ElarmS and the next large earthquake in Italy

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Abstract: We evaluate the capability of ElarmS to work as an Early Warning System for the next destructive earthquake in Italy. Potential sources were retrieved from the Database of Individual Seismogenic Sources (DISS; http://www.ingv.it/DISS/) and from the catalogue of historical earthquakes (CPTI04; http://emidius.mi.ingv.it/CPTI/). Based on the geometry of the new Italian Broad-Band Seismic Network, we estimate the "Alert time" for each source from different nucleation points and the size of the shadow zone, the area already affected by S-waves. We present our results for peninsular Italy with a particular attention to the metropolitan areas of Napoli, (Southern Italy) that have been selected as a test site for the SAFER project (http://www.saferproject.net/), plus Roma and Firenze.

Keywords: (Max 6). Early warning, earthquake, active fault, seismic source, Italy.

Introduction

Recent developments in rapid detection and hazard assessment of earthquakes combined with modern digital seismic networks and rapid communications have lead to the development and implementation of early warning system (EWS) in several countries prone to damaging earthquakes. The purpose of these systems is to issue a warning some time before the arrival of the damaging ground shaking. Early warning methodologies use two approaches to provide warning. They exploit the travel time difference between the S-waves, slower but more destructive, and the P-waves, faster but less damaging, and they use data gathered from seismometers close to the epicenter to provide warning to regions at greater distance. An existing implementation of these ideas is ElarmS [Allen and Kanamori, 2003; www.ElarmS.org]. ElarmS is designed to take advantage of a dense seismic network distributed across a seismically active region such as California [Wurman et al., 2007; Tsang et al., 2007] and Italy [Olivieri et al., 2008]. The hypocenter is determined by detecting the P-waves at the closest stations and grid searching around the triggered stations, at the same time the earthquake magnitude is estimated from the dominant period and the amplitude of the first few seconds of seismogram following the P-onset.

As shown by Olivieri et al. [2008], ElarmS has the potential for being used as an effective early warning system in Italy. This conclusion was drawn after evaluating the capability of the system to accurately locate recent earthquakes as recorded by the new Italian Seismic Broadband Network (**Figure 1**) and to give rapid but reliable estimates of the magnitude. Olivieri et al. [2008] conclude that the minimum requirement for releasing a reliable alert would be four P-wave triggers and 3 seconds of P-wave data recorded at three stations. Depending on the epicentral location, the station distribution, and regional P- and S-wave velocities, this minimal dataset can be used to estimate the expected warning time at any location for a specific scenario earthquake. An estimate of the "shadow zone," i.e. the area that will have already experienced the destructive part of the ground shaking by the time the Early Warning can be disseminated.

To estimate potential warning times for future earthquakes in Italy we must therefore ask where future large earthquakes will strike? While we do not know where the next earthquake will strike we do know where future large earthquakes are likely to occur. This is based on mapping of fault systems with recognized geological activity including fault segments that have generated strong earthquakes in historical times and are likely to be the parent structures of future earthquakes. The purpose of this work was to evaluate the capability of ElarmS to "protect" key areas and critical infrastructure from possible future earthquakes on these known active faults. We thus developed warning scenarios by evaluating the size of the shadow zone for a number of source zones for which the maximum credible earthquake and the parameters of its causative fault are known. This was done using the latest version of the Database of Individual Seismogenic Sources (DISS; Figure 1) [DISS Working Group, 2007; http://www.ingv.it/DISS/] which contains the results of investigation of active tectonics in Italy during the past 20 years [Basili et al., 2008]. We also explored, retrospectively, how ElarmS would have performed today in the case of three earthquakes that occurred in historical time causing significant damage in Firenze (Florence) in 1920, Roma (Rome) in 1915, and Napoli (Naples) in 1456. Our assessment of warning times and shadow zones presented here is based on the distribution of the existing seismic network and the current active fault database. These estimates would need to be updated with future advances in active fault mapping and improvements to the seismic network. In this work we do not consider the small magnitude diffuse seismicity that occurs in many parts of Italy, but only earthquakes occurring on main faults and capable of generating the larger destructive event.

Potential Seismic Sources

DISS is a repository of geologic, tectonic, and active fault data for the Italian territory and some surrounding regions. It highlights the results of several decades of research work, with special emphasis on data and conceptual achievements of the past 20 years, thereby providing a new and unified view of active and seismogenic processes. DISS is also built taking into account physical constraints on rates of crustal deformation, the continuity of deformation belts, and the spatial relationships between adjacent faults, both at the surface and at depth. Each record in DISS is georeferenced and fully parameterized. Geologic maps and cross sections, seismic reflection profiles, geodetic data, seismic tomography, and uplift data are commonly used to constrain the geometry of faults. Where data are scarce or unreliable, the fault size is usually constrained using empirical relationships. For strike, dip and rake all available information from geological maps and focal mechanisms are used. Further constraints on rake can be obtained from maps of the principal stress and strain axes and from GPS velocity fields. The fault top and bottom depths are estimated through geological sections, seismic tomography images, depth distributions of instrumentally recorded earthquakes. A detailed account of how these parameters are estimated is given by Basili et al. [2008].

Building on the availability of this extensive tectonic information, we selected a set of potential seismic sources and applied a method similar to that used by Lorito et al. [2008] to calculate deterministic scenarios of earthquake-generated tsunamis in the Mediterranean basin. In this method, a Source Zone (SZ) is one that includes an active tectonic structure at regional scale. The geometric and kinematic properties of the structure are assumed to exhibit only limited variations inside the SZ. Similarly, the rheological and dynamic properties of the tectonic structure are assumed to allow equally large earthquakes to be released throughout the SZ. We then assumed that a SZ is made up of a number of individual fault segments, each of them capable of releasing an earthquake. For each SZ we identified a Maximum Credible Earthquake (MCE) and an associated Typical Fault (TF). The TF is defined by parameters that must comply with both the seismological properties of the MCE and the tectonic properties of its parent SZ. The TF is allowed to float, i.e. it was placed at regular steps along strike of the entire SZ. Steps were taken at one fault length. At each new position the TF could release its MCE with a number of different nucleation points. The centroid of fault patches with an average surface of ~12 km^2 were used as the possible nucleation points. This procedure allows a number of potential scenarios to be explored based on the information that is more robust – the location and geometry of the fault(s) – without needing to know the exact location of the end points of the coseismic rupture. In other words, the limited knowledge on the internal structure of the SZ, and hence of any permanent segment boundaries, is accommodated by considering multiple scenarios and assuming that such boundaries do not exist. To assess the MCE for each SZ we selected the largest earthquake that has ever occurred in that zone and for which there exists, or is possible to obtain, reliable magnitude estimates. We assumed that such an earthquake may repeat anywhere within its parent SZ at any time in the future.

Figure 2 shows the selected SZs in map view. From North to South they are: 1) Lunigiana-Garfagnana; 2) Mugello-Sansepolcro-Trevi; 3) Norcia-Ovindoli-Barrea; 4) Pescolanciano-Castellino del Biferno; 5) Castelpetroso-UfitaValley; 6) Pago Veiano-Montaguto; 7) Irpinia-Agri Valley-Mercure Basin; 8) Vallata-Monteverde. SZ 1), 2), 3), 5), and 7) represent the well known alignment of NW-SE striking normal faults that accommodate the Apennine extension, whereas 4), 6), and 8) represent the westernmost part of a set of E-W structures with normal-oblique kinematics. For each SZ we identified the MCE as the largest historical earthquake associated with the source zone in DISS. The TF of each SZ is the individual fault that is known to be the MCE causative fault. Table 1 summarizes the parameters of each TF and the associated MCE along with its macroseismic intensity (MCS scale) actually observed in Firenze, Roma, and Napoli during the relevant earthquakes. The selected SZs are those that host the causative faults of the largest known earthquakes that damaged Firenze, Roma, and Napoli in historical time.

Shadow Zone determination

We define the shadow zone for an EWS the area where the destructive part of the seismic waves has already arrived at the time when the warning can be released. We consider the centroid of each patch of the fault as the potential nucleation point on the fault and estimate the warning time by searching for the third and fourth closest stations. This is required to apply our ElarmS warning criteria that at least 1 second of P-wave data is available for the trigger/picking purposed at four stations and 3 seconds of P-wave data is available at three or more stations for the magnitude estimation. Note that magnitude and location estimates are provided by ElarmS prior to this requirement being met, however, we choose this threshold as an appropriate point in time to issue a first warning [Olivieri et al., 2008].

We use Vp = 5.8 km/s to estimate the arrival times of P-waves at seismic stations, and Vs = 3.2 km/s to estimate the distance reached by S-waves at the warning time. We also consider the latency of data transmission; each second of delay to transmitting data is a second of lost warning time. The latency of a seismic data stream is the time delay between the actual time of ground motion at some seismic station and the time the data is received for processing at some network center. The latency depends on several factors including the size of the data packets generated by the digitizer, the mechanism used to transmit the data, the bandwidth of the communications, packet retransmissions, and errors. INGV network relays most data using one of two transmission media, satellite IP and the internet (TCP-IP). The latency is therefore variable ranging from a minimum of 2-4 seconds and a maximum of 10 seconds. This value is crucial to estimating the warning time, and cannot be neglected when using a dense network with some stations within 50 km, for which the P-wave travel time can be shorter than 10 seconds. Given the variability in the latency we consider three cases by fixing the latency for all the stations at 3, 5 and 10 seconds. This allows us to explore the best and worst cases, and to understand how improvement in the transmissive part of the network can increase the efficiency of an early warning system.

Results and Conclusion

Figure 2 summarizes the aggregated results obtained from all the simulations described above. Red, blue and green lines describe the integrated Shadow Zone for all the possible earthquakes in the source zones given 10, 5 and 3 seconds data latency respectively. Since we do not know where nucleation will occur within the identified source zones, Figure 2 contours the worst-case scenario of nucleation on the fault segment closest to the warning location for each of the different latencies, warning times could of course be greater. Some of the most urbanized areas including Roma and Napoli are well outside even the worst-case scenario nucleation for a 10-second latency in data transmission. This means that for these cases an alert could be issued a few to tens of seconds before the arrival of the most disruptive part of the shaking. This is enough time to execute simple but effective action to mitigate the impacts of the earthquake. For example, taking cover under a desk is an action that reduced personal injuries but only one second. Moving away from hazardous machinery and chemicals is another possibility. Electronically controlled devices can also be moved to a safe mode. Elevators can stop at the next floor and open before power is lost, machinery can be slowed or brought to a halt. Figure 2 also shows that most of the Firenze-Roma-Napoli high-speed railway lay outside of the shadow zone for 5 sec latency, thereby providing the opportunity to start to slow and stop trains during a major earthquake that could damage the railway tracks.

Figure 3 shows three retrospective cases of actual earthquakes that have occurred in the past and damaged the cities of Firenze in 1920, Roma in 1915, and Napoli in 1456 (Table 1). These scenarios illustrate that warning times for destructive earthquakes will likely be greater than that shown in Figure 2 which assumes a nucleation on the section of the fault closest to the cities. For these events the warning times could be 9 seconds for Roma and 4-5 seconds for Napoli event with a 10 second data latency, reducing the latency to 5 seconds would increase the warning time by 5 seconds. Only Firenze is inside the 10 sec latency contour (Figure 3). Providing warning in a repeat of the 1920 earthquake would require latency to be less than 3 seconds. It is important to note that ElarmS discriminates between large destructive earthquakes and moderate earthquakes. This means that actions would not be triggered in a moderate non-destructive earthquake preventing unnecessary reactions and panic. The potential effects of ElarmS can be estimated referring to the macroseismic field for the three retrospective cases (MCS values as from Stucchi et al 2007 and

Fracassi and Valensise 2007). In figure 4, we show the percentage of observerd intensity point that lay outside the 3s, 5s and 10s latency contour lines. For the largest observed intensity in figure 4, that lay right at the epicenter, we get 0% as expected since an early warning system can not reduce the damaging effects close to the epicenter. For the three earthquakes, shortening the latency time from 10s to 5 and to 3s increases the warned localities for each intensity level up to 30% and 50% respectively. For Naples, wven in the worst case, the early warning, if in place, would have warned the 12% of localities that suffered intensity IX MCS.

In conclusion we find that implementing an early warning system in Italy using the existing seismic networks could provide warning of coming damaging ground shaking. This warning could be used to help reduce the impact of earthquakes on the population and to important and sensitive infrastructure in the most densely urbanized areas. Warnings would likely be available for Roma and Napoli. In the case of Firenze the earthquake source zone that could potentially generate the next important earthquake is too close to the city for the current seismic network to provide warning. Further study is necessary to see if an enhancement to the seismic network in the area that surrounds the potential epicenter would allow warnings to be provided.

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Figure captions

Figure 1 – Black triangles represent the broadband and 5-second stations of the Italian National Seismic Network used in this study. Red polygons represent the seismogenic sources from DISS 3.0.4.

Figure 2 – Map showing the aggregated results for all SZs. Red, blue, and green lines contour the limit of the Shadow Zone for a latency of 10, 5, and 3 seconds, respectively. Thick red lines indicate the seven Source Zones described in table 1 each one with its characteristic earthquake.

Figure 3 – Above: maps showing the results for the three cities under analysis and their nearest and most damaging historical earthquakes for which the causative fault is known. A) Firenze: in this case the city is outside the 3 seconds latency Shadow Zone but completely included by the other 2 cases (5 and 10 seconds). B) Roma: in all the hypotheses for the latency Roma results well outside of the Shadow Zones. C) Napoli: same as Roma. Below: Intensities for the strongest known earthquakes to affect the three towns from the historical catalogue (1400AD to 2000AD). On vertical axis the maximum Intensity (MCS) reported for the respective town. The arrows indicate the occurrence of the scenario earthquake shown in the maps above.

Figure 4 – Percentage evaluation of number of localities that lay outside the 3 (green), 5 (blue), 10 (red) seconds contour as shown in figure 3 for the three selected most damaging historical earthquake: a) event 2, b) event 3, c) event 8 in table 1

Table 1 – Parameters of the typical faults, selected from DISS 3.0.4 (DISS Working Group, 2007), and maximum credible earthquakes for each source zone along with their intensity at the selected localities. Latitude and longitude coordinates are given at the typical fault centroid. * Stucchi et al. [2007], ^ Fracassi and Valensise [2007]. Is: Intensity at the site in MCS scale; F: felt; FI: Firenze; RM: Roma; NA: Napoli.

#	Lat	Lon	Strike (deg)	Dip (deg)	Rake (deg)	L (km)	W (km)	Depth (km)	Slip (m)	M0 E+19 (Nm)	Mw	Date dd/mm/yyyy	Mw	Is FI	Is RM	Is NA
1	44.18	10.32	305	40	270	18	11.3	1.0-8.3	0.50	0.31	6.4	07/09/1920	6.48*	5*	-	-
2	43.96	11.47	298	40	270	14	9.8	0.6-6.9	0.45	0.19	6.2	29/06/1919	6.18*	6*	-	-
3	41.97	13.62	145	60	270	28	15.4	1.0-14.3	1.06	1.37	6.7	13/01/1915	6.99*	3*	6-7*	5*
4	41.66	14.50	269	70	230	36	14.9	11.0-25.0	2.50	4.02	7.0	30/12/1456	7.16^	-	-	F^
5	41.29	14.74	311	60	270	25	14.3	1.0-13.4	0.90	0.97	6.6	05/06/1688	6.72	-	F*	8*
6	41.03	15.46	280	64	237	31	15.0	1.5-15.0	0.95	1.33	6.7	23/07/1930	6.72	-	3*	7*
7	40.80	15.29	310	60	270	28	15.0	1.0-14.0	1.65	2.08	6.8	23/11/1980	6.89	3*	4*	7-8*
8	41.24	15.06	277	70	230	30	14.9	11.0-25.0	2.00	2.68	6.9	05/12/1456	6.90^	-	-	8^