the foredeep in different sectors with important lateral stratigraphic variations. This complex structural and stratigraphic setting makes it difficult to locate earthquakes (especially the offshore ones) and makes the focal depth of the seismic events poorly constrained if you use routine and one-dimensional velocity models. Even if the seismometric network geometry is not suitable, especially in the case of azimuthal gaps greater than 180° (the case of offshore earthquakes), and the shallow velocities are extremely slower than those commonly used in the internal Apennines, 3D velocity models created ad hoc, combined with advanced location techniques can obtain more accurate locations and a significant reduction of the error estimate, especially on focal depth. To carry out this study it became necessary to preliminarily create an adequate catalogue containing only the coastal earthquakes (in a range of 50 km at the turn of the coast approximately from Porto Sant' Elpidio to Riccione) occurred and recorded by the network of seismographs operating in this area from December 1996 until December 2015. The catalogue has been also clean from all those earthquakes with a registration number lower than 5 in order to not regard minor earthquakes that haven't enough information for a good location. For the Umbria-Marche region a 9 layers tomographic model is available, with a lateral resolution of 15 km and 4 km in depth (Carannante et al. 2013); this model is not well constrained for the coastal area and especially in the Adriatic offshore, due to the scarcity of events and the external position of this area in relation to the centre of the tomography grid and the majority of the stations. This is confirmed by the fact that the location with this model sometimes have associated errors even higher than those obtained with a 1D velocity model. Adding complexity to the model does not necessarily improve its accuracy; a well constrained 1D velocity model may produce, as in this case, more accurate locations than a 3D model which is not suitable for the area (Husen and Hardebeck, 2010). To overcome these limitations, a 3D velocity model has been created by integrating geophysical and geological information obtained through the

numerous geophysical surveys for hydrocarbon researches. This model was then integrated with that resulting from seismic tomography and was used for relocation with the innovative software NonLinLoc (Lomax and Curtis, 2001). Although this procedure shows much lower associated errors (RMS, ERH, ERZ) than the 1D and 3D-Carannante locations, the mixed 3D model still has large margins of improvement, especially as regards the allocation of velocities in the layers between the base of the Pliocene and the Mesozoic limestones. In order to further improve the earthquake locations, the best NonLinLoc location was then used as starting position to relocate with the HypoDD software, based on the double differences algorithm (Waldhauser and Ellsworth, 2000) which tends to be less dependent on the velocity model and reduces location errors due to the presence of Earth model uncertainties. NonLinLoc locations show a shift, moving from the 3D-Carannante model to the 3D-mixed model through the 1D, where the focal depths increase, the epicentres cluster and the distance from the coast generally decreases. The reduction of the errors and the new locations, imply that the accuracy of earthquakes location using the 3D mixed velocity model is substantially improved. The location obtained with this velocity model has been thus chosen as input for relocation using the HypoDD software. Uncertainties computed by HypoDD are usually few orders of magnitude smaller than the corresponding uncertainties for locations with linear and nonlinear methods (Waldhauser and Ellsworth, 2000). This trend is enhanced if we can use higher precision relative arrival time measurements especially if evaluated by using cross-correlation tecniques. Looking at the results, the Conero sequence represents the most critical case, because of the wide azimuthal gap around the epicentres; that is not so crucial in localitions of other two clusters of seismicity, recognizable in front of Senigallia and in the Rimini area: in any case the focal depth is poorly constrained with respect to the epicentre location, despite the addition of S-phase observations. The locations of the Conero and Rimini clusters show a similar, NW-SE distribution, but with different focal depths: the Conero sequence is shallow with depths between 5 and 10 km, while the Rimini cluster is located between 10 and 15 km; the Senigallia cluster shows a greater dispersion both in the planar distribution and in depth, ranging between 5 and 20 km.

ESC2018-S42-861

THE ESTIMATION OF EARTHQUAKE PROPERTIES AND SEISMIC MICROZONATION BY USING 3D SEISMIC REFRACTION AND UPHOLE DATA: A STUDY FROM LOWER INDUS BASIN PAKISTAN

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Local site conditions are largely dependent on the seismic ground motions and therefore play an important role to construct an earthquake-resistant design. An attempt to support this argument has been made by using seismic refraction survey and up-hole logging data. The primary and secondary velocity is computed through seismic refraction survey and up-hole logging data and further shear wave velocity (VS) is estimated by using Lee equation. Soil amplification factor and soil fundamental period are measured and based on VS value soil type is identified to check the susceptibility to earthquake liquefaction for the study area located in the Lower Indus Basin of Pakistan. Based on seismic shear wave velocity (VS30) from the surface to the depth of 30 meters we have characterized site response for simplified earthquake resistant design and site classification and this classification is made by using the standards given by National Earthquake Hazard Reduction Program (NEHRP) the USA. Average horizontal spectral amplification term related to earthquake engineering unified with site response investigation in every micro-zonation study by Nakamura uses horizontal components over specified period bands for the provision of ground response on a regional scale ratio for the period of 0.4 to 2 seconds is used. Our results reveal that the local site settings give increase to significant local amplification (SLA) of ground motion during earthquakes. The intensity of ground motions during the 1906 San Francisco earthquake was strongly related to the local site conditions. The measurements of geotechnical and earthquake engineering parameters and micro-zonation of the study area on a regional scale have been made. This whole study is based on two layers consolidated and unconsolidated up to the depth of 65 meters approximately. For geotechnical and geophysical investigations primary and secondary waves are used. Furthermore, the implication of shear wave for construction of average horizontal spectral amplification maps and micro-zonation

map of study area. This study confirms that study region is prone to earthquake waves due to the presence of unconsolidated/alluvium in above layer.

ESC2018-S42-884

MAPPING THE DIFFRACTION PATTERNS OF SURFACE WAVES BY ALPARRAY

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The AlpArray seismic network stretches hundreds of kilometers in width and more than thousand kilometers in length. It is distributed over the greater Alpine region (Europe) and consists of around 250 temporary and around 400 permanent broadband stations with interstation distances around 40 km. The density of the network allows to track the distortion of travel times and azimuthal deviations of long-period surface waves (30 – 150 s). 30 teleseismic earthquakes from 2016 and 2017 from the first two years of the AlpArray project cover the full range of azimuths. We map the propagation of surface waves by two independent methods. First, we pick group and phase times. Group travel times are much more sensitive to distant heterogeneity then phase times. Using simple Gaussian beam time-delay modeling of the heterogeneity effects on group propagation times, we are able to estimate the distance of the heterogeneity, its position, lateral size and magnitude of the velocity anomaly, which had caused the observed time distortion. Phase times are, on the other hand, compared with the results of the second method of mapping the deviations: We utilize an array beamforming technique for surface waves. The signal is well-recognized and the fundamental mode for Rayleigh waves is separated before the beamforming. Instead of searching for energy of all possible signals as in traditional beamforming, we identify the frequency-dependence of surface wave phase velocity and the true directions of propagation. We consider each AlpArray station as a centre of a subarray of neighboring (6 – 15) stations with a diameter of 80 km. This allows us to calculate the local phase velocity for more than 500 stations included in the AlpArray project. As we have the full vector of phase velocity (true direction as well as the absolute value of the velocity), we can observe deviations of the backazimuths with respect to the great circles for each subarray. These deviations are frequency-dependent throughout the whole region. They follow the same pattern as the phase (and group) times picked at each station separately (see the first method). The observation serves not only as a detector of upper mantle heterogeneities, but it also allows to determine how phase and group travel time delays and wavefront healing can affect global and regional tomographic studies.

ESC2018-S42-919

CRUST VELOCITY MODEL AND EARTHQUAKE RELOCATION OF THE NORTHERN MIDDLE MAGDALENA VALLEY, COLOMBIA

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The Middle Magdalena Valley (MMV) is an intermountain basin enclosed by the two easternmost branches of the Andes Cordillera so-called Central Cordillera and Eastern Cordillera (Sarmiento 2011). A simultaneous hypocenter-velocity inversion was implemented using a catalog of local seismicity. The catalog was provided by the Colombian Seismological Network and contains more than 4 000 local events detected from February 2014 to March 2016 registered by 19 stations. A local one-dimensional velocity model derived from the 100 best earthquakes was obtained. It consists of six layers with depths up to 100 km and P wave velocities from 4.0 to 8.2 km/s with a Vp/Vs ratio of 1.74. The model includes a Moho depth of 40 km. The station corrections range from -0.03 to 0.89 s for P waves and -0.08 to 1.36 s for S waves. The obtained velocity model was employed for earthquake relocation using the Hypocenter algorithm included in the SEISAN package (Havskov et al 2010). The new locations yielded shorter hypocentral errors and RMS compared with the previous model (Ojeda, A. and J. Havskov 2001). The results highlight the crust shallow seismicity until 40 km depth and the deeper seismicity from 40 to 140 km depth, which displays the Caribbean plate subducting beneath the South American plate. The double differences method was implemented for the shallow events

using the HypoDD algorithm (Waldhauser 2001). The new locations show a major concentration of events towards the borders of the valley where the regional faulting lies. In the central part of the basin, the crustal seismicity is scarce, indicating that the sedimentary sequence of approximately 8 km thickness is seismically inactive. Finally, we present partial results of the ambient noise recordings and stacking of almost two years of normalized data to disclose S waves velocity variations in the upper crust, through a tomography. This contribution can be used as a basis for new crustal modelling and seismic source studies. It also improves the seismic monitoring of the MMV in Colombia.

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ESC2018-S42-933

DISCRIMINATION OF SMALL MICRO-EARTHQUAKES AND CHEMICAL EXPLOSIONS AT LOCAL DISTANCES USING MACHINE LEARNING

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We developed an automatic system to discriminate between natural earthquakes and chemical explosions in the area of a planned nuclear power plant in Pyhäjoki, Bothnian Bay region, Finland. The site has a local seismic network of 10 stations with 250 Hz sampling rate. The largest diameter of the network is about 100 km. The seismicity in the area is low. About 30 micro-earthquakes are observed in a year. In the same time hundreds of chemical explosions are observed. Spurious anthropogenic signals are also observed daily. Occasionally in winter time hundreds of ice-quakes in short time periods complicate the automatic processing of the seismic bulletin. The processing of the final earthquake bulletin needs laborious manual analysis and checking the automatic solutions. Automatic seismic event classification makes this process faster. In this work, we apply advanced machine learning methods for discriminating between seismic signals. The methods include artificial neural networks, diffusion maps, support vector machine, logistic regression, nearest neighbors classifier, gradient boosting classifier, decision tree, random forest, and Bayesian networks. The capability of different methods are compared. Three different classification configurations are tested: single station classification with voting, whole network classification with missing data processing and classification with stacked data from available stations. The earthquakes in the area are small. The magnitude range of the earthquakes used in machine learning is from -0.7 to 2.3. The magnitude range of the earthquakes used in machine learning is from -0.4 to 2.2. The station to hypocenter distance range is from 4 km to 150 km. All explosions in the data set are from quarries or mines and from construction sites and they are delayed shots. Spectra of delayed shots show spectral undulation which is absent in spectra of earthquakes. Most of the input parameters for the classifiers show amount of spectral undulation. Spectra of noise prior to the signal was subtracted from spectra of the signal. Then baseline was subtracted from the spectra to reveal the undulation. Several parameters were computed from the processed spectra including variation, skewness, kurtosis, and mean of highest peaks. Also P to Sg spectral ratios are used to separate the earthquakes from explosions. The data set consists of 113 earthquakes and 129 explosions. The network has been in full operation from autumn 2016and with 5 stations from summer 2014. Thus the number of earthquakes is rather small. In preliminary classification 90% of the events were classified correctly. This is satisfactory considering the the distance range and small size of the micro-earthquakes and the explosions.

ESC2018-S42-934

DETERMINISTIC AND PROBABILISTIC SEISMIC HAZARD MAP ON THE TERRITORY OF REPUBLIC ARMENIA

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The paper reports on a new deterministic and probabilistic map of seismic hazard zones in the territory of the Republic of Armenia. The mentioned maps is suggested as a normative map to be used in the norms of BC of RA (Building codes of RA) for use in building in regions of seismic hazard.

ESC2018-S42-938

STUDY OF SEISMICITY AND SEISMOLOGICAL INVESTIGATIONS ON THE TERRITORY OF ARMENIA

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In the paper a brief review on the development of the studies carried out in the field of structural and focal seismology is given. Based on the results of these studies as well as the complex seismological analysis of the Spitak earthquake in 1988, the most promising and actual directions for further development of seismological research in Armenia were identified. These studies are conditionally grouped into three directions: structural seismology, seismicity and seismic regime, physics of the earthquake source. In this paper, we briefly outline the main tasks and results of the studies carried out at Institute of Geophysics and Engineering Seismology after A. Nazarov of the Republic of Armenia in each of these fields.

ESC2018-S42-964

SURFACE WAVE DISPERSION ANALYSIS IN TURKEY

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We present preliminary results from a regional-scale study of surface-wave group and phase velocity dispersion across western Turkey and Central Anatolia. Our database for the region is populated with seismograms from regional events recorded at permanent three-component digital broadband stations operated by Kandilli Observatory and Earthquake Research Institute (KOERI). We have measured the group velocities using a single-station method. In the first place, we have compared the group velocities of the fundamental mode Rayleigh wave for different broadband seismometers with varying frequency coverage (namely with low frequency cut-off of 30 s, 120 s, 300s, and 360 s). Furthermore, we calculated the group velocities of the fundamental mode Rayleigh and Love wave for different ray paths using earthquakes with different backazimuth, to understand the azimuthal variations in Turkey. Moreover, group velocities are inverted to find the 1D crust and upper mantle S wave velocity structures and compared with the previous studies. We repeated the same surface wave inversion procedure using synthetic seismograms in order to observe the sensitivity to S wave velocity at different depths on the same travel paths. In addition, Rayleigh and Love wave phase-velocity dispersion curves were estimated for two-station paths across the study region. The aim of this study is to understand the reliability of the 1D S-wave velocity inversion for crust and upper-mantle structures from surface waves, which will then be used for joint inversion with receiver functions. From this point of view, results that will be presented are the preliminary steps of more comprehensive study.

ESC2018-S42-983

TELESEISMIC EVENTS RECORDED AT THE BELGIAN ANTARCTICA BASE

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Belgium has equipped its Antarctica base with a broadband seismometer since 2010. Since then, the Royal Observatory of Belgium routinely measures global teleseismic events and reports the time arrivals to ISC in its official bulletin.

During the same period, thousands of earthquakes have been reported by international catalogues along the boundaries of the Antarctica Plate with the South-America, African or Australian plates. In this communication, we report on the available dataset and provide some estimation of the lower magnitude threshold of detectable events in the 3000 km range north of the Base.

ESC2018-S42-1011

VALIDITY OF EMPIRICAL FOURIER SPECTRAL MODELS FOR LARGE MAGNITUDE EVENTS IN TURKEY.

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In their recent studies Bora et al (2013, 2015) proposedan empirical predictive equation for Fourier Amplitude Spectra (FAS). Their equation is based on the seismological parameters as moment magnitude (Mw), Joyner-Boore distance (Rjb), the time-averaged shear-wave velocity in the upper 30 m of the soil column beneath the recording site (Vs30), the stress drop (Δσ) and kappa (K0). Since the method utilizes a point source approximation, earthquakes with M>6.5 are discarded from the analyses. Hence, the main objective of this study is to test the validity of the empirical FAS equation by Bora et al.(2013,2015) for large magnitude events, particularly events occurred in Turkey. A total of 96 strong motion recordings from 3 earthquakes are chosen from PEER NGA West-2 database. In addition to these, number of 234 strong motion recordings from 10 earthquakes are selected from RESORCE database. Magnitude and Rjb ranges are between 6.4-7.6 and 20-370km, respectively. An equation of Vs30-K0 by Edwards & Fah (2013) is employed into the analyses. Regional estimations of K0, if exists, is also utilized. One of the most important parameters affecting the spectra, constant stress drop value is gradually increased for all events, starting from 10 MPa. Goodness of fitting in the frequency range of engineering interest is evaluated through coherency functions. This work presents and discusses the coherency functions with changing Δσ parameters, including event specific Δσ. In addition to that possible improvement of the coherencies with the use of local K0 is also discussed. Keywords: Fourier Amplitude Spectrum, Empirical Fourier Spectral Models, Ground Motion Prediction Equation.

ESC2018-S42-1056

ENGINEERING SEISMOLOGY ASPECTS OF THE AUGUST 1ST 2014 (MW5.3) ALGIERS EARTHQUAKE: SOURCE PARAMETERS, WAVE PROPAGATION AND SITE EFFECTS IN SELECTED SITES

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On August 1st, 2014 a moderate-sized earthquake with moment magnitude Mw= 5.3 struck the capital city of Algiers at 05:11:17.6 (GMT+1). The earthquake caused the death of 6 peoples and injured 420, mainly following a panic movement among the population. The main shock is felt in eight (08) cities surrounding Algiers and recorded by twenty seven (27) digital ETNA stations; twenty three (23) stations in free field and four (04) in structure. The data is minutely processed using ormsby band pass filter to not lose any signal information. The nearest station to the epicenter recorded a moderate peak ground acceleration (PGA) of 0.14g. Acceleration in the N-S direction is generally greater than that in the E-O direction. This observation is valid almost at all stations which recorded this event. This is due normally to directionality effect of the fault. The amplitude and the frequency content vary according to the seismological parameters such as the magnitude of the earthquake, the epicentral distance as well as the geological conditions of the site. The frequency content may have a reduced or wide frequency distribution and may be characterized by several parameters like predominant frequency fp, response spectral acceleration Sa(f) and smoothed spectrum predominant frequency f0. Generally, the results revealed an increase in the three parameters depending on the epicentral distance of the station. Nevertheless, we observed a weak correlation of the parameter fp with respect to the two other parameters. In second phase, source and wave propagation parameters of the main shock are estimated using reliable records. Using Brune spectral model for the source effect, seismic moment, corner frequency

and stress drop are estimated. The magnitude is calculated for each station and the average is considered the final magnitude of the earthquake. The corner frequency is estimated by minimizing the Fourier amplitudes of the seismic event and Brune source of all the recording stations and has the value of 1.35Hz. The wave propagation attenuation is modeled as the product of the geometrical and anelastic attenuations. The geometrical attenuation, which is not proportional to the epicentral distance, is generally taken as 1/R and the anelastic attenuation decreasing exponentially with quality factor. We observed a large value of the quality factor which means a rapid attenuation of the seismic motion in this region.

ESC2018-S42-1081

THE EXTRAORDINARY SEISMIC SWARM OF MAY 2018 IN WEST BOHEMIA

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In May 2018 an unusual earthquake swarm occurred in the West Bohemia region, which was extraordinary by activating two fault patches separated by a 2 km gap which differed in the character of seismicity - the typical swarm-like activity with maximum ML magnitudes of 3.3 has progressively changed into a typical mainshock-aftershock character with a ML 3.8 mainshock. The yet incomplete manual arrival time pick, which were available for larger events only were supplemented by automatic picks and refined by waveform cross-correlation measurements. The resulting precise locations show a fine structure of the activated fault zone and monotonous subhorizontal and later downward migration of hypocenters in the lower hypocenter cluster and upward migration in the upper cluster. Moreover, during the swarm activity, a separate part of the fault zone was activated at distances of 8 km with magnitudes reaching 2.6. This behaviour - unusual activity spreading is new and worth discussing. Preliminary estimations of focal mechanisms are in agreement with standard expectations for the area and correspond to events locations along the fault system. We also determined the local Vp/Vs ratios using the double-difference Wadati method. Several sub-clusters respecting spatial and temporal evolution of the swarm were subject of the analysis. Results relieved monotonous decrease of VpVs with duration of the activity. The highest observed values 1.7 were associated with early onset of the activity, where pure swarm-type character was evident, while low values down to 1.5 corresponded to the later mainshock-aftershock-type activity. The statistical analysis of magnitudes and interevent times, shows also distinct character from different periods of activity and is used, along with the velocity ratio characteristics, to decipher the background driving forces of the new swarm activity.

This event was proudly supported by:

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36th General Assembly of the European Seismological Commission
2-7th September 2018, Valletta, MALTA
http://www.escmalta2018.eu

ISBN: 978-88-98161-12-6

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