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The seismicity of Ischia island

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Abstract

Ischia is a volcanic island, west to the caldera of Campi Flegrei, Southern Italy. Since the deployment of a modern seismic network in 1970, until the 21st August 2017 earthquake, the seismicity of Ischia has been characterized by low magnitude (Md≤2.3) earthquakes located in the northern part of the island, mostly beneath the town of Casamicciola Terme at very shallow depths (around 500 m). Some of these events seem to have occurred on the same seismogenetic structure, in the northern part of the island. This area coincides with that where the devastating events of 1881 and 1883 occurred and where the small magnitude seismicity recorded between 1927-1936 was located. The August 2017 seismic sequence affected the same area. The current network configuration is able to locate shallow events with M≥1.0 and to detect smaller earthquakes or other types of natural and artificial events (e.g. blast fishing, geothermal well explosions; see section 2). Here we present the catalogue of earthquakes recorded on Ischia between 1999 and February 2018 and we compare the August 2017 seismic sequence with the background seismicity. Furthermore we have identified a sequence of events possibly linked to the explosion of a geothermal well on the island.

1 - Introduction

Ischia is one of the three volcanic complexes around the city of Neaples on the tyrrhenian margin of south Italy, which last erupted in 1302 (Civetta et al., 1991). Its eruptive history has been accompanied by remarkable ground uplift due to the resurgence of the ancient caldera (Orsi et al., 1991; Acocella and Funiciello, 1999; Molin et al., 2003; Paoletti et al., 2013) that was formed after the eruption of the Mount Epomeo Green Tuff, about 55 ky.b.p (Civetta et al., 1991). Its recent geological history is dominated by the earthquakes of 1881 (De Rossi M. S., 1881) and 1883 (Carlino et al., 2010), which seriously affected Casamicciola Terme, and the other municipalities of the island (Fig. 1). After this event, in 1885, the scientist Giulio

Grablovitz (1846-1928) founded a Geophysical Observatory on the island. In this observatory Grablovitz installed a seismic tank, an instrument capable of measuring and recording on paper the oscillations of the water contained in a tank, with respect to the ground (Ferrari, 2009). The Geophysical Observatory stopped working for scientific purposes in 1923. Although not all of the observations made at the Observatory of Grablovitz have come down to us in a complete form, this scientific institution has, however, prompted attention around the geophysical phenomena of Ischia (Parascandola, 1937). This study allows us to know that the first decades after 1885 were characterized by very low seismicity. In the same observatory a seismic station has been installed in 1993, and it has successively been upgraded into a multi-parametric station, with the addition of new seismometric and accelerometric sensors (Capello et al., 2011). This site, along with other three seismic stations on the island, are managed by the Osservatorio Vesuviano and allowed to monitor the seismicity of the island in the last decades.

Geophysical and geochemical measurements have shown the presence on the island of an extensive hydrothermal system, which in some cases has led to explosion of geothermal wells, as in 1995, 2001 (Chiodini et al., 2004).

For what concerns ground deformation, in the past history of the island, geological evidences have shown that it was characterized by strong uplift episodes, in particular an uplift of more than 700 m occurred after the Mount Epomeo green tuff eruption $\sim$ 55ky.b.p. (Vezzoli, 1988). The current trend of deformation shows a general subsidence of the Mt. Epomeo block and areas characterized by active landsliding (Manzo et al., 2006).

In the following, the present work describes in detail the seismicity of the island in relation to its structural and volcanic setting and with respect to the main features of the historical seismicity. Moreover, a comparison between the August 2017 seismic sequence and the previous seismicity is reported.

2 - The seismic network

Since the installation of the first permanent modern seismic stations in 1993 (OC9), the seismic network of Ischia has undergone a progressive improvement that continues today. Currently the network consists of four permanent sites: IOCA/OC9 (Osservatorio di Casamicciola), IFOR/FO9 (Forio d'Ischia), CAI (Castello Aragonese), and IMTC (Monte Corvo) (Fig. 1 and Table 1). Until 2009 the seismic network consisted exclusively of analogue stations (OC9, FO9 and CAI). In 2009 the analogue station FO9 was complemented by a digital broadband station (IFOR), equipped with a Guralp CMG-40T seismometer and an InfraCyrus infrasound sensor (Buonocunto et al., 2011). In 2011 the site of OC9 was implemented with a broadband seismometer, an accelerometer and a broadband infrasound sensor (Chaparral 25V). In April 2015 a new seismic station, IMTC, was installed in the area of Monte Corvo (Fig. 1) and was equipped with a Guralp CMG-40T 60s and a GILDA datalogger (Orazi et al., 2006). In August 2017, after a Magnitude 4.0 earthquake that caused two casualties and serious damage to Casamicciola Terme, several mobile seismic stations were added to the Ischia network (Fig. 1 and Table 1). At the present, all the data recorded by the permanent stations are continuously transmitted in real-time to the monitoring center of Osservatorio Vesuviano using both analog (16 bit A/D conversion) and digital (24 bit A/D conversion) systems.

A complete seismic catalogue is available since 1999 and includes 269 seismic transients of local origin. In figure 2 we show the numerical proportion among different types of signals that are classified based on their waveform characteristics and frequency components. Examples of transient signals of the different categories are shown in figure 3, both in the time and in the frequency domain. The categories are: earthquakes (29.0%; Fig. 3A); explosions (13.7%; Fig. 3C,F); landslides (5.9%; Fig. 3B); other (51.3%; Fig. 3D,E). The category "others" contains all the transient of unknown origin or which cannot be clearly classified. Some of the events falling in this category are probably of natural origin (e.g. thunder, Fig. 3D).

Local earthquakes (A in Fig. 3) usually have a peculiar high frequency onset, followed by an almost exponential waveform envelope. The landslide signals are generally characterized by an emergent onset and a frequency content <10 Hz. In figure 3B we show a 1000 s long recording of a significant landslide occurred at the town of Casamicciola Terme on 2009-11-10 which caused a casualty (Santo et al., 2012). Explosions from illegal fishing activities along the coast of the island are often recorded with clear signals, characterized by a marked low-frequency (<5 Hz) seismo-acoustic phase, following the event onset (Fig. 3C). Thunder is usually characterized by a broad spectrum and by an irregular waveform envelope (Fig. 3D). On 2005-09-10 at 15:11 UTC, a powerful seismic signal, accompanied by a loud boom, was recorded by stations as far as 80 km away from Ischia (Fig. 3E). D'Auria et al. (2006) associated this transient to the atmospheric trajectory and the subsequent airburst of a bolide, about 15 km SW of the island, at an elevation of about 11.5 km.

In figure 3F we show the spectrogram of one of the three seismo-acoustic signals recorded during the explosions of a geothermal well on 2005-03-27 and discussed in section 5.

For understanding the geodynamics of Ischia, the study of local earthquakes is doubtless an important topic. The accelerometric station IOCA was installed in 2011. Its records were fundamental during the August 21st 2017 earthquake with duration Magnitude (Md)=4.0, which signal saturated all the other stations located on the island.

In figure 4 we represent the spectrograms of two earthquakes of comparable magnitude, recorded by the accelerometer IOCA: the Md=1.6 earthquake of 2013-12-10 and the Md=1.5 earthquake of 2017-08-30, and the spectrogram of the 21 August 2017 main earthquake. The spectral content is quite similar, however their waveforms are different, probably due to a different location and mechanism. The 2017 earthquake has been located, below the town of Casamicciola Terme at a depth of 1.8 km, using the improved seismic network of Osservatorio Vesuviano and two stations of the mobile seismic network (Fig. 1 and Table 1). The improvement of the network after 21th August allowed a better characterization of the earthquake parameters providing insights into the dynamics of the island.

3 - Magnitude statistics

Since 1999, at least 78 earthquakes have been identified on the recordings of the Ischia seismic network (updated to February 21st 2018). In Table 2 (see Table S1, available in the electronic supplement to this article) we report the whole seismic catalogue with the hypocentral parameters of the located earthquakes. Magnitudes are estimated using a duration magnitude relationship derived for the Campi Flegrei caldera (D'Auria et al., 2011). Before 2017 the seismicity of Ischia has been characterized by small and very shallow events, most of which were detectable only in Casamicciala Terme, which is the main simogenetic zone of the island, therefore many parameters, in Table 2, are undetermined. For the same reason, defining a magnitude-duration scaling was not easy. Thus the scale created for the Campi Flegrei was adopted on the basis of the similar geological and volcanological context of the two volcanoes. The duration of the seismic recording is estimated through the visual analysis of the seismograms. In figure 5 the magnitude versus time plot shows that during the whole considered time interval the seismicity rate was low and almost stationary with a sudden rise during the August 2017 seismic swarm. Earthquakes with $M \geq 1.9$ have been always felt by people (black dots in figure 5), although earthquakes with a lower magnitude have sometimes been perceived (e.g. the 2007-06-06 event with $M=1.3$).

The Gutenberg-Richter (GR) statistics shows a b-value of 0.75 ± 0.13 and a magnitude of completeness $M_c=1.3 \pm 0.15$ (Fig. 6). These parameters were estimated using the approach of Ogata and Katsura (1993).

In order to quantify the performance of the seismic network we have estimate the magnitude thresholds for earthquake detection and location. Following Tramelli et al. (2013) we have computed theoretical P-wave amplitudes for an earthquake of a given magnitude comparing them with an average seismic noise level at each station. Using a single corner frequency spectral model (Boatwright et al., 1991) and taking into account geometrical spreading and anelastic attenuation we have computed theoretical amplitudes from each possible hypocenter to each seismic station for the magnitude range from -1 to 4. Computations have been performed considering a homogeneous velocity model with P-wave velocity of 3.5 km/s and a P-wave quality factor Q_P=100. The former value is a rough average of a 3D model resulting from seismic tomography (D'Auria et al., 2008), while the Q_P comes from the extrapolation of an average value of Q_S retrieved for the Campi Flegrei caldera (Del Pezzo and Bianco, 2013). We have estimated as average noise level the value of 2×10^{-5} m/s for the stations located on the Ischia Island. This value is comparable with the results obtained by Del Pezzo et al. (2013) for the Campi Flegrei area.

In figure 7 we show the obtained location and detection thresholds. This analysis allows understanding where earthquakes, with a certain magnitude, can occur without being recorded by any seismic station. On panels a and c we plot the detection threshold (i.e. the minimum magnitude for an earthquake to be detected) at different depths. It can be seen that the network is able to detect all the events with a magnitude higher than 0.5 located at a depth of 500m or less in most part of the island; the magnitude threshold increases in the southeast of the island. Close to the seismic station the detection threshold is obviously much lower reaching values even less than 0. At depth of 2 km the threshold reaches values of about 1.0 over the whole island (Fig. 7). This result is compatible with the magnitude of completeness estimated from the GR relationship (Fig. 6).

We have also estimated the magnitude threshold for earthquakes that could be located. In our case we have chosen it as the minimum magnitude for an earthquake to be detected by at least 3 stations, assuming that at least one S wave arrival time is available. On panels b and d of figure 7 we show the results of this analysis. On average the minimum magnitude for a superficial earthquake (depth=500m) to be located is around 1.5. The value obviously increases with the hypocentral depth. Earthquakes deeper than ~ 2.0 km beneath the Ischia Island are not expected on the base of a study conducted by Castaldo et al., (2017), who used the temperature distribution of the crust and the physical information of the rocks derived from several and different observation to define the 3D brittle/ductile transition below the island.

4 - Hypocenter locations

We have been able to locate 28 events having a number of phase pickings between 3 and 4. Locations have been performed using a probabilistic approach (NonLinLoc, Lomax et al., 2000) in a 3D tomographic velocity model (D'Auria et al., 2008). Hypocenters and their uncertainty ellipsoids are shown in figure 8. Even if most of the hypocenters have large uncertainties (Fig. 8), it can be seen that they are all located in the northern part of the island, with a cluster of earthquakes located beneath the town of Casamicciola Terme at a depth of about 500 m. This location coincides with the area affected by the historical seismicity, in particular the destructive earthquakes of 1881 and 1883 and the small magnitude earthquakes of the 1927-1936 (Parascandola, 1937; Carlino et al., 2010).

5 - The March 27th 2005 seismo-acoustic transients

In the recent history of Ischia some events, related to the violent degassing of exploratory geothermal boreholes, have been observed (Chiodini et al., 2004). We report the analysis of a sequence of events that are likely related to this kind of phenomenon. Between 00:48 and 00:51 UTC of 2005-03-27 the seismic network of Ischia recorded a sequence of at least three seismic transients with complex waveforms (Fig. 9). In the same time interval, various people living in towns at the SW corner of the island (Panza and Sant'Angelo) reported hearing loud rumbles. The three events represent a unique sequence occurred within few minutes therefore we assume a common source for them.

The waveforms of the three recorded events are quite different. However, they have two common features: a first phase with an emergent onset and a second, strongest, seismic phase with an impulsive onset. The traveltime differences of this strongest phase are not compatible with the body wave velocities of the area. To study the origin of this phase and to locate the source of these 3 events we used a probabilistic Bayesian approach. Assuming a similar source location for all the events, and setting the source depth to 0, we can define a probability density function (p.d.f.):

$$p(c,x,y) = e^{-m(c,x,y)},$$

where the misfit function *m* is defined as:

$$m(c,x,y) = \sum_n \sum_i \sum_{j>i} \frac{\left[\left(t_i^{OBS}-t_j^{OBS}\right)^2-\left(t_i^{TH}-t_j^{TH}\right)^2\right]}{\sigma_i{}^2+\sigma_j{}^2}.$$

The index *n* runs over the event number (1-3), while indices *i* and *j* indicate the stations. σ is the weight associated to each station. This approach mimics the double different method of Waldhauser and Ellsworth (2001) and does not require the computation of the origin time. Theoretical traveltimes are computed considering a straight path and a constant velocity c. The marginal p.d.f. over the wave velocity:

$$p_c = \int_{x,y} p(c,x,y)dx\,dy,$$

is represented in figure 10. At its maximum likelihood $\hat{c}$ is 750 m/s, which is consistent with the velocity of a surface wave. To locate the event we compute the conditional p.d.f.: $p_{xy}(x,y) = p(\hat{c},x,y)$, which is plotted on a map in figure 10. The maximum probability values are located in the SW corner of Ischia, between the towns of Panza and Sant'Angelo. This area coincides with that were rumbles were reported.

In summary, data indicate that a powerful source of surface and sound waves was located between Panza and Sant'Angelo with complex source time functions, evidenced by analysing the difference in the waveforms envelope between the 3 events. A likely source of this signal is the violent repeated gas release from a borehole. In this case, the exact location of the well has not been identified, but similar episodes recorded in the past were unequivocally linked to the explosion of boreholes (Chiodini et al., 2004).

6 - The seismic sequence of August 2017

The seismic sequence started with the Md=4.0 earthquake, located ~1.2 km below the town of Casamicciola Terme. The earthquake occurred at 20:57 local time spreading the panic among the inhabitants and the numerous tourists on the island. Most of the buildings located in the southwest part of the town of Casamicciola Terme were highly damaged and two people died because of this earthquake (https://ingvterremoti.files.wordpress.com/2017/09/rapporto-di-sintesi-sul-terremoto-6-settembre-2017_l.pdf; Nappi et al., 2018). The seismic traces recorded by the velocimeters on the island were saturated because of the high amplitudes. Conversely the accelerometric recording of the station IOCA located at about 1 km away from the hypocenter recorded the full signal dynamic and a peak-ground-acceleration of 0.28 g was registered in this site (Fig. 4). The mainshock was followed by 24 low magnitude (Md<2.1) aftershocks. The last events was recorded on 21st February 2018. All the hypocenters of these events are located within an area of less than 8 km^2 with a maximum depth of 2.5 km.
DInSAR measurements observed a maximum coseismic deformation of about 4 cm in LOS (Line Of Sight) (De Novellis et al., 2018). A shallow depth of the source was confirmed by the inversion of these data. Moreover a macroseismic survey evidenced the presence of WNW-

ESE to E-W and WSW-ENE preferential coseismic fracture direction in the whole epicentral area (Nappi et al., 2018).

7 - Conclusions

We have characterized the recent seismicity of Ischia, considering hypocenters of the background seismicity, as well as the August 2017 sequence. We observe that they are mostly located in the same area affected by the historical seismicity and their depth is usually very shallow (Fig. 8 and Table 2). The low hypocentral depth of the earthquakes confirms the presence of a very shallow ductile-creep transition (~2000m) as described by Castaldo et al. (2017).

While the seismicity of nearby volcanoes, Campi Flegrei and Vesuvius, shows a clear relationship with the dynamic of the volcanic hydrothermal system (D'Auria et al., 2011; D'Auria et al., 2013), in Ischia, the recorded seismicity does not seem to be correlated with the geothermal activity (Chiodini et al., 2004). The highest geothermal activity is indeed located in the south-west portion of the island, which seems to be nearly aseismic, as evident by the top panels of figure 8. This probably suggests that seismogenesis at Ischia is related to the dynamic of structural features of the northern part of the island (Orsi et al., 1991; Acocella and Funiciello, 1999; Molin et al., 2003; Paoletti et al., 2013).

Even if the current seismic energy release rate is low (700MJ/year), shallow hypocenters led to strong ground accelerations even for moderate magnitude event, as shown by the M_d=4.0 21st August 2017 earthquake, which excited a PGA of 0.28 g at the station IOCA.

Currently the seismic network configuration allows to detect earthquakes down to magnitude 0.0 in the northern part of the island and to locate earthquakes of $M \geq 1$ in the same area. Those thresholds increase moving southward. In the future, the uncertainty in hypocentral parameters of local earthquake, could be reduced by increasing the network density.

Moreover the addition of infrasound sensors to the existing seismic stations provides a useful tool to discriminate among different kind of seismic events. In particular, it can be useful to identify and locate explosions of geothermal boreholes, as occurred on March 2005 that can be a further possible source of risk for the population of the island.

Data and Resources

Seismograms used in this study were courtesy of Osservatorio Vesuviano, Istituto Nazionale di Geofisica e Vulcanologia, Italy (www.ov.ingv.it). Part of the data are available at the following database: http://sismolab.ov.ingv.it/sismo/. The seismic traces can be obtained by contacting anna.tramelli@ingv.it.

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List of Figure Captions

Figure 1 – Current configuration of the seismic monitoring network of Ischia. Relevant toponyms are annotated. The green triangles indicate the mobile seismic stations installed after the Md=4.0 21st August 2017 earthquake, which location is marked by a blue star. The red ellipse indicates the possible epicentral area of the 1881 (De Rossi, 1881) and 1883 earthquakes (Carlino et al., 2010). Blue circles are the deep wells drilled in the island of Ischia by SAFEN Company since 1954 (Carlino et al., 2014). The red solid stains represent the main fumarole fields on the island while yellow stains are the main hot springs.

Figure 2 – Classification of the 269 local seismic transients recorded since 1999-01-01.

Figure 3 – Example recordings for the OC9 station (vertical component). A) Local earthquake (recorded on 2007-06-06 07:25 UT, Md=1.3); B) Landslide at Casamicciola (2009-11-10 07:00 UT); C) Artificial explosion (2006-04-14 02:14 UT); D) Thunder sequence (2009-11-28 07:49 UT); E) Bolide shockwave (2005-09-10 15:11 UT); F) Seismo-acoustic events possibly linked to the explosion of a geothermal well (2005-03-27 00:51 UT).

Figure 4 – Comparison between seismograms and spectrograms of the Md=1.6 earthquake recorded on 10/12/2013 (a), the Md=1.5 earthquake recorded on 30/08/2017 (b) and the Md=4.0 earthquake recorded on 21/08/2017 (c) at IOCA accelerometric station.

Figure 5 – a) Magnitude vs time plot. Black circles represents events felt by people. b) The cumulative energy plot. Note that the y-axis has a logarithmic scale.

Figure 6 – Fit of the Ogata-Katsura distribution (dashed line) with the magnitude distribution of the Ischia catalogue (stars), compared with the cumulative magnitude distribution of the Ischia catalogue (crosses). The best-fit of the cumulative magnitude distribution is also reported (solid line).

Figure 7 – Theoretical magnitude thresholds for the earthquake detection (a, c) and location (b, d) at the depths indicated on the left. Red crosses mark the position of seismic stations.

Figure 8 – The top panels represent earthquake hypocenters recorded between 1999 and 20 - 08-2017, red circles, and after 20-08-2017, blue circles, on a map and along a N-S cross-section. The size of the circles is proportional to the magnitude (see inset on the top-right). The bottom panels represent instead, the corresponding confidence ellipsoids (same colors as the top panel).

Figure 9 – Waveforms of the seismo-acoustic events of 2005-03-27. On the left the 3 main events recorded by the vertical component of OC9. On the right the event of 00:48 recorded by the vertical components of all the stations. Seismograms are aligned on the arrival time of the main phase (see sec. 5 for details). All times are UTC.

Figure 10 – On the top the marginal p.d.f. for c. The dashed vertical line represents the maximum likelihood value of 750 m/s. On the bottom the conditional p.d.f. for the source location. Stars indicate the position of seismic stations.

Tables

Table 1- Seismic stations' information: coordinates, location, installation time, sampling rate, seismic sensor and data logger. Some station are equipped with both velocimeter and accelerometer and all the data are recorded continuously. The stations with name starting with T belong to the mobile seismic network installed after the 21st August 2017 earthquake. The GILDA data logger is a homemade system developed by Osservatorio Vesuviano (Orazi et al., 2006). The stations locations are shown in Fig. 1. "sps" stands for samples per second.

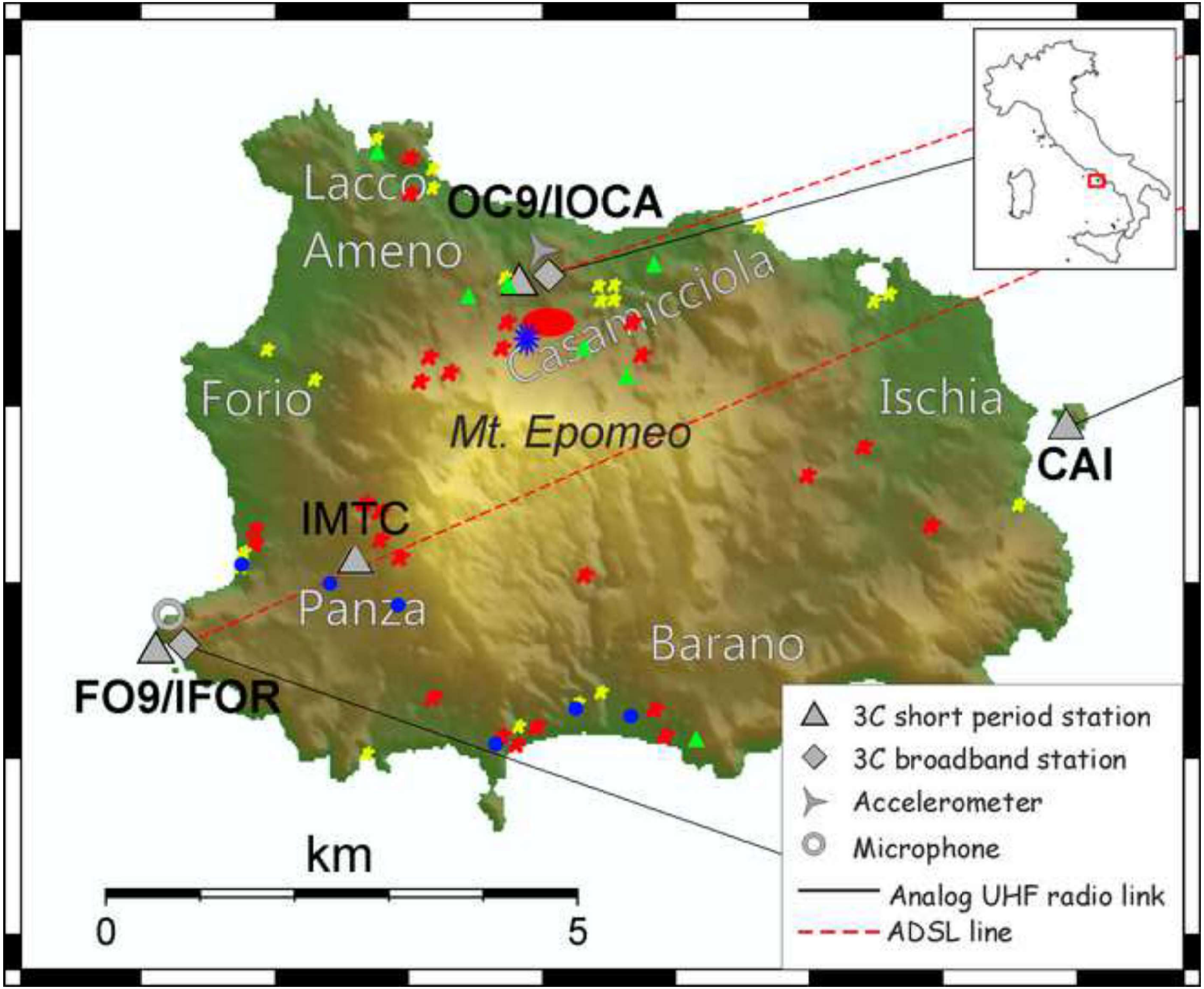
Name	Coordinates	Location	Installation	Sensor	Data logger	sps
CAI	40.7322N 13.9655E 103 m	Aragonese Castle	1996	MarkL4-3C	Analog	100
OC9 IOCA	40.7468N 13.9014E 123 m	Casamicciola Observatory	1993 9/2/2011	MarkL4-3C Guralp CMG-40T 60s Episensor ES-T	Analog GILDA	100 100 200
FO9 IFOR	40.7115N 13.8551E 234 m	Forio Punta Imperatore	1995 11/2009	MarkL4-3C Guralp CMG-40T 60s	Analog GILDA	100 100
IMTC	40.7209N 13.8758E 209 m	Monte Corvo	17/4/2015	Guralp CMG-40T 60s	GILDA	100
T1361	40.7567N 13.8789E 7 m	Lacco Ameno Negombo	26/08/2017	Lennartz LE-3Dlite	Nanometrics Taurus	100
T1362	40.7346N 13.9100E 303 m	Casamicciola T. Via Pera di Basso	26/08/2017 disinstalled 03/10/2017	Lennartz LE-3Dlite Episensor ES-T	Nanometrics Taurus+Trident	100 100
T1363	40.7455N 13.9135E 50 m	Casamicciola T. Via Cretaio	31/08/2017	Lennartz LE-3Dlite	Lennartz MARSlite	125
T1364	40.7426N 13.8905E 129 m	Lacco Ameno Hotel Grazia	31/08/2017	Lennartz LE-3Dlite	Nanometrics Taurus	100
T1365	40.7014N 13.9181E 130 m	Barano Hotel Villa a Mare	18/09/2017	Lennartz LE-3Dlite	Gilda	100
T1366	40.7373N 13.9046E 213 m	Casamicciola T. Via S. Barbara	03/10/2017	Lennartz LE-3Dlite Episensor ES-T	Nanometrics Taurus	100 100
T1367	70.7435N 13.8952E 81 m	Casamicciola T. Hotel V.Janto	23/10/2017	Lennartz LE-3D/5s	Gilda	100

Table 2 – Earthquake catalog of Ischia since 1999-01-01 (updated to February 21st 2018). In the last column the letter F indicates that the earthquake has been certainly felt by people. N.D. means “not determined”.

Id.	Date	Time (UT)	Lat. (°N)	Lon. (°E)	Depth (km)	Mag.	Notes
1	1999-01-20	12:40:42	N.D.	N.D.	N.D.	0.9	
2	1999-09-05	02:11:32	N.D.	N.D.	N.D.	0.4	
3	1999-09-05	02:16:45	N.D.	N.D.	N.D.	0.4	
4	1999-11-06	23:54:27	N.D.	N.D.	N.D.	1.5	
5	2000-01-09	23:36:55	N.D.	N.D.	N.D.	0.9	
6	2000-08-26	12:48:41	N.D.	N.D.	N.D.	0.4	
7	2000-08-26	12:49:14	N.D.	N.D.	N.D.	-0.1	
8	2000-08-26	21:47:26	N.D.	N.D.	N.D.	-0.1	
9	2000-11-13	08:07:06	N.D.	N.D.	N.D.	0.9	
10	2001-07-03	21:40:01	40.7669	13.8724	1.06	1.5	
11	2001-07-04	07:24:36	N.D.	N.D.	N.D.	0.9	
12	2001-07-27	20:11:41	40.7411	13.9158	0.55	2.3	F
13	2001-11-29	21:03:01	N.D.	N.D.	N.D.	0.8	
14	2001-12-06	09:23:08	N.D.	N.D.	N.D.	0.4	
15	2002-03-31	01:20:33	N.D.	N.D.	N.D.	1.1	
16	2002-06-07	08:22:46	N.D.	N.D.	N.D.	0.6	
17	2002-06-07	13:47:51	N.D.	N.D.	N.D.	0.4	
18	2003-07-21	15:35:54	N.D.	N.D.	N.D.	0.6	
19	2003-12-14	17:51:28	40.7589	13.8971	0.01	1.3	
20	2004-09-03	01:49:44	40.7385	13.9001	0.74	1.5	
21	2005-03-25	12:49:18	N.D.	N.D.	N.D.	N.D.	
22	2005-05-04	15:27:27	40.7343	13.9034	1.13	0.5	
23	2005-05-04	15:28:02	N.D.	N.D.	N.D.	0.5	
24	2006-03-19	21:21:04	N.D.	N.D.	N.D.	0.9	
25	2006-11-14	04:41:03	N.D.	N.D.	N.D.	-0.8	
26	2007-06-06	07:25:55	40.7410	13.9138	0.55	1.3	F
27	2008-04-05	11:16:01	40.7390	13.9203	0.52	2.3	F
28	2009-07-17	03:26:29	N.D.	N.D.	N.D.	0.9	
29	2011-06-04	23:13:40	40.7470	13.8728	1.45	1.4	
30	2011-06-05	12:37:56	40.7410	13.9156	0.51	1.9	F
31	2011-06-05	14:10:03	40.7527	13.9154	1.88	2.2	F
32	2011-06-05	15:55:07	40.7390	13.9195	0.54	1.2	
33	2011-06-05	16:20:26	N.D.	N.D.	N.D.	0.7	
34	2011-06-05	20:26:47	N.D.	N.D.	N.D.	0.7	
35	2011-06-22	00:55:05	N.D.	N.D.	N.D.	-0.8	
36	2011-06-22	01:51:36	N.D.	N.D.	N.D.	-0.8	
37	2011-06-22	02:31:08	N.D.	N.D.	N.D.	-0.5	
38	2011-06-22	02:33:45	N.D.	N.D.	N.D.	-0.5	
39	2013-12-10	13:07:05	N.D.	N.D.	N.D.	1.5	F
40	2014-02-09	11:56:27	N.D.	N.D.	N.D.	N.D	
41	2014-02-09	11:56:32	N.D.	N.D.	N.D.	1.6	F
42	2014-07-04	16:19:50	40.7698	13.9211	1.54	1.2	

43	2015-11-01	11:02:21	N.D.	N.D.	N.D.	1.3	
44	2016-02-10	23:25:26	N.D.	N.D.	N.D.	0.7	
45	2016-02-10	23:45:51	N.D.	N.D.	N.D.	0.6	
46	2016-02-10	23:49:28	N.D.	N.D.	N.D.	0.6	
47	2016-08-31	18:11:11	40.7680	13.8942	2.96	1.9	F
48	2016-08-31	18:11:29	40.7347	13.9027	-0.47	2.3	F
49	2017-08-21	18:57:51	40.7385	13.8967	1.24	4.0	F
50	2017-08-21	19:00:06	N.D.	N.D.	N.D.	0.4	
51	2017-08-21	19:00:44	N.D.	N.D.	N.D.	1.0	
52	2017-08-21	19:00:54	N.D.	N.D.	N.D.	0.9	
53	2017-08-21	19:01:57	N.D.	N.D.	N.D.	0.2	
54	2017-08-21	19:02:28	N.D.	N.D.	N.D.	1.3	
55	2017-08-21	19:03:17	N.D.	N.D.	N.D.	N.D.	
56	2017-08-21	19:16:36	N.D.	N.D.	N.D.	-0.3	
57	2017-08-21	19:18:07	40.7346	13.9162	-0.39	1.1	
58	2017-08-21	19:19:09	40.7346	13.9014	1.56	0.5	
59	2017-08-21	19:38:25	40.7346	13.8985	-0.51	1.3	
60	2017-08-21	19:38:39	40.7382	13.8944	-0.36	1.3	
61	2017-08-21	19:38:52	40.7375	13.9110	2.52	1.3	
62	2017-08-21	23:09:34	N.D.	N.D.	N.D.	0.1	
63	2017-08-21	23:19:51	N.D.	N.D.	N.D.	0.2	
64	2017-08-21	23:20:23	N.D.	N.D.	N.D.	-0.1	
65	2017-08-22	00:00:17	N.D.	N.D.	N.D.	1.1	
66	2017-08-22	05:15:10	40.7420	13.9032	-0.13	0.6	
67	2017-08-22	07:30:35	40.7341	13.8918	0.30	1.1	
68	2017-08-23	03:04:12	40.7349	13.8935	1.52	2.1	F
69	2017-08-23	04:17:38	40.7390	13.8914	0.23	1.3	
70	2017-08-23	20:30:54	N.D.	N.D.	N.D.	1.0	
71	2017-08-30	08:49:42	40.7388	13.9008	1.80	1.5	F
72	2017-08-30	13:30:15	40.7385	13.8877	0.34	0.9	
73	2017-10-08	06:17:29	40.7368	13.9004	1.05	0.9	
74	2017-12-25	06:59:41	40.7571	13.8765	1.21	0.7	
75	2018-01-30	04:14:41	N.D.	N.D.	N.D.	0.2	
76	2018-01-30	04:16:30	N.D.	N.D.	N.D.	0.5	
77	2018-02-21	23:05:13	N.D.	N.D.	N.D.	0.4	
78	2018-02-21	23:05:29	N.D.	N.D.	N.D.	-0.1	

Figure 1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Ameno
Casamicciola
Forio
Mt. Epomeo
Ischia
CAI
IMTC
Panza
Barano
FO9/IFOR
km
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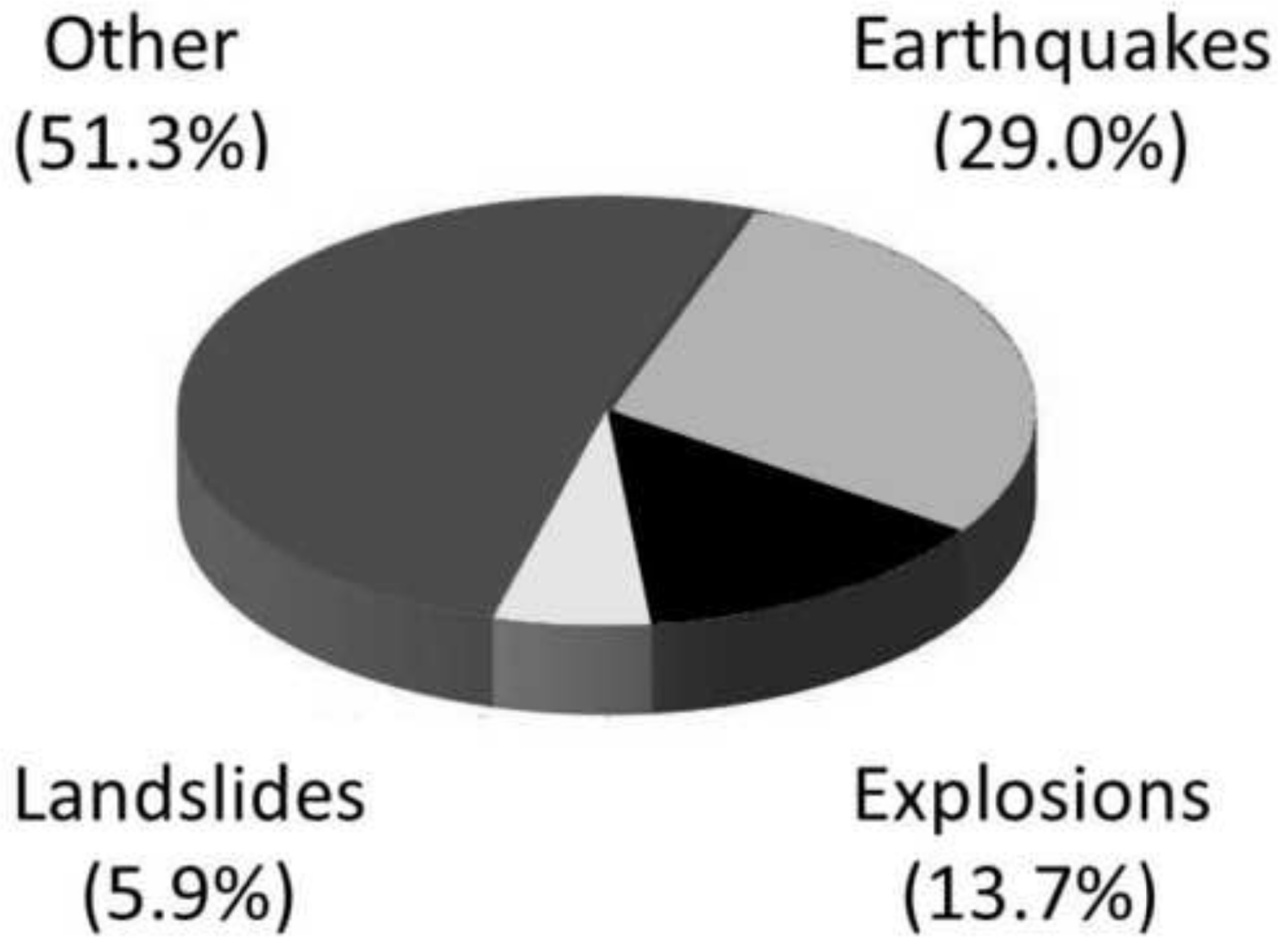
3C broadband station
Accelerometer
Microphone
Analog UHF radio link
ADSL line

Figure 2



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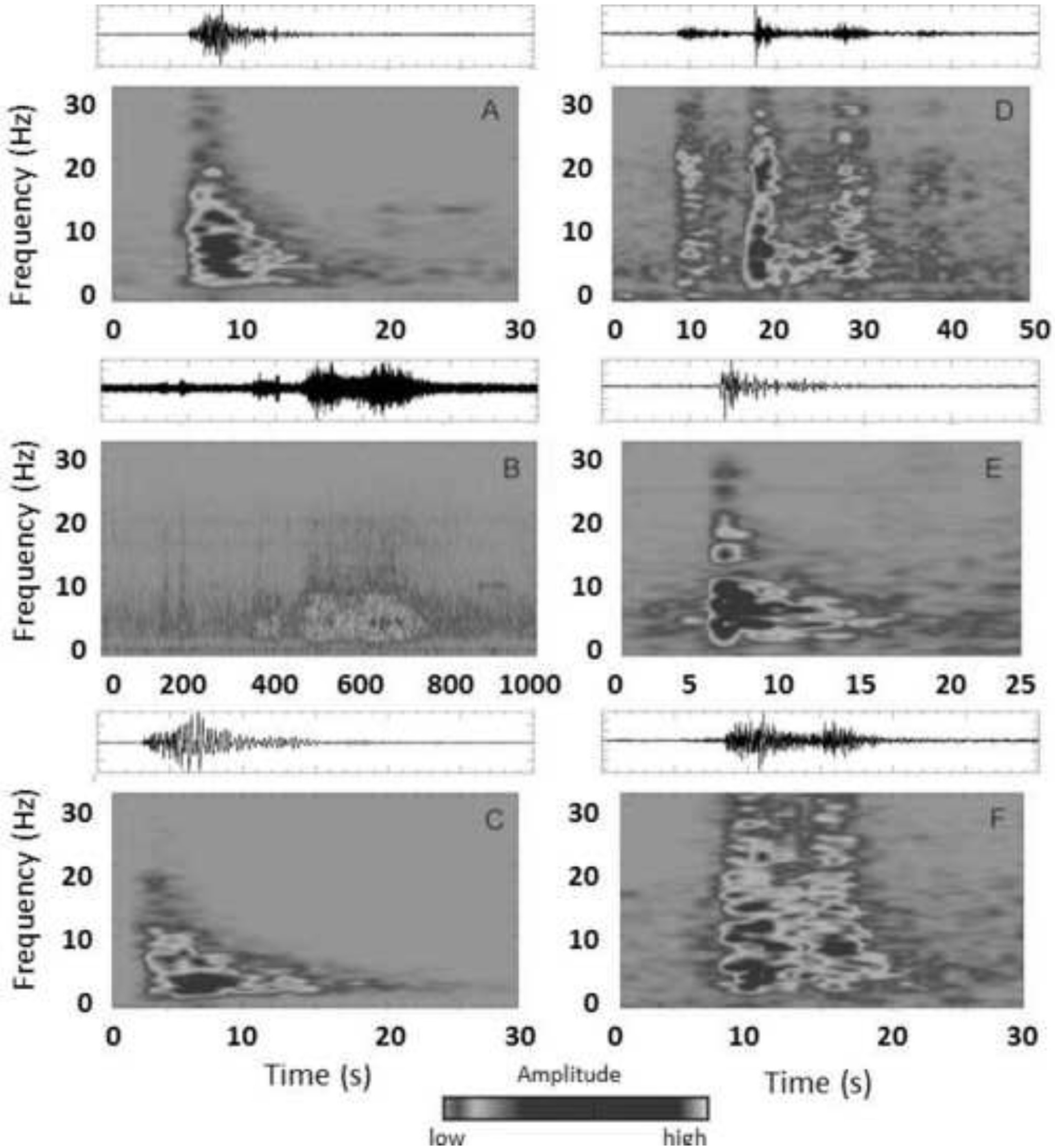

Figure 4

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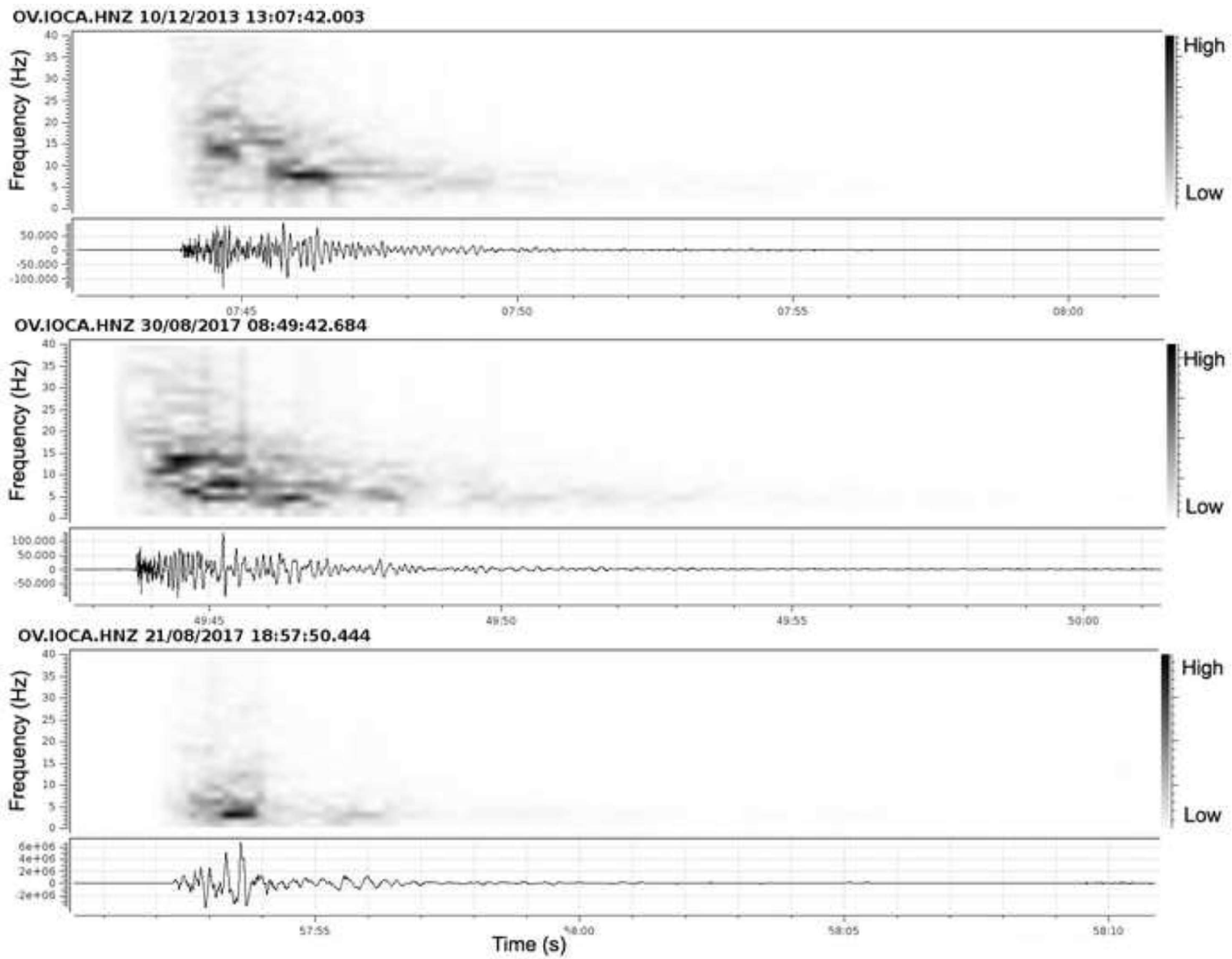

Figure 5

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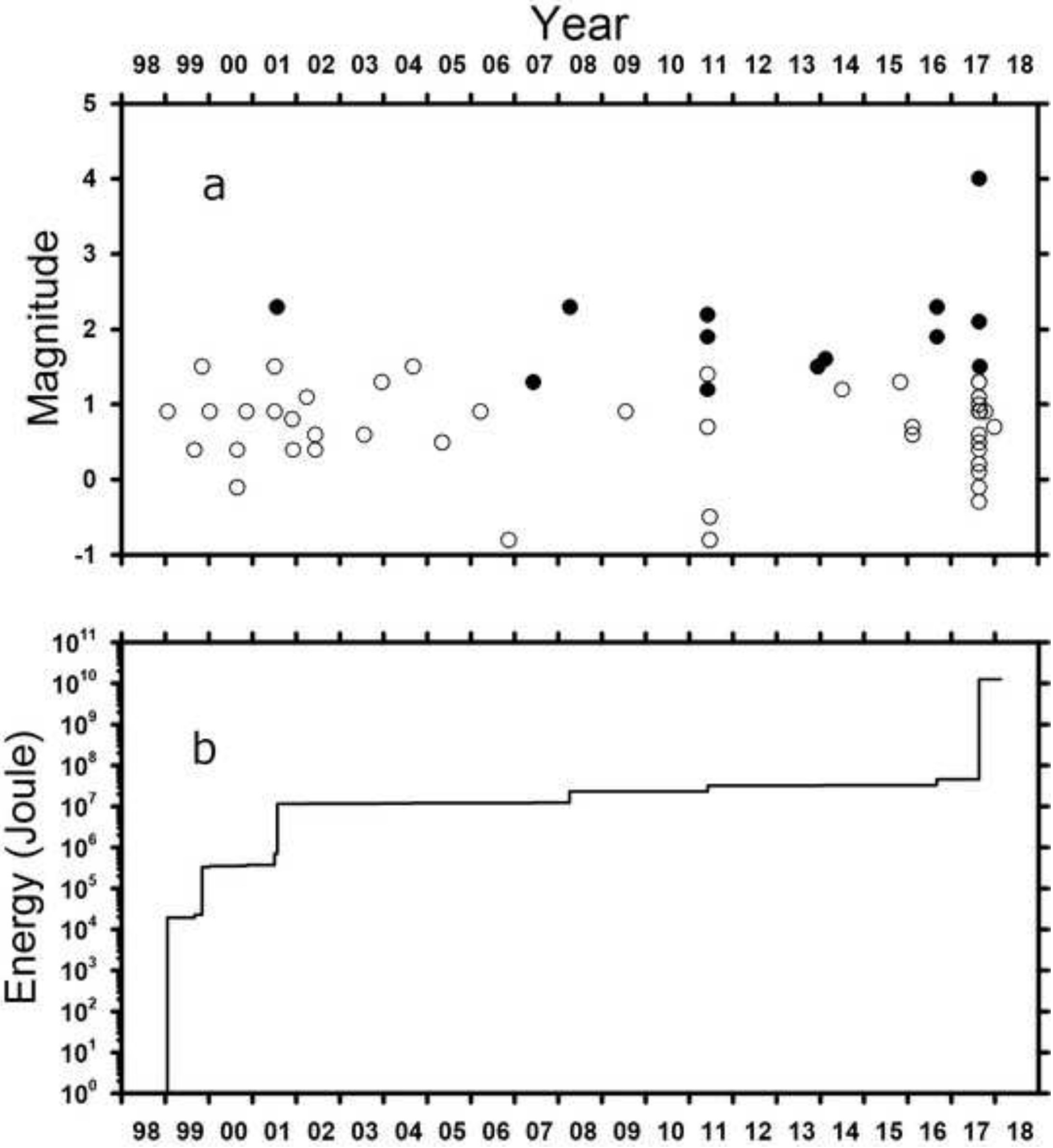

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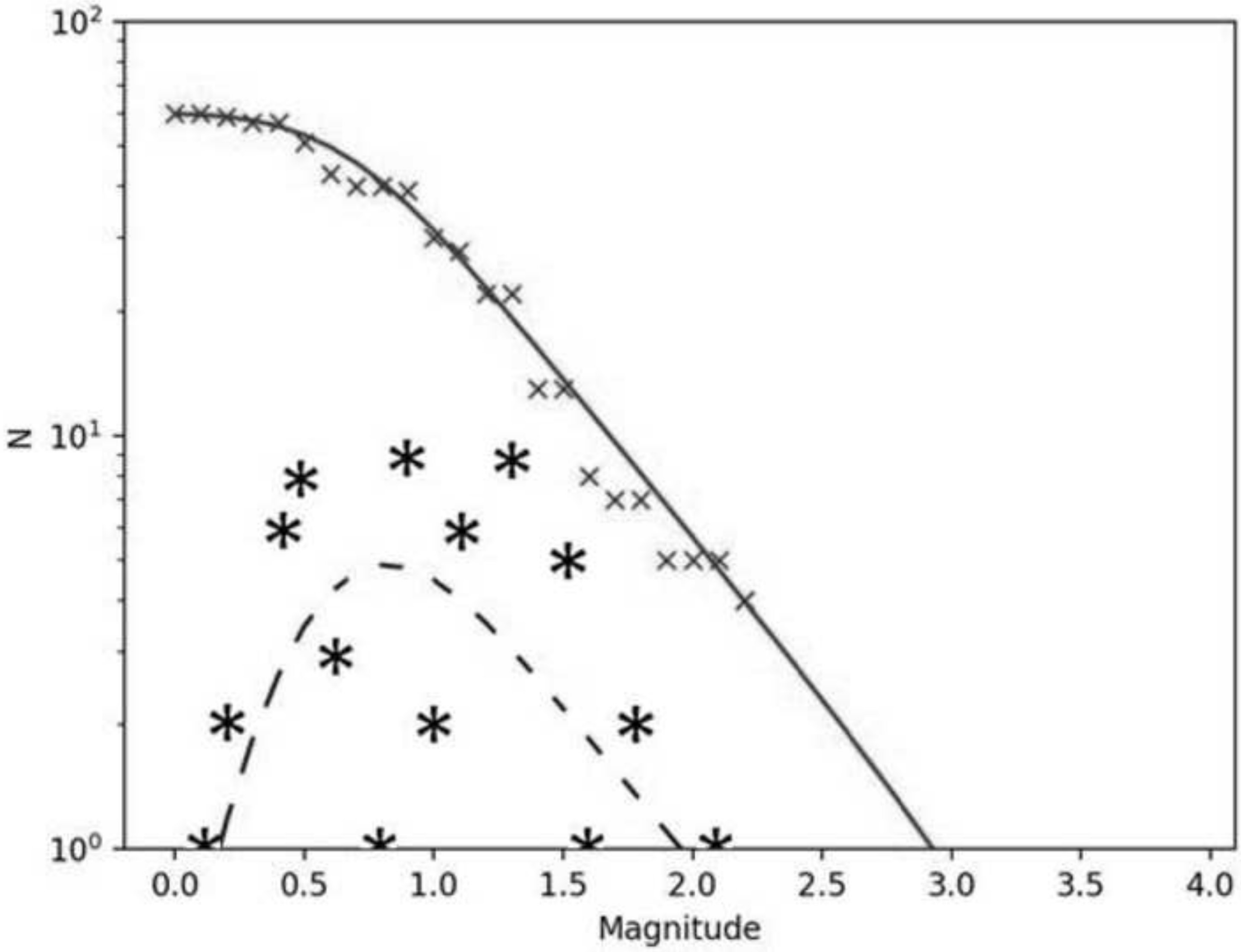

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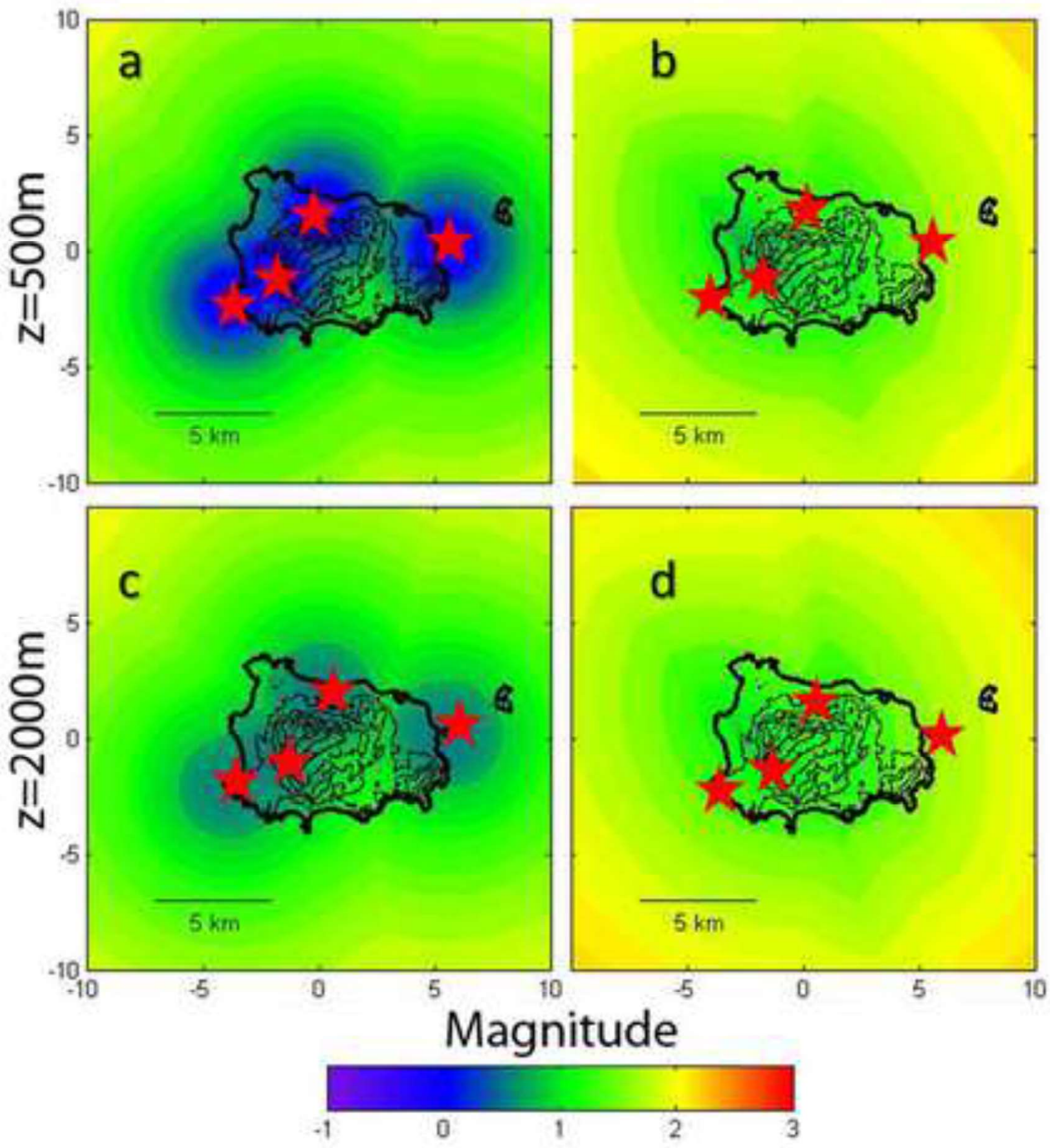

Figure 8

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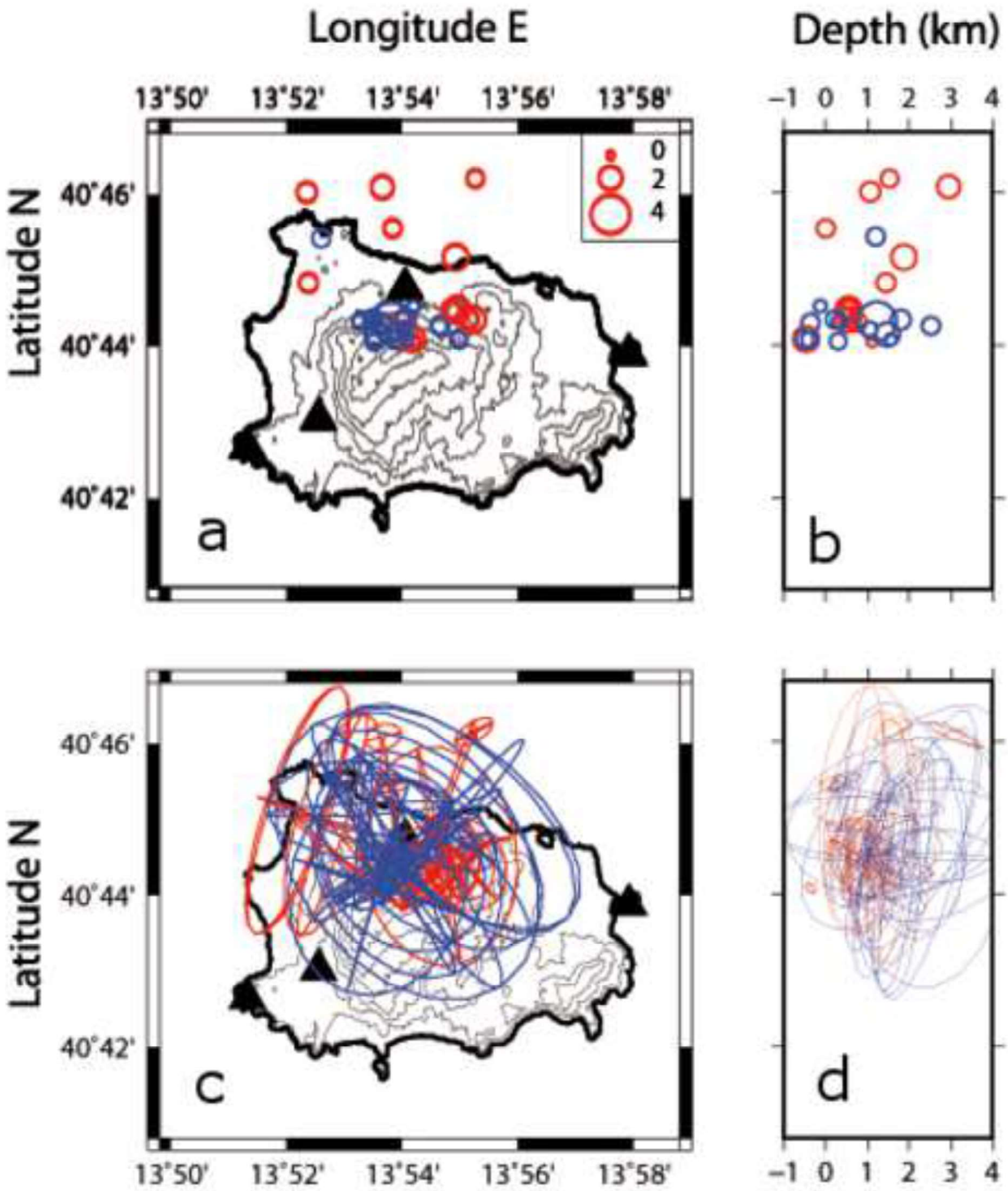

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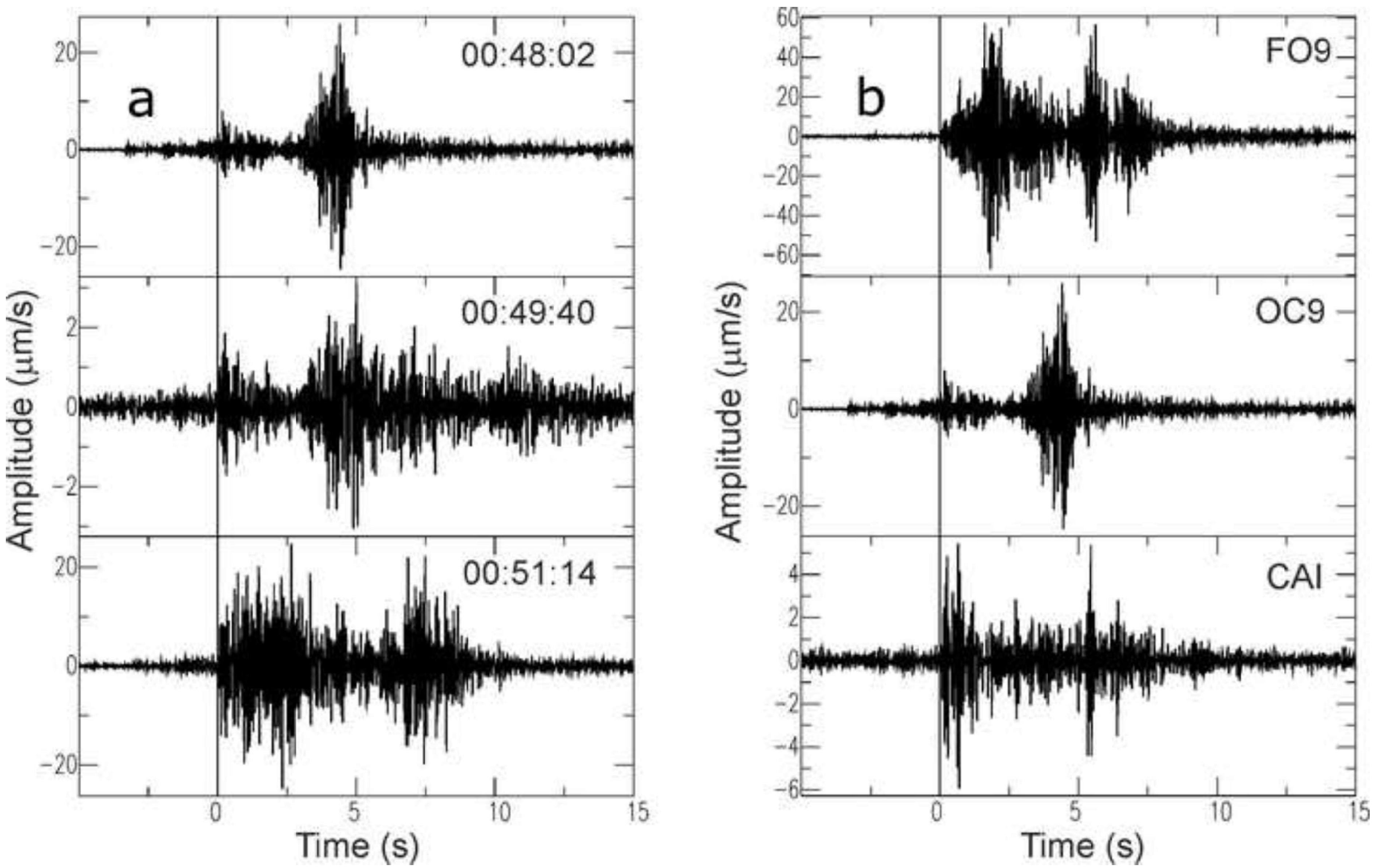
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00:51:14
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FO9
OC9
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Amplitude (μm/s)
Time (s)

Figure 10

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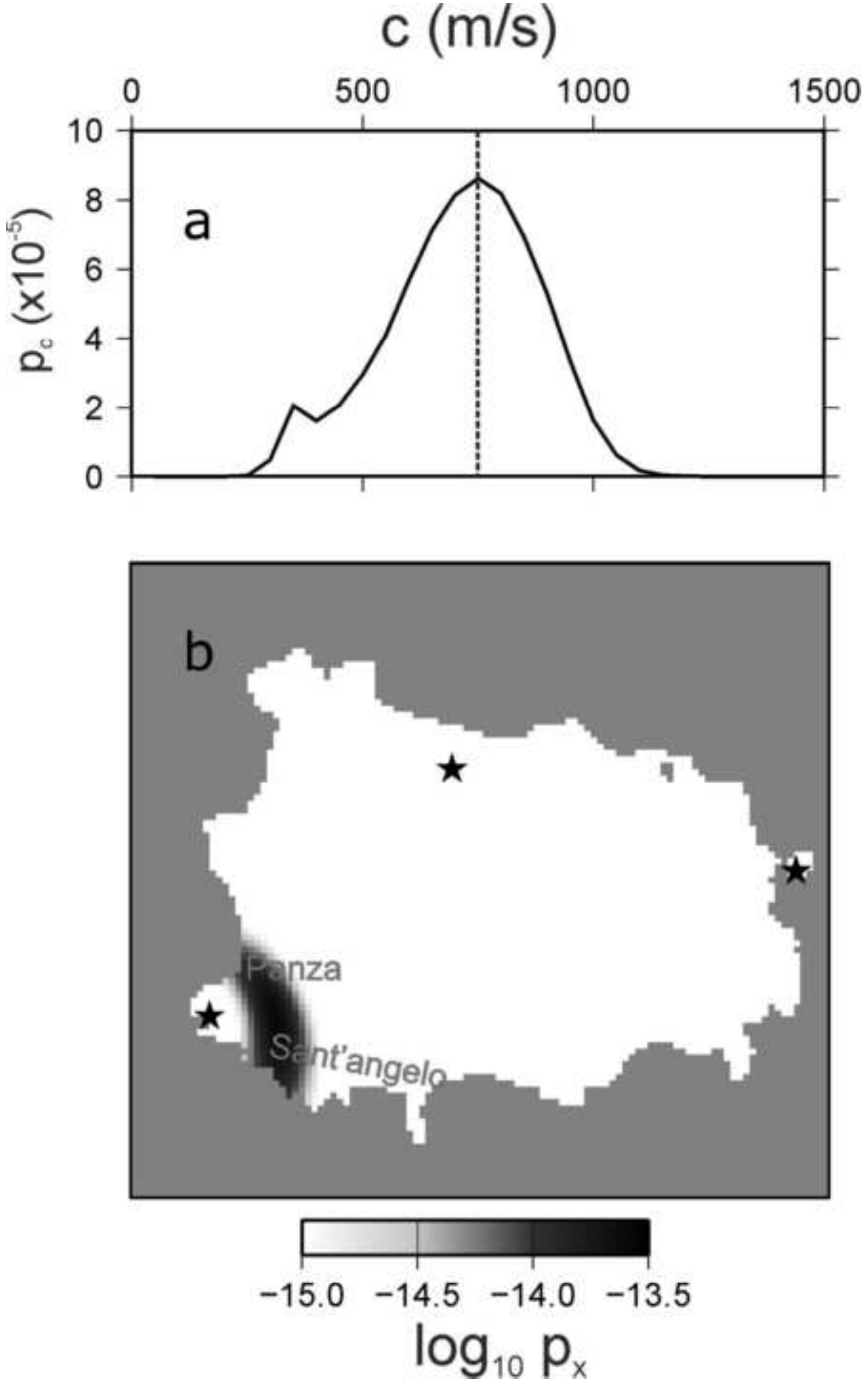

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IMTC	40.7209N 13.8758E 209 m	Monte Corvo	17/4/2015	Guralp CMG-40T 60s	GILDA	100
T1361	40.7567N 13.8789E 7 m	Lacco Ameno Negombo	26/08/2017	Lennartz LE-3Dlite	Nanometrics Taurus	100
T1362	40.7346N 13.9100E 303 m	Casamicciola T. Via Pera di Basso	26/08/2017 disinstalled 03/10/2017	Lennartz LE-3Dlite Episensor ES-T	Nanometrics Taurus+Trident	100 100
T1363	40.7455N 13.9135E 50 m	Casamicciola T. Via Cretaio	31/08/2017	Lennartz LE-3Dlite	Lennartz MARSlite	125
T1364	40.7426N 13.8905E 129 m	Lacco Ameno Hotel Grazia	31/08/2017	Lennartz LE-3Dlite	Nanometrics Taurus	100
T1365	40.7014N 13.9181E 130 m	Barano Hotel Villa a Mare	18/09/2017	Lennartz LE-3Dlite	Gilda	100
T1366	40.7373N 13.9046E 213 m	Casamicciola T. Via S. Barbara	03/10/2017	Lennartz LE-3Dlite Episensor ES-T	Nanometrics Taurus	100 100
T1367	70.7435N 13.8952E 81 m	Casamicciola T. Hotel V.Janto	23/10/2017	Lennartz LE-3D/5s	Gilda	100

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3	1999-09-05	02:16:45	N.D.	N.D.	N.D.	0.4	
4	1999-11-06	23:54:27	N.D.	N.D.	N.D.	1.5	
5	2000-01-09	23:36:55	N.D.	N.D.	N.D.	0.9	
6	2000-08-26	12:48:41	N.D.	N.D.	N.D.	0.4	
7	2000-08-26	12:49:14	N.D.	N.D.	N.D.	-0.1	
8	2000-08-26	21:47:26	N.D.	N.D.	N.D.	-0.1	
9	2000-11-13	08:07:06	N.D.	N.D.	N.D.	0.9	
10	2001-07-03	21:40:01	40.7669	13.8724	1.06	1.5	
11	2001-07-04	07:24:36	N.D.	N.D.	N.D.	0.9	
12	2001-07-27	20:11:41	40.7411	13.9158	0.55	2.3	F
13	2001-11-29	21:03:01	N.D.	N.D.	N.D.	0.8	
14	2001-12-06	09:23:08	N.D.	N.D.	N.D.	0.4	
15	2002-03-31	01:20:33	N.D.	N.D.	N.D.	1.1	
16	2002-06-07	08:22:46	N.D.	N.D.	N.D.	0.6	
17	2002-06-07	13:47:51	N.D.	N.D.	N.D.	0.4	
18	2003-07-21	15:35:54	N.D.	N.D.	N.D.	0.6	
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22	2005-05-04	15:27:27	40.7343	13.9034	1.13	0.5	
23	2005-05-04	15:28:02	N.D.	N.D.	N.D.	0.5	
24	2006-03-19	21:21:04	N.D.	N.D.	N.D.	0.9	
25	2006-11-14	04:41:03	N.D.	N.D.	N.D.	-0.8	
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31	2011-06-05	14:10:03	40.7527	13.9154	1.88	2.2	F
32	2011-06-05	15:55:07	40.7390	13.9195	0.54	1.2	
33	2011-06-05	16:20:26	N.D.	N.D.	N.D.	0.7	
34	2011-06-05	20:26:47	N.D.	N.D.	N.D.	0.7	
35	2011-06-22	00:55:05	N.D.	N.D.	N.D.	-0.8	
36	2011-06-22	01:51:36	N.D.	N.D.	N.D.	-0.8	
37	2011-06-22	02:31:08	N.D.	N.D.	N.D.	-0.5	
38	2011-06-22	02:33:45	N.D.	N.D.	N.D.	-0.5	
39	2013-12-10	13:07:05	N.D.	N.D.	N.D.	1.5	F
40	2014-02-09	11:56:27	N.D.	N.D.	N.D.	N.D	
41	2014-02-09	11:56:32	N.D.	N.D.	N.D.	1.6	F
42	2014-07-04	16:19:50	40.7698	13.9211	1.54	1.2	

43	2015-11-01	11:02:21	N.D.	N.D.	N.D.	1.3	
44	2016-02-10	23:25:26	N.D.	N.D.	N.D.	0.7	
45	2016-02-10	23:45:51	N.D.	N.D.	N.D.	0.6	
46	2016-02-10	23:49:28	N.D.	N.D.	N.D.	0.6	
47	2016-08-31	18:11:11	40.7680	13.8942	2.96	1.9	F
48	2016-08-31	18:11:29	40.7347	13.9027	-0.47	2.3	F
49	2017-08-21	18:57:51	40.7385	13.8967	1.24	4.0	F
50	2017-08-21	19:00:06	N.D.	N.D.	N.D.	0.4	
51	2017-08-21	19:00:44	N.D.	N.D.	N.D.	1.0	
52	2017-08-21	19:00:54	N.D.	N.D.	N.D.	0.9	
53	2017-08-21	19:01:57	N.D.	N.D.	N.D.	0.2	
54	2017-08-21	19:02:28	N.D.	N.D.	N.D.	1.3	
55	2017-08-21	19:03:17	N.D.	N.D.	N.D.	N.D.	
56	2017-08-21	19:16:36	N.D.	N.D.	N.D.	-0.3	
57	2017-08-21	19:18:07	40.7346	13.9162	-0.39	1.1	
58	2017-08-21	19:19:09	40.7346	13.9014	1.56	0.5	
59	2017-08-21	19:38:25	40.7346	13.8985	-0.51	1.3	
60	2017-08-21	19:38:39	40.7382	13.8944	-0.36	1.3	
61	2017-08-21	19:38:52	40.7375	13.9110	2.52	1.3	
62	2017-08-21	23:09:34	N.D.	N.D.	N.D.	0.1	
63	2017-08-21	23:19:51	N.D.	N.D.	N.D.	0.2	
64	2017-08-21	23:20:23	N.D.	N.D.	N.D.	-0.1	
65	2017-08-22	00:00:17	N.D.	N.D.	N.D.	1.1	
66	2017-08-22	05:15:10	40.7420	13.9032	-0.13	0.6	
67	2017-08-22	07:30:35	40.7341	13.8918	0.30	1.1	
68	2017-08-23	03:04:12	40.7349	13.8935	1.52	2.1	F
69	2017-08-23	04:17:38	40.7390	13.8914	0.23	1.3	
70	2017-08-23	20:30:54	N.D.	N.D.	N.D.	1.0	
71	2017-08-30	08:49:42	40.7388	13.9008	1.80	1.5	F
72	2017-08-30	13:30:15	40.7385	13.8877	0.34	0.9	
73	2017-10-08	06:17:29	40.7368	13.9004	1.05	0.9	
74	2017-12-25	06:59:41	40.7571	13.8765	1.21	0.7	
75	2018-01-30	04:14:41	N.D.	N.D.	N.D.	0.2	
76	2018-01-30	04:16:30	N.D.	N.D.	N.D.	0.5	
77	2018-02-21	23:05:13	N.D.	N.D.	N.D.	0.4	
78	2018-02-21	23:05:29	N.D.	N.D.	N.D.	-0.1	

Article Title: The seismicity of Ischia island

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The seismic catalogue of Ischia island (January 1999 - February 2018).

Here we report the catalogue of the earthquakes recorded in Ischia between 1999 and February 2018. In order to easily share the catalogue, we have created a comma-separated values file (CSV) which allows to store tabular data in plain text. The CSV file contains a sequential number as the Id of each seismic event (column *a*); date and time (columns *b* and *c*); latitude, longitude and depth (columns *d*, *e* and *f*); magnitude of each earthquake (column *g*) and a "Notes" field (column *h*) in which the letter "F" indicates that the earthquake was felt by the people. Many hypocentral parameters are undetermined because most of the recorded earthquakes are small and have been recorded by the single station of Casamicciola Terme which is very close to the seismogenic area. The catalogue is described in greater detail in the body of the article, in which it is also inserted as Table 2.

Caption

Table S1. The seismic catalogue of Ischia in January 1999 - February 2018. A) event ID; B) event date; C) event time; D) hypocentre latitude; E) hypocentre longitude; F) hypocentre depth; G) duration magnitude; H) "Notes" dedicated to reporting if the earthquake was felt by the population (F = Felt).

Supplemental Material (csv)

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Supplemental Material (All Other Files, i.e. Movie, Zip, csv)

catalog.csv