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A temporary network for monitoring seismicity in the Mugello basin (Northern Apennines, Italy)

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Cover Azimuthal variation of the HVSR - Station CRCL (detail) | *In copertina Variazione azimutale dell'HVSR - Stazione CRCL (particolare)*

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Abstract

Within the geodynamic context of the Northern Apennines (Italy), one of the most relevant seismogenic areas is the Mugello basin (North-Eastern Tuscany). The area has a well-documented record of seismicity; the two major historical earthquakes occurred in 1542 (Mw=6.0) and in 1919 (Mw=6.4). The proximity of the Mugello Basin to densely-urbanized areas and the potential impact of strong earthquakes on the cultural heritage in the nearby (~30km) city of Florence makes a better knowledge of the seismicity in that area an important target. Following this argument, by mid-2019 we deployed 9 temporary stations within and around the Mugello basin, complementing the permanent monitoring networks currently operating in the area. This report describes the details of the temporary network deployment and shows sample recordings and locations from a Mw=4.5 earthquake which struck the NW margin of the basin on Dec. 9, 2019.

Keywords 9M Temporary seismic network (MULTIPLY); Mugello Basin

Introduction

The region around the Mugello basin (Northern Tuscany) represents one of the most important seismogenic areas of the Northern Apennines. Large historical earthquakes have occurred, such as the Mw=6.0, 1542 and the Mw=6.4, 1919 events [Rovida et al., 2016]. Its proximity to densely-urbanized areas and the potential impact of strong earthquakes on the cultural heritage in the nearby (~30km) city of Florence makes a better knowledge of the seismicity in the Mugello basin an important target. To this respect, one of the principal, still unresolved issue concerns the location, extent and geometry of the fault(s) responsible of the 1542 and 1919 earthquakes. Other, more general questions regard (i) the mechanism driving the abrupt transition from an extensional to compressional stress regime at the internal and external sides of the belt, respectively, and (ii) the geometry of, and role played by, a transfer zone oriented transversely (NE-SW) to the main strike of the belt [e.g., Piccinini et al., 2014].

The study area is currently monitored by a number of permanent seismic stations, with inter-station distances of 10-30 km range. Augmenting the density of stations in the region would increase both the sensitivity in earthquake detection, and the accuracy in the determination of source parameters. These elements have a crucial importance to the assessment of the seismic hazard. First, the precise location of microseismicity helps to delineate the position, size and geometry of active seismogenic structures. Second, increasing the completeness of a catalog improves the robustness of earthquake recurrence relationships. Last, dense spatial sampling of earthquake signals provides crucial constraints to the definition of the empirical ground motion predictive relationships.

In order to address these issues, a specific project was planned for improving the instrumental coverage of the Mugello basin and adjoining areas.

In this report we describe the installation of 9 temporary seismic stations, complementing the permanent networks presently operating, with the main goal to increase both the completeness and accuracy of the seismic catalog over the whole area. Furthermore, under the perspective of increasing the coverage currently offered by the Italian National Seismic Network (INSN hereinafter; [INGV Seismological data Centre, 2006]) the installation of this temporary network is an opportunity to analyse the noise conditions of each site and therefore the possibility of considering some of them for a subsequent permanent installation.

1. Area of study

The Northern Apennines is a NW-SE striking fold-and-thrust belt composed of a pile of NW-verging tectonic units that developed during Cenozoic collision between the European plate (Corso–Sardinian block) and the Adria plate [e.g., Carminati et al., 2012, and references therein]. The Mugello basin is a ~30 km long, WNW-ESE trending basin, filled with late Pliocene-Pleistocene alluvial and lacustrine deposits [e.g., Benvenuti, 2003] (Figure 1). The basin is likely to have developed under an initial phase of compression, followed by the Early-Middle Pleistocene transition to extension and normal faulting [Sani et al., 2009]. Seismicity, geodetic and geologic data support the hypothesis that extensional tectonics is the current tectonic regime affecting the upper crust in this area and the whole Tyrrhenian side of the Apennines, while crustal shortening characterizes the Adriatic side [Bonini et al., 2016; Piccinini et al., 2014].

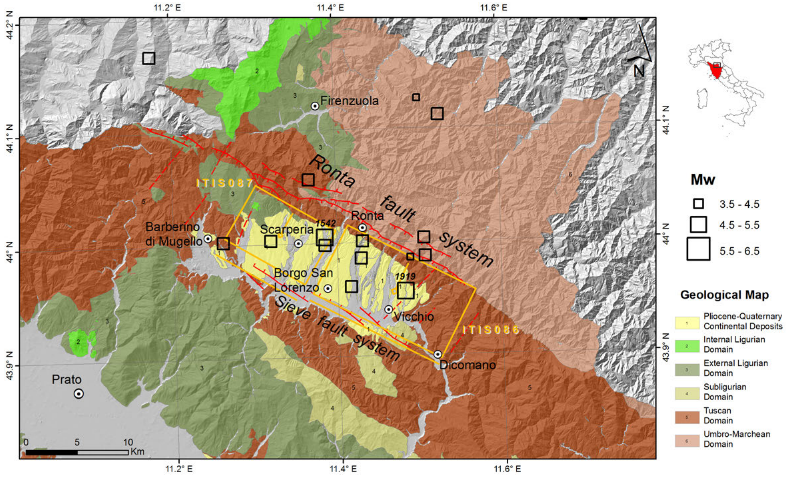

Figure 1 Geological map of the study area, compiled from maps of Regione Toscana geological projects "Cartografia Geologica della Regione Toscana a scala 1:10.000" and "Continuo geologico della Regione Toscana" (https://www.regione.toscana.it/-/geologia). We show Geological Domains only. The red lines represent the active extensional faults which bound the basin. The two yellow symbols indicate the Individual Seismogenic Sources associated with the 1542 and 1919 earthquakes. Both sources are described in the Database of Individual Seismogenic Sources (DISS), with DISS–IDs ITIS086 (Mugello East) and ITIS087 (Mugello West). The black squares indicate the historical earthquakes reported in the CPTI15 catalog [Rovida et al., 2016].

The basin is bordered by two NW-SE-trending sets of normal faults, namely the Ronta (to the NE) and Sieve (to the SW) fault systems. Both systems pertain to the larger Etrurian Fault System (EFS) proposed by Boncio et al. [2000]. This composite source runs for hundreds of kilometers along the backbone of the Northern Apennines, from North-Western Tuscany to Southern Umbria, marking the western extensional border of the Northern Apennines. Detailed analysis of recent seismic sequences (March 2008 and September 2009, with largest magnitude of M4.5) suggests that those events were likely controlled by the activation of small segments of the Ronta fault system (Figure 1) [Bonini et al., 2016; Piccinini et al., 2014]. On the other side, both the 1542 and 1919 destructive earthquakes are thought to be related to normal faulting along the NE-dipping Sieve fault system (Figure 1) [DISS Working Group, 2018]. However, for the 1919 earthquake alternative solutions have been proposed, invoking rupture of a NE-SW-striking normal fault (see the commentary at source ITIS086 - Mugello East in [DISS Working Group, 2018]).

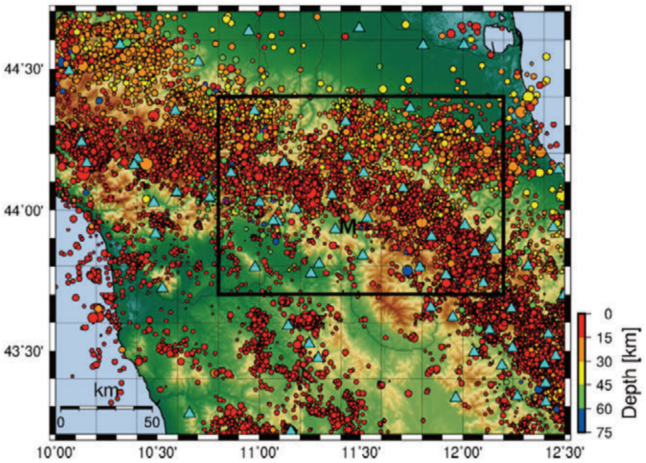

Figure 2 Seismicity for the 2005-2019 time span available from Italian Seismicity Catalogue (CSI). The size of the dots is proportional to the magnitude (ranging from 0.1 to 5) of the events and their colour depends on the depth of the hypocenter. The triangle-shaped symbols represent the seismic stations in the area. The black box encloses the study area that contains the Mugello basin (M).

2. The 9M MULTIPLY network

Presently, the area is monitored by stations (IV network) from INSN [INGV Seismological Data Centre, 2006] of the Istituto Nazionale di Geofisica e Vulcanologia (INGV hereinafter). Further stations are from the Fondazione PARSEC - Parco delle scienze e della cultura (http://www.csn.prato.it/, last accessed December 2020), some of which are shared with INSN (Figure 3).

2.1 Site selection

Taking into account these permanent installations, we defined a tentative geometry of the temporary network in order to achieve a complete azimuthal coverage of the basin over a distance range of about 20 km. After gathering information about the potential sites from local and regional authorities, from November 2018 to May 2019 we conducted numerous scouting surveys of the sites previously identified on map. Site selection criteria included the ease of access, good GPS signal reception, possibility of data transmission via UMTS digital telemetry, adequate sun exposure to allow powering the instruments through photovoltaic panels. During the scouting surveys, we also used a portable seismic station to assess the noise conditions of the sites.
Figure 3 shows the distribution of the stations in the whole area. The stations of the temporary network are represented with red symbols and two of them are sites from the PARSEC Network (BOSL and VISG). The seismic stations of the permanent networks correspond to the blue symbols.

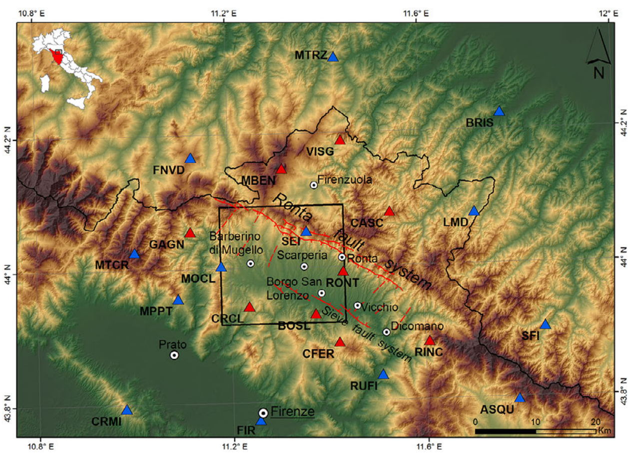

Figure 3 Present configuration of the seismic stations in the study area. The stations of the temporary network are represented with red symbols and two stations are also stations of the PARSEC Foundation (BOSL and VISG). The blue symbols represent the seismic stations of the permanent networks. (details about the DEM can be found in [Tarquini et al., 2007] and [Tarquini et al., 2012]. The black square encompasses the area selected for plotting locations in Figure 9.

2.2 Installation of seismic stations

From the end of May 2019 to the beginning of July, we installed the 9 seismic stations of the temporary network. The details of the installation (Figure 4) are:

- The seismometer is placed on a cement base settled down at the bottom of a ~50 cm-deep hole. The seismometer is then enclosed by a box covered by styrofoam sheets for thermal insulation. The whole installation is enclosed by a second, larger box for weathering protection.
- The acquisition-recording module is positioned in a separate box, together with the batteries, the power stabiliser, and the router for digital UMTS data transmission. The solar panels are mounted on a metallic frame, robustly anchored to the ground.

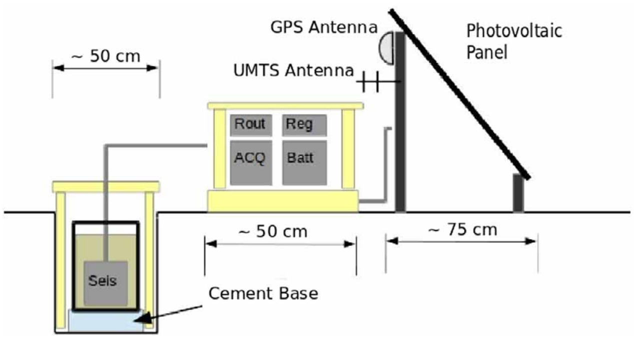

Figure 4 Configuration of the temporary seismic stations. The seismometer is placed on a cement base settled down at the bottom of a ~50 cm-deep hole. The acquisition-recording module, the batteries, the power regulator and the UMTS router for data transmission are stored in a separate box. The photovoltaic panels, mounted on a metallic frame, are robustly anchored to the ground.

At the beginning, the stations recorded data locally, on an internal hard-disk. Then, from the end of July 2019, the INGV team of Pisa progressively deployed UMTS routers, so that since October 2019 data from all the stations are received in real time by a SeiscomP3 server located at INGV, Pisa. We registered the temporary network as 9M to the International Federation of Digital Seismograph Networks (FDSN) with the name of MULTIPLY (Mugello Temporary Seismic Deployment; [Bruni et al., 2019]).
Data from 3 of these seismic stations are forwarded to the INSN acquisition center, thus contributing to the seismic monitoring of the area.

3. Instrumental characteristics and data

Instruments have been provided by SEIS-UK, the Natural Environment Research Council (NERC) Geophysical Equipment Facility (GEF) based in the University of Leicester, UK, upon acceptance of a specific application. They consist of 40TD broadband Guralp seismometers, whose frequency response is flat to velocity from 30s to 100Hz. Each seismometer is connected to a 24-bit CMG-DCM/EAM Guralp acquisition module (Figure 5); time synchronization is achieved via reception of the GPS time signal. The acquisition modules are also equipped with an internal 40Gb hard-disk.
The standard configuration of the temporary stations also includes four photovoltaic panels of 36W, two power batteries, a power stabiliser, a GPS antenna and a UMTS router (Figure 4). Table 1 shows some information about the temporary stations. In the Appendix we report the data sheet of each station.

Figure 5 The 40TD broadband Guralp seismometer on the left and the DCM/EAM Guralp acquisition module on the right.

Dataloggers are set in continuous recording mode with a sampling rate of 100 sps. Site quality at individual stations of the temporary network is evaluated by calculating the Probabilistic Power Spectral Densities (PPSD) of the spectral power as a function of the frequency [McNamara and Buland, 2004; McNamara and Boaz, 2005], which are compared with the Earth's seismic noise models NLNM and NHNM (New Low- and High-Noise model, respectively) of Peterson [1993]. PPSD have been evaluated from consecutive power spectral densities (PSD) estimates taken on 600-s-long windows overlapped by 50%, spanning 7 days of continuous recording.

Station	Lat (WGS84)	Lon (WGS84)	Z (m.a.s.l.)	Local area	Municipality
MBEN	4.414.831	113.107	1061	Monte Beni	Firenzuola
BOSL	4.393.093	1.137.433	380	Borgo San Lorenzo	Borgo San Lorenzo
CASC	4.408.059	1.153.222	740	Cascheta	Palazzuolo sul Senio
CFER	4.388.798	1.142.189	673	Collefertile	Borgo San Lorenzo
CRCL	4.394.426	1.123.742	506	Il Lavacchio	Croci di Calenzano
GAGN	4.405.697	1.111.862	670	Gagnaia	Cavarzano
RINC	4.388.639	1.160.719	955	Rincine	Londa
RONT	4.399.353	1.143.296	341	Ronta	Borgo San Lorenzo
VISG	4.418.896	1.143.431	727	Visignano	Firenzuola

Table 1 Configuration of the seismic stations from the 9M network.

In addition to the PPSD analysis, we investigated the possible presence of local amplification effects on the sites. For this purpose, we used the H / V spectral ratio method [Nakamura, 1989]. The method consists of averaging the Fourier spectra of the two horizontal components of the seismic noise wave field, then computing the ratio with the corresponding spectrum of the vertical component. A curve is thus obtained which represents the ratio of the amplitudes H/V as a function of frequency. The H/V ratios were obtained over consecutive, 60-s-long noise windows spanning one day of continuous recording.
PPSD and HVSR data at the different sites are reported in Supplementary materials.

4. Recording a local sequence

The new deployment recorded a Mw=4.5 earthquake that struck the NW margin of the Mugello basin on December 9, 2019 at 03:37:03 UTC. Figure 6 shows the seismograms of the main event recorded by the 9M stations. The earthquake caused damages that resulted in the evacuation of more than 150 residents and economic losses of several millions of euro.

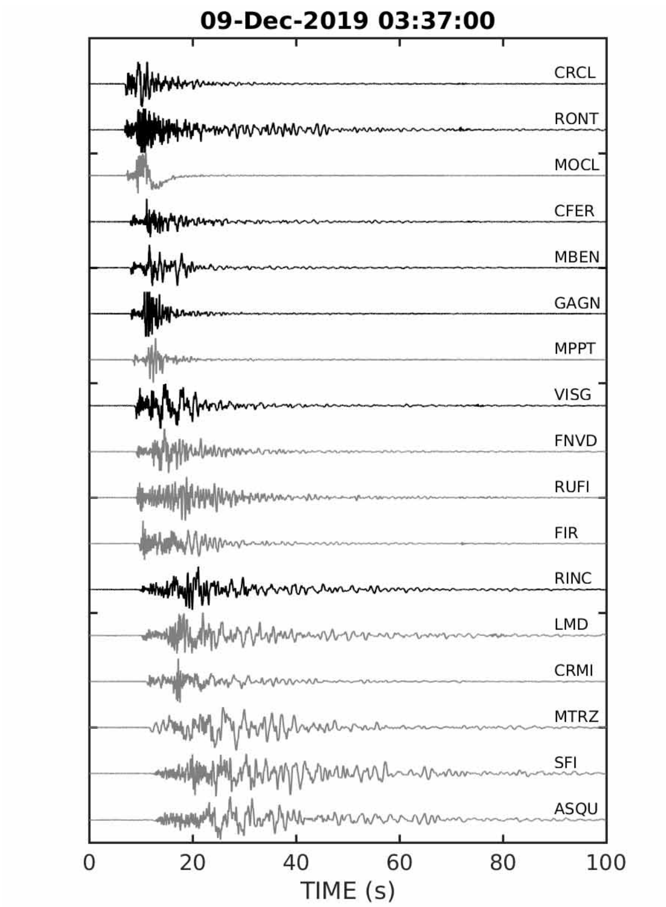

Figure 6 Vertical-component seismograms from stations of the national and 9M networks (gray and black lines, respectively) for the Mw=4.5 earthquake occurred on December 9, 2019.

In Figure 7 we show the daily plot of the seismicity recorded by the 9M station RONT during the 9th of December 2019.

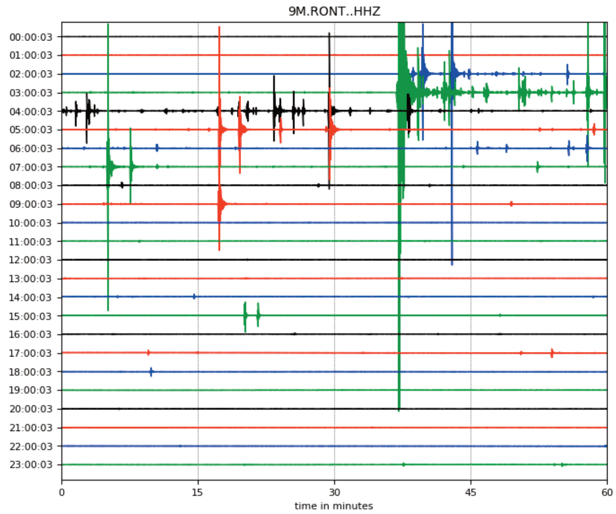

Figure 7 Daily plot of the seismicity recorded by the 9M station RONT on 9th December 2019.

The aftershock sequence lasted for about one month, accounting for some 280 earthquakes with magnitudes in the [0.5-4.5] range. Figure 8 shows the temporal trend of the local magnitude ML as reported in the INGV catalog, and the cumulative release of seismic moment. For each event, the seismic moment M0 is estimated from the catalog magnitude using the formula M0 = 10^(1.5*ML+9.1) (N*m) [Kanamori, 1977].

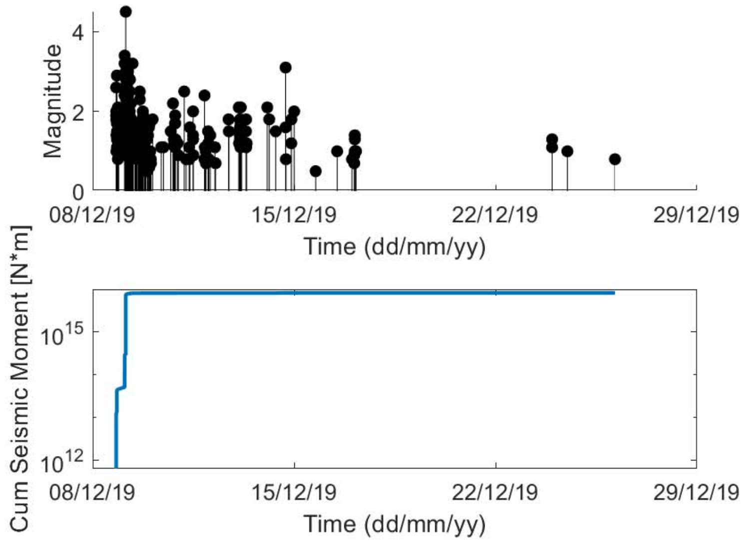

Figure 8 The upper panel shows the local magnitude versus time; the bottom panel shows the cumulative seismic moment release during the sequence.

We relocated the events reported in the INGV catalog by integrating P- and S-wave arrival times measured at the 9M network, with those from IV stations located within 30km from the epicentral area. We used a non-linear, probabilistic procedure in which the model parameter space is explored using the Octet Tree sampling method, as implemented in the NLLoc software package [Lomax et al., 2009]. In this software, theoretical travel times are calculated in reciprocal geometry using a finite-difference scheme [Podvin and Lecomte, 1991]. The velocity model used for the location is taken from Piccinini et al. [2014] and reported in Table 2.

Top (km)	VP (km/s)	VS (km/s)
-2.00	5.030	2.779
1.00	5.620	3.105
3.00	5.730	3.166
5.00	5.760	3.182
9.00	5.820	3.215
11.00	5.880	3.249
15.00	6.110	3.376
19.00	6.410	3.541
30.00	7.770	4.293

Table 2 Velocity model proposed by Piccinini et al., [2014].

The location algorithm is based upon the original work of Tarantola and Vallette [1982], in which the a posteriori location errors are derived from: (a) data uncertainties, which are directly expressed as the picking error in seconds, and (b) model errors, i.e. uncertainties in the prediction of travel times as a consequence of a poor knowledge of the velocity model. These latter errors are implemented using the relationship: Cij = SigmaTime2 exp(-0.5(D2ij)/ R2), where Cij is the element of the data covariance matrix associated with the i-th and j-th estimates of arrival time; Dij is the distance in km between the i-th and the j-th stations; SigmaTime is a characteristic error (in seconds) in travel-time predictions; R is a correlation length controlling the degree of error correlation between stations. This latter quantity is related to a characteristic scale length of the heterogeneities in the medium. In our application, we used SigmaTime=0.1s, and R=1 km.

In Figure 9 we compare the new locations of the sequence to the original ones reported in the INGV catalog; these two data sets are referred to as 9M+IV and IV, and plotted using red and light blue symbols, respectively.

Despite the differences in network geometry and velocity model, the two sets of locations exhibit a similar epicentral pattern, delineating a 6-km-long, NW-striking structure (Figure 9a,c). The three-dimensional fault geometry, however, is much better delineated by the 9M+IV locations, which clearly delineate a SW-dipping planar structure extending over the 6-11 km depth interval (Figure 9d). This geometry is in agreement with the Time Domain Moment Tensor (TDMT) solution of the mainshock reported by the INGV catalog (http://cnt.rm.ingv.it/event/23558121), which indicates a normal fault striking N105°E and dipping about 45°. Normal faulting along a NW-SE striking structure is also obtained for the 9M+IV location, by inverting P-wave polarities using the HASH code (Figure 9c) [Hardebeck and Shearer, 2009].

While comparing the IV and 9M+IV locations, however, one has also to consider that some stations of the 9M network (specifically: RONT, RINC and VISG) have been shared in real time with the INSN acquisition center, and therefore also used for IV locations.

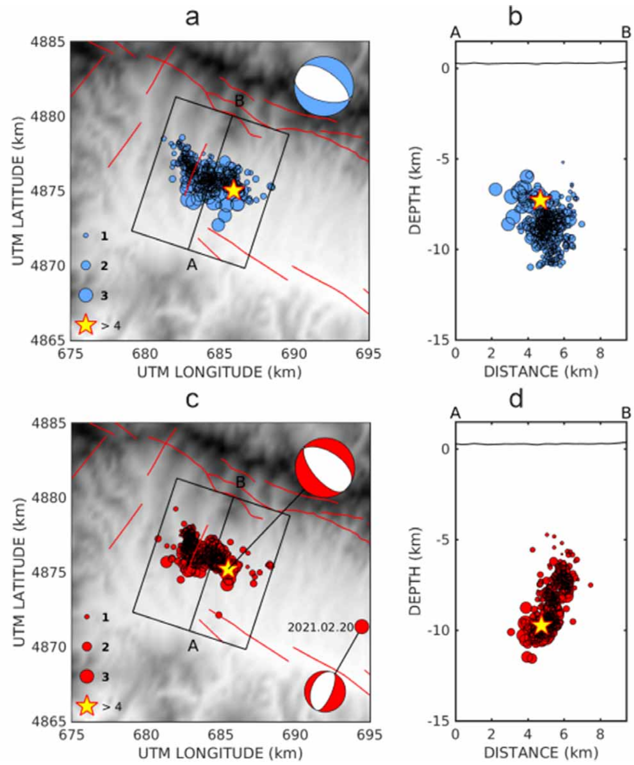

Figure 9 Epicentral maps and vertical cross sections for the December 2019 seismic sequence located using data from the IV (a,b) and 9M+IV (c,d) configurations. The area corresponds to the black box reported in Figure 3. Symbols size is proportional to magnitude according to the scale reported at the bottom left in panels (a) and (c); stars indicate the mainshock. The focal mechanism in panel (a) refers to the double-couple component of the TDMT solution reported by the INGV catalog. The focal mechanisms in (c) indicate the fault plane solutions derived from inversion of P-wave polarities for both the Dec. 2019 mainshock, and the February 20, 2021, ML=3.1 earthquake described at the end of this Section.

In Figure 10 we compare the location quality (RMS standard error, uncertainties along horizontal and vertical coordinates) for the IV and 9M+IV catalogs. As expected, both residuals and uncertainties associated with the integrated 9M+IV catalog are significantly lower than those derived from IV one. However, the two sets of uncertainties are not directly comparable, given the different location procedures and velocity models adopted.

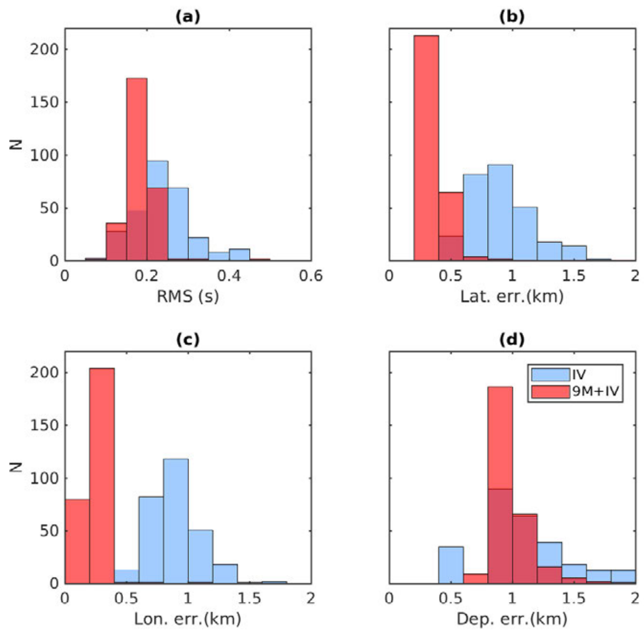

Figure 10 Comparison of locations quality for the 2019 Mugello sequence. Panels illustrate the RMS standard error (a), and the uncertainties (2 standard deviations) along the two horizontal and the vertical coordinates (b,c,d). Blue bars refer to locations from IV catalog (http://cnt.rm.ingv.it); red bars are locations obtained using the 9M+IV integrated network.

In a companion work (Investigation of a seismic sequence using deep learning: an application to the 2019, Mw 4.5 Mugello (Italy) earthquakes, by S. Cianetti, R. Bruni, S. Gaviano, D. Keir, D. Piccinini, G. Saccorotti, and C. Giunchi, submitted to the Journal of Geophysical Research), we applied Machine Learning techniques for the automatic earthquake detection and the subsequent picking of P- and S-wave arrival times. Our results indicate that integrating data from the permanent and the 9M MULTIPLY networks yields an improvement in the number of locatable events by about a factor 4, i.e. from 279 to around 1000. In terms of completeness magnitude, the improvement is larger than 1 magnitude unit, i.e. from about 1 of the permanent network, to ~ -0.1 of the integrated one.

A more exhaustive picture about the improvement in location precision is obtained by considering a small-magnitude earthquake which is located inverting only IV data and 9M+IV data, in both cases using the same velocity model of Table 2. (Figure 11). This simple exercise indicates that the addition of arrival times data from the local network permits decreasing the location errors by about a factor 2 for the two horizontal coordinates, and a factor 3 for the depth coordinate (Table 3).

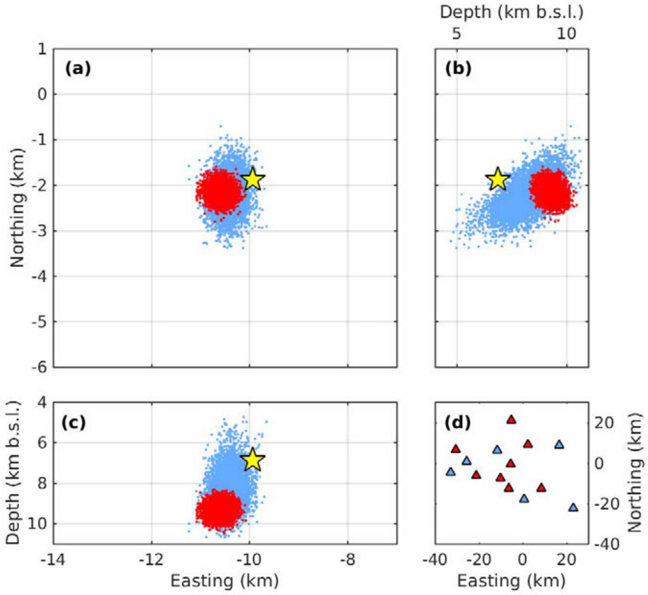

Figure 11 Source location resulting from travel-time inversion of a ML=1 earthquake occurred on 2020 Sept. 14 - 09:00:30UTC, about 3km NW of Borgo San Lorenzo (http://cnt.rm.ingv.it/event/25268101). Dots are samples of the likelihood function of source location for the IV and 9M+IV configurations, light blue and red colour, respectively. The star marks the location reported by the INGV catalog. The origin of the coordinate system is set at a point located at 44.0°N, 11.5°E. The panel at the bottom right illustrates the network geometries used for the two different locations.

	2σ lon err (km)	2σ lat err (km)	2σ dep err (km)
IV	0.41	0.75	1.75
9M	0.30	0.33	0.64

Table 3 Location uncertainties for the 9M+IV and IV configurations, for the event shown in Figure 11.

The December 2019 is the most relevant sequence of the area since the installation of the 9M network. Apart from that sequence, the only relevant earthquake affecting the basin is a ML=3.1 event occurred on the 20th of February, 2021, a few kilometers East of Borgo San Lorenzo

(http://cnt.rm.ingv.it/event/26118671). (see location and focal solution in Figure 9c). That earthquake was not preceded by any foreshock activity, and it was followed by just a single locatable (ML~0.5) aftershock not reported by INGV's catalog.
Other less energetic sequences, all located externally to the 9M-MULTIPLY network, occurred on: June 2020 close to Palazzuolo sul Senio, Mmax=2.5 (http://cnt.rm.ingv.it/event/24556401); March 2021, close to Firenzuola, Mmax=2 (http://cnt.rm.ingv.it/event/26238351); April 2021, West of Palazzuolo sul Senio Mmax=2.2 (http://cnt. rm.ingv.it/event/26498141).

5. Conclusions

In this report we describe the installation of the 9M-MULTIPLY network in the Mugello basin. The aim of the deployment is to complement the permanent stations presently active, in order to increase both completeness and accuracy of the seismic catalog for the area. The network will remain operational until the end of May, 2021. So far, the temporary stations have operated quite constantly and continuously; gaps in data acquisition have been mostly due to shortage of power, especially in winter times, when the solar panels have been occasionally covered by snow. Due to the remoteness of most of the sites, a further issue regarded the occasional loss of the UMTS signal. Should the 9M network be added to INGV's permanent monitoring system, our studies indicate that the completeness magnitude would be improved by about 1 magnitude unit, and the location errors would decrease by at least a factor 2. From a first overview of the azimuthal coverage of the area and the noise conditions at the sites, we identify some 9M stations which would have priority for being converted to a permanent installation. These sites are RONT, RINC, and CRCL, respectively covering the NE, SE, and SW margins of the basin. The most peripheral stations MBEN and CRCL would instead contribute to improve the coverage of sources located on the external (Adriatic) sector of the study area. However, the actual possibility to use these sites for permanent installations depends on a number of other factors, primarily the availability of landlords in hosting the instruments. To this respect, a valid alternative for covering the SW border of the Mugello basin could be offered by integrating site BOSL, currently part of the local network belonging to the Fondazione PARSEC.
Data provided by the 9M-MULTIPLY network are currently under analysis, and they will hopefully contribute to increase our knowledge about the seismogenic sources and crustal structure for this important sector of the Northern Apennines. On the other side, the elements provided by this report may be of help to better define the strategies for the future development of the INSN in the area.

Acknowledgements

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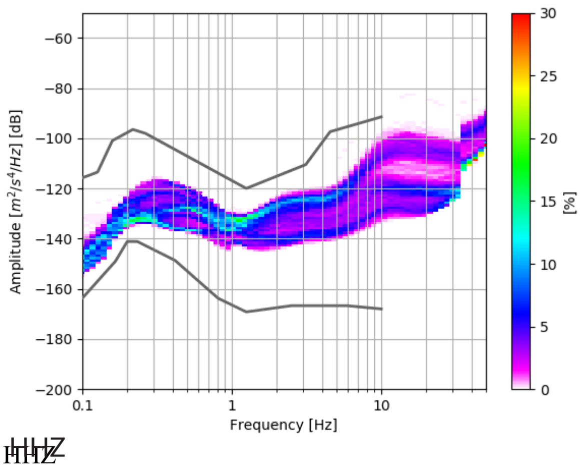
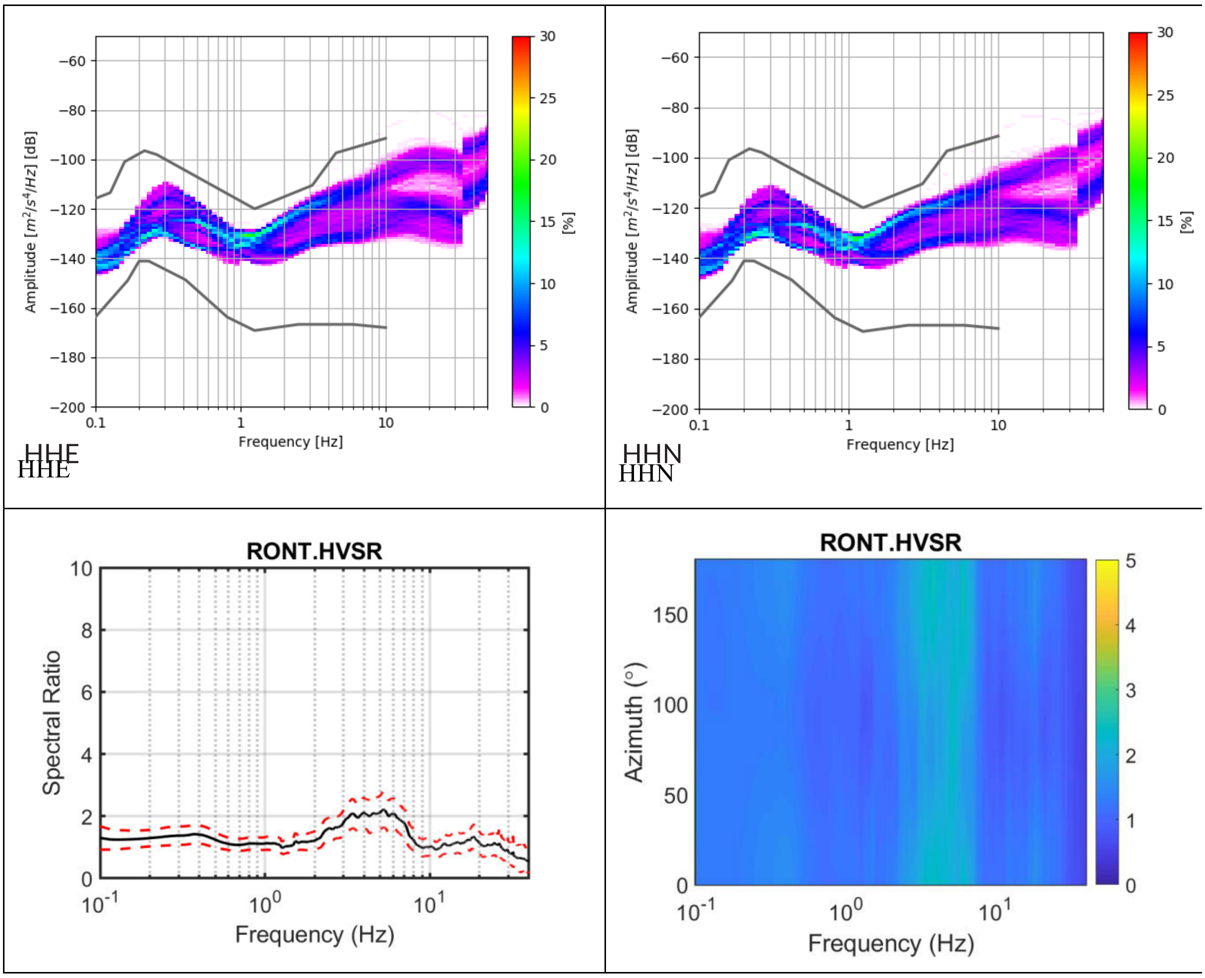
SUPPLEMENTARY MATERIALS

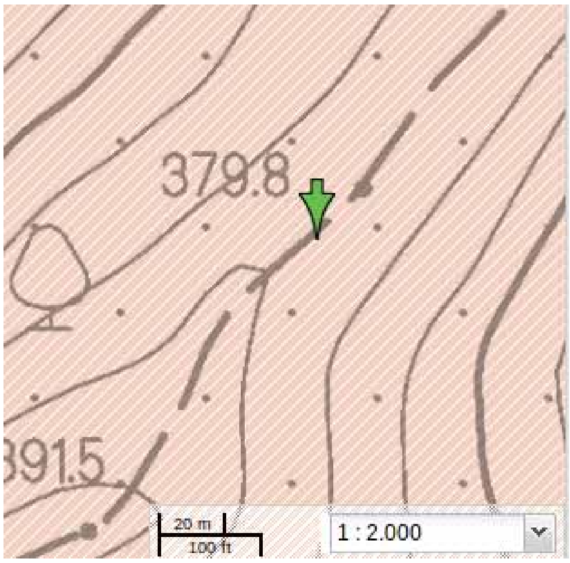
Station datasheet

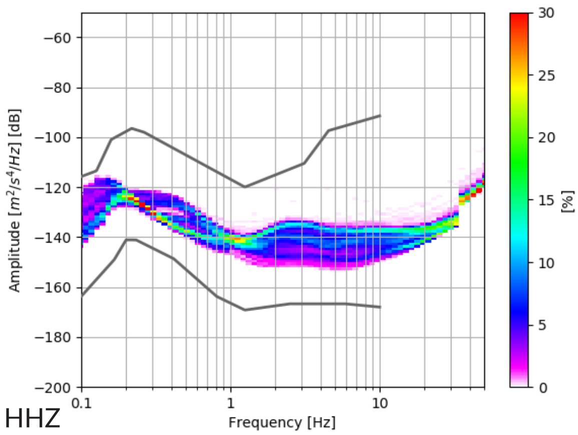
Station ID	RONT
Municipality	Borgo San Lorenzo
Local Area	Le Ville (Ronta Campagna)
Latitude (° WGS84)	43.99354
Longitude (° WGS84)	11.43295
Altitude (m.s.l.m)	341
Geology	VILa (Continental Deposits)
Soil	Polygenic Conglomerates
Power	5 solar panels (4 of 36W + 1 of 100W)
UMTS coverage	-109 dB
Sensor	T4A96/D0504
Datalogger	DCM-911
Installation date	30/05/2019




Amplitude [$m^2/s^4/Hz$] [dB]
Frequency [Hz]
[%]
HHE
HHN
RONT.HVSR
Spectral Ratio
Frequency (Hz)
RONT.HVSR
Azimuth (°)
Frequency (Hz)

Station ID	BOSL
Municipality	Borgo San Lorenzo
Local Area	Borgo San Lorenzo
Latitude (° WGS84)	43.93093
Longitude (° WGS84)	11.37433
Altitude (m.s.l.m)	380
Geology	FAL4 (Membro di Lonnano, siltiti e arenarie)
Soil	Arenarie di Monte Falterona
Power	2 solar panels of 100W
UMTS coverage	-109 dB
Sensor	T4A82/D0491
Datalogger	DCM-856
Installation date	11/06 - 03/07/2019





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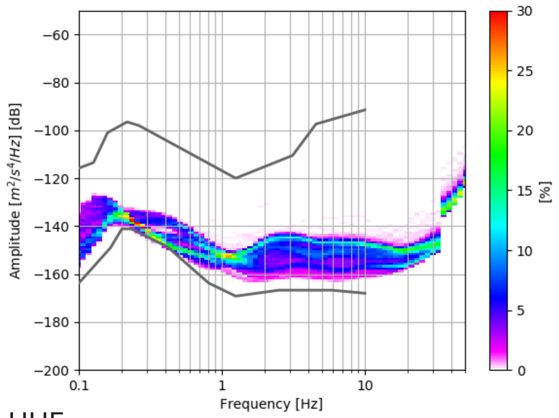
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Frequency [Hz]
[%]

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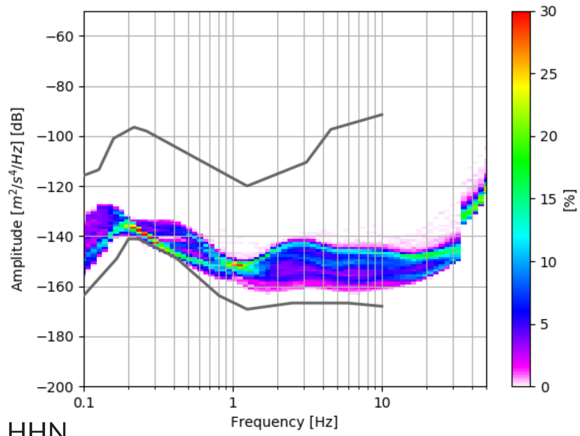
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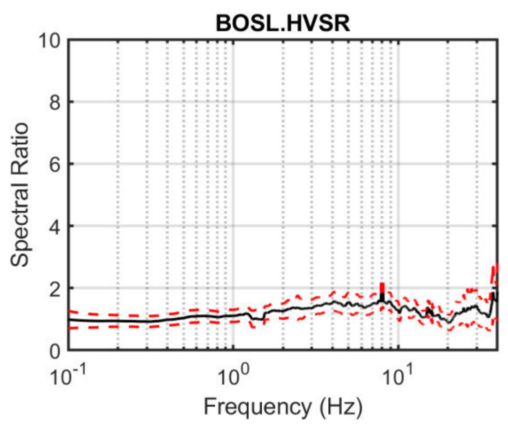
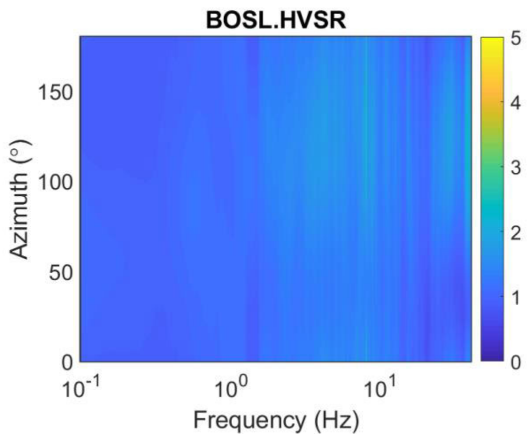
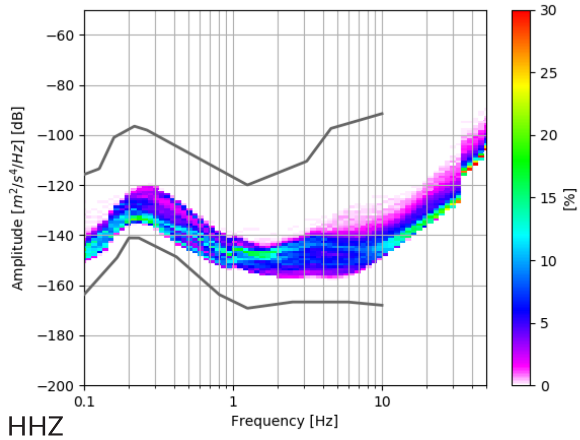
Frequency [Hz]
[%]

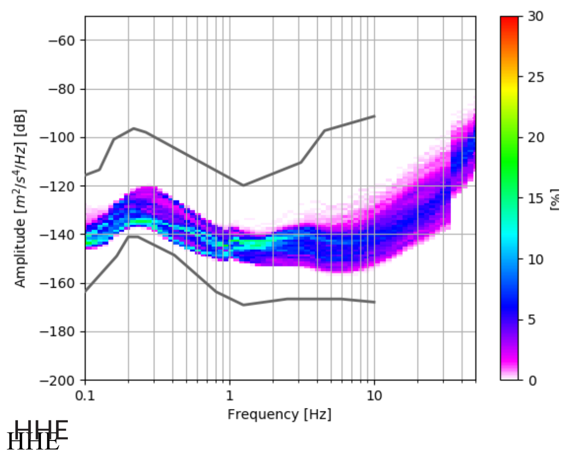
HHN


BOSL.HVSR
Spectral Ratio
Frequency (Hz)


BOSL.HVSR
Azimuth (°)
Frequency (Hz)

Station ID	VISG
Municipality	Firenzuola
Local Area	Visignano
Latitude (° WGS84)	44.18896
Longitude (° WGS84)	11.43431
Altitude (m.s.l.m)	727
Geology	FMA12 (Membro di Castel del Rio)
Soil	Formazione marnoso-arenacea
Power	2 solar panels of 150W
UMTS coverage	-89 dB
Sensor	T4A94/D0502
Datalogger	DCM-904
Installation date	12/06/2019




Amplitude [m²/s⁴/Hz] [dB]
Frequency [Hz]
[%]
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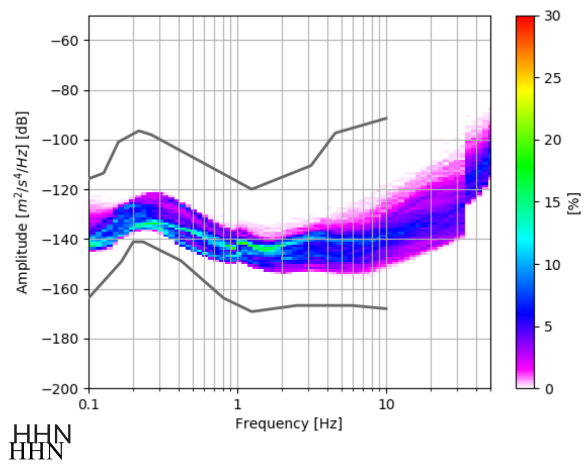
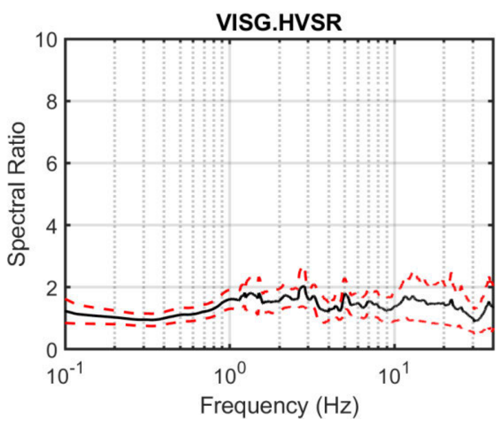
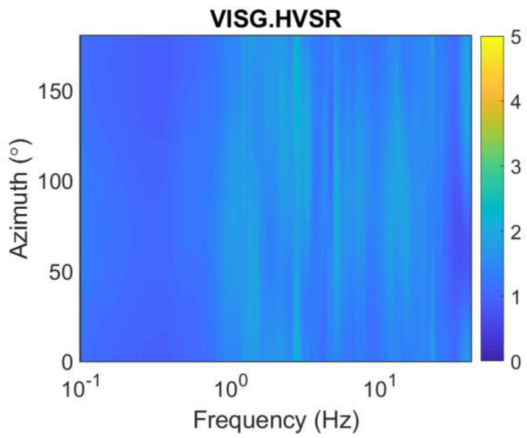
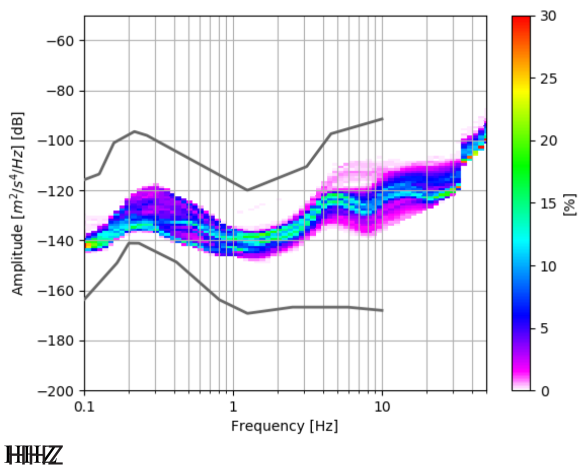
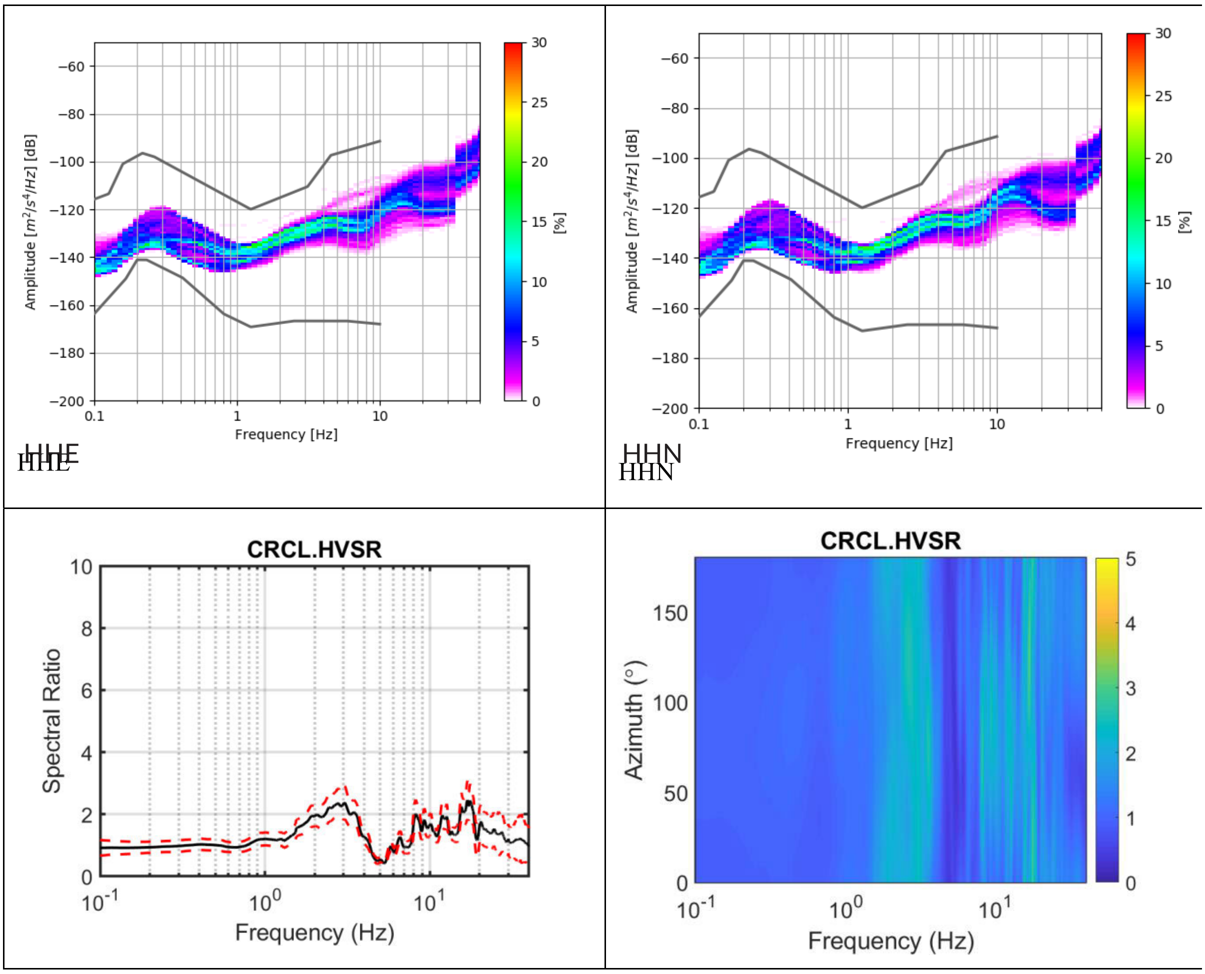

Amplitude [m²/s⁴/Hz] [dB]
Frequency [Hz]
[%]
HHN


VISG.HVSR
Spectral Ratio
Frequency (Hz)

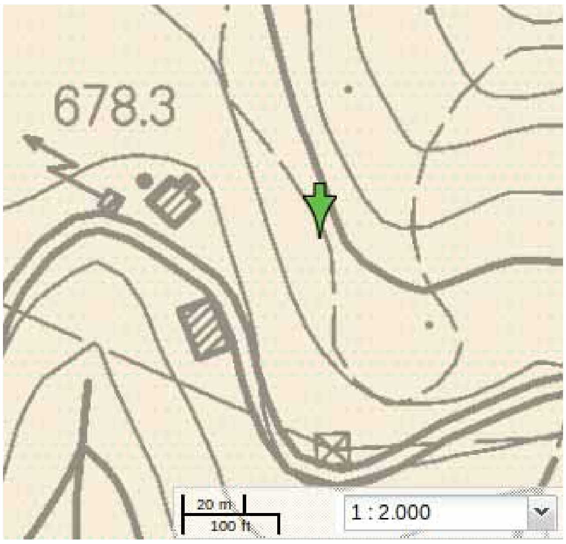

VISG.HVSR
Azimuth (°)
Frequency (Hz)

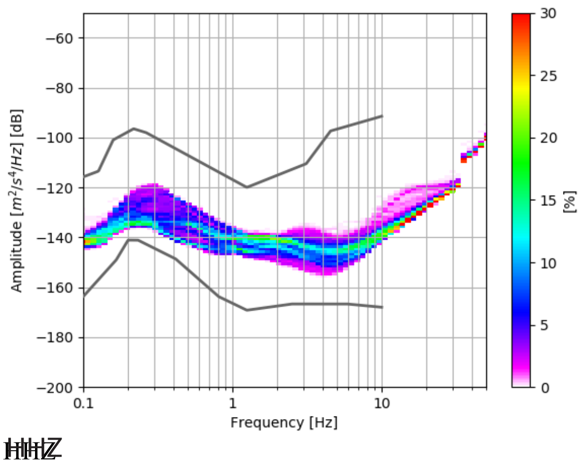
Station ID	CRCL
Municipality	Croci di Calenzano
Local Area	I Cavalieri del Colle, Via di Cupo
Latitude (° WGS84)	43.944353
Longitude (° WGS84)	11.237515
Altitude (m.s.l.m)	506
Geology	MLL (M. Morello Formation)
Soil	Carbonatic flysch, limestone (calcari) marnosi e marne
Power	4 solar panels 36W
UMTS coverage	-97dB
Sensor	T4902/DC30
Datalogger	EAM-2104
Installation date	20/06/2019

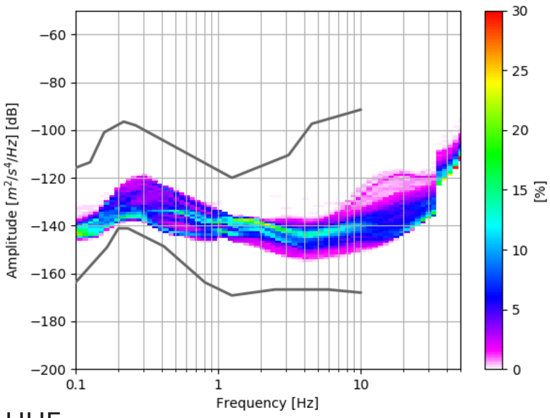



Amplitude [$m^2/s^4/Hz$] [dB]
Frequency [Hz]
[%]
HHE
HHN
CRCL.HVSR
Spectral Ratio
Frequency (Hz)
CRCL.HVSR
Azimuth (°)
Frequency (Hz)

Station ID	GAGN
Municipality	Cavarzano
Local Area	Gagnaia
Latitude (° WGS84)	44.05697
Longitude (° WGS84)	11.11862
Altitude (m.s.l.m)	670
Geology	TCG1 (Membro a megastrati arenacei)
Soil	Torbiditi arenaceo pelitiche e silitico pelitiche
Power	4 solar panels 36W
UMTS coverage	-96dB
Sensor/Digitiser	T4A90/DB65
Datalogger	DCM-935
Installation date	26/06/2019







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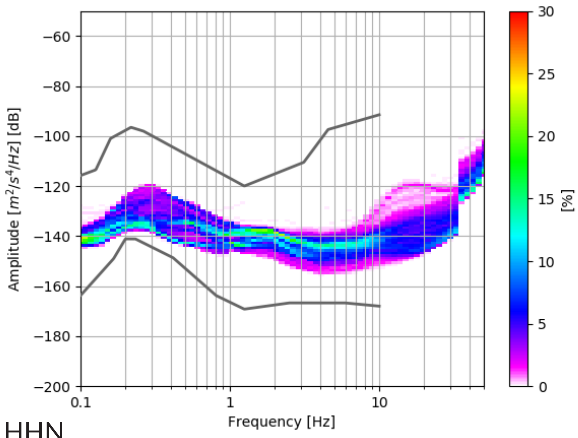

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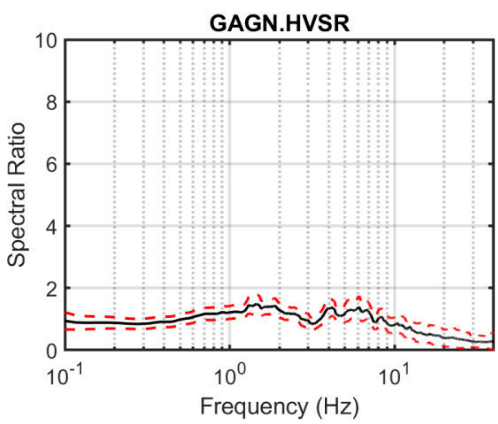
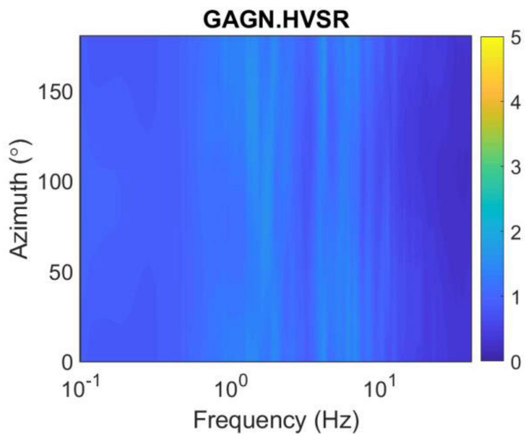
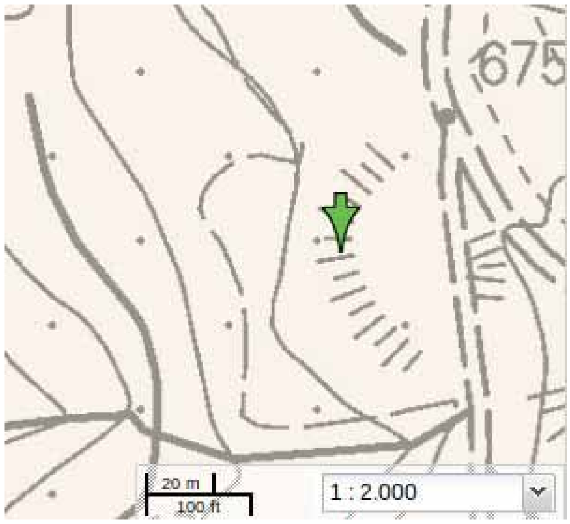
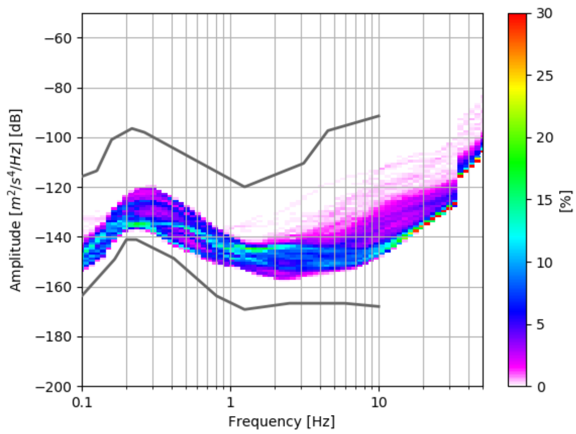




Station ID	CFER
Municipality	Borgo San Lorenzo
Local Area	Località Campestri, Collefertile
Latitude (° WGS84)	43.88798
Longitude (° WGS84)	11.42189
Altitude (m.s.l.m)	673
Geology	VIC (Marne di Vicchio)
Soil	Marne siltose e marne calcaree
Power	4 solar panels 36W
UMTS coverage	-101dB
Sensor	T4A87/D
Datalogger	DCM-674
Installation date	27/06/2019





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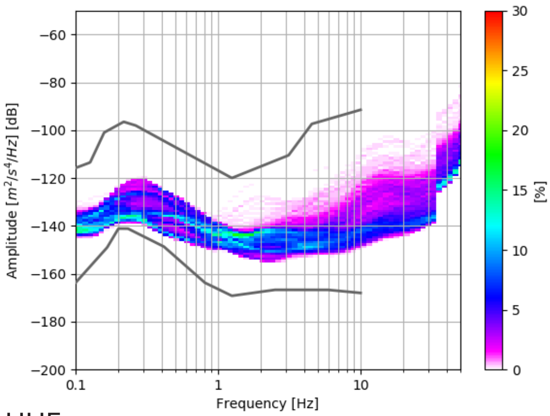

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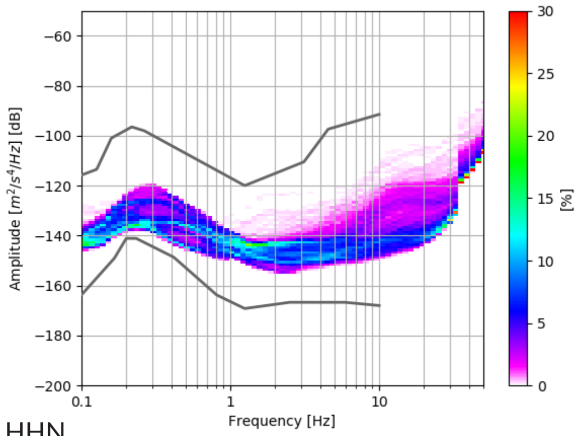

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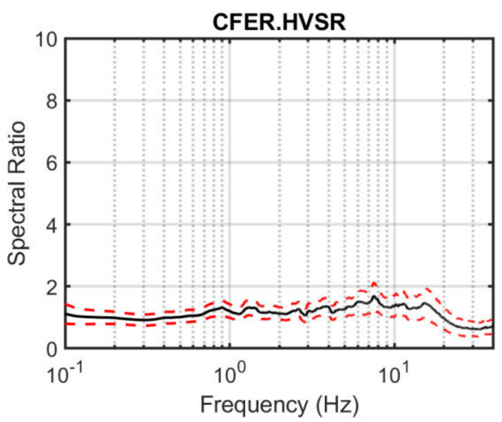
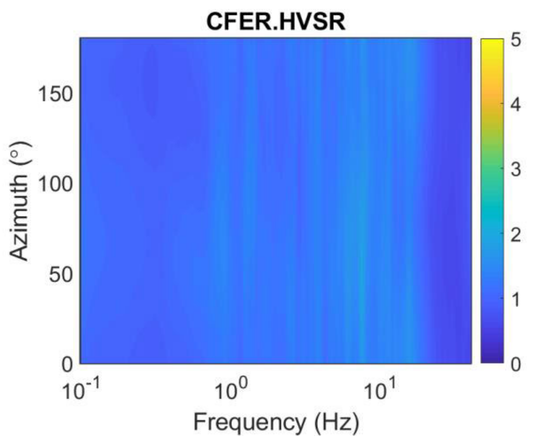
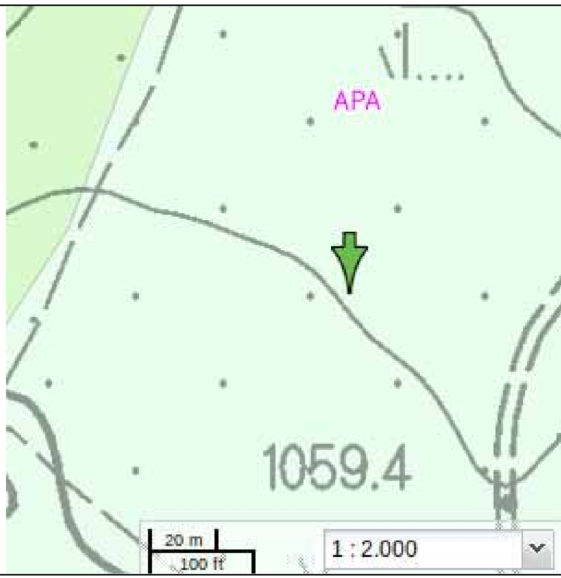
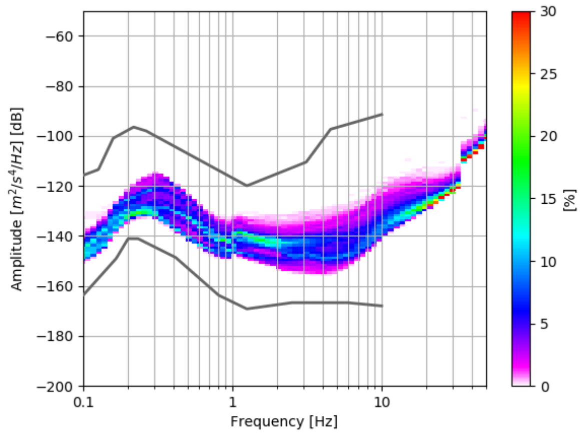




Station ID	MBEN
Municipality	Firenzuola
Local Area	Monte Beni
Latitude (° WGS84)	44.14831
Longitude (° WGS84)	11.3107
Altitude (m.s.l.m)	1061
Geology	APA (Argille a Palombini)
Soil	Argilliti grigie e calcilutiti
Power	4 solar panels 36W
UMTS coverage	-103dB
Sensor	T4A97/D0513
Datalogger	DCM-858
Installation date	03/07/2019





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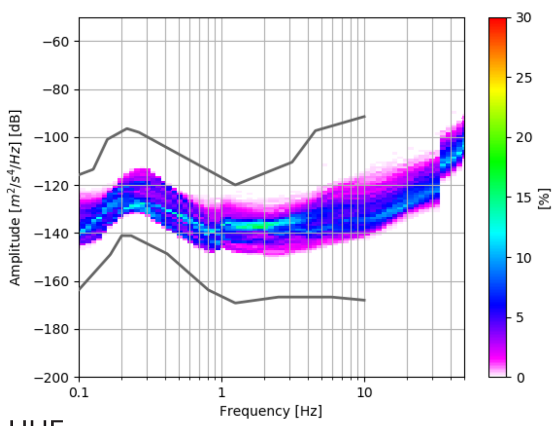
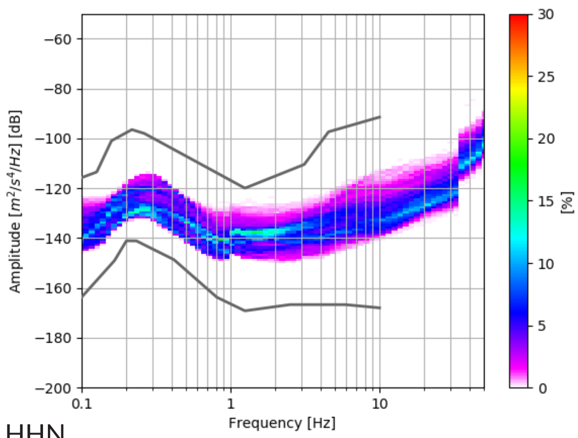


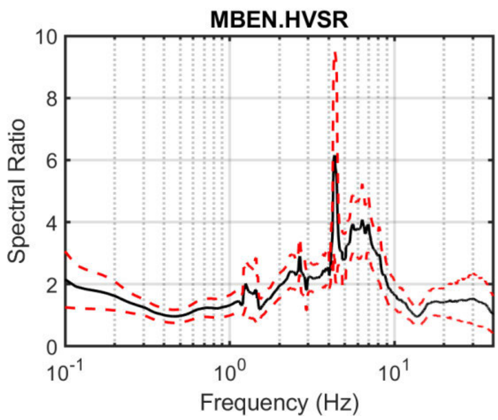
HHE

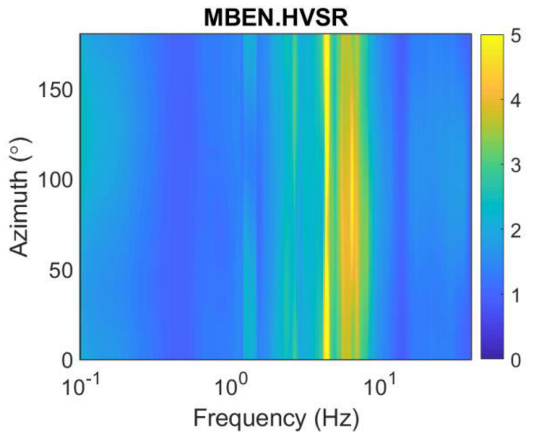
HHE



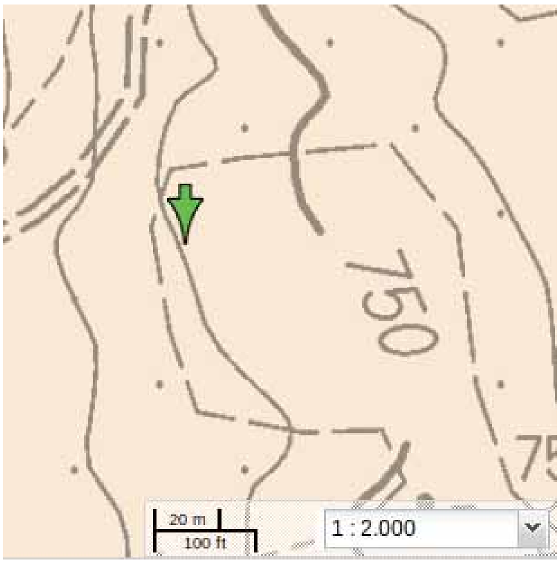
HHN

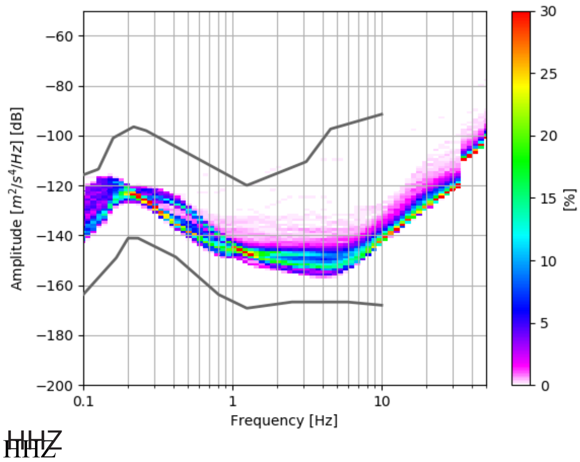
HHN

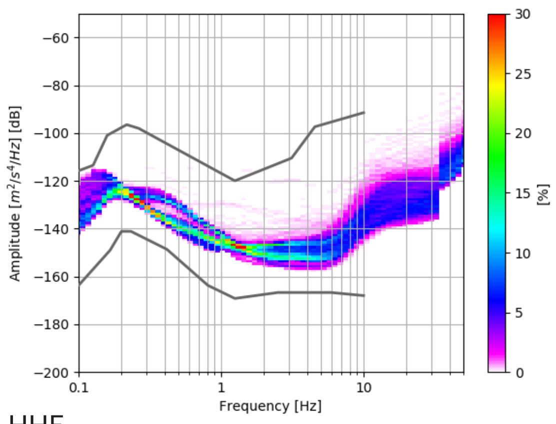




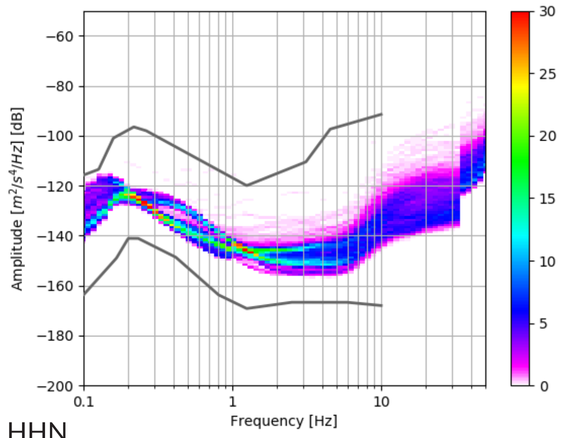
Station ID	CASC
Municipality	Palazzuolo sul Senio
Local Area	Ca’di Scheta, Località Lozzole
Latitude (° WGS84)	44.08059
Longitude (° WGS84)	11.53222
Altitude (m.s.l.m)	740
Geology	FM4A (Membro di Galeata)
Soil	Formazione marnoso-arenacea
Power	4 solar panels 36W
UMTS coverage	-94dB
Sensor	T4A84/D0493
Datalogger	EAM-2105
Installation date	04/07/2019



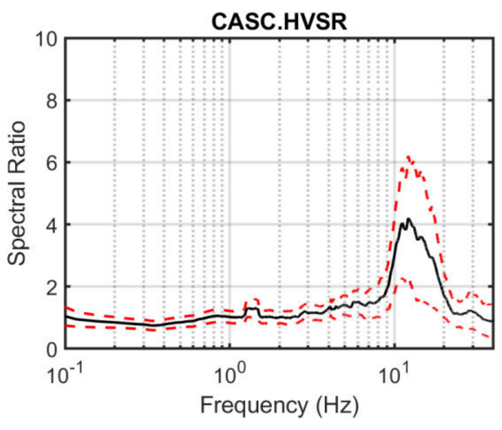


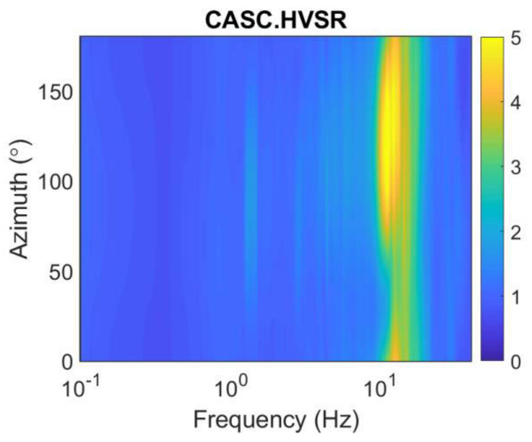

Amplitude [m²/s⁴/Hz] [dB]
Frequency [Hz]
[%]

HHE


Amplitude [m²/s⁴/Hz] [dB]
Frequency [Hz]
[%]

HHN


CASC.HVSR
Spectral Ratio
Frequency (Hz)


CASC.HVSR
Azimuth (°)
Frequency (Hz)

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