

NISBAS – THE NETWORK OF ITALIAN SURFACE-BOREHOLE ACCELEROMETERS AND SEISMOMETERS

M. Mucciarelli¹, E.R. Diez Zaldivar², M.R. Gallipoli³, G. Laurenzano¹, L. Martelli⁴, L. Moratto¹, E. Priolo¹, M. Romanelli¹, T.A. Stabile³

¹ Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) – Centro di Ricerche Sismologiche, Trieste-Udine, Italy

² Centro Nacional de Investigaciones Sismológicas (CENAI), Santiago de Cuba, Cuba

³ Consiglio Nazionale delle Ricerche, Istituto di Metodologie per l'Analisi Ambientale (CNR-IMAA), Tito Scalo (PZ), Italy

⁴ Regione Emilia-Romagna, Servizio Geologico, Sismico e dei Suoli, Bologna, Italy

Introduction. NISBAS - *the Network of Italian Surface-Borehole Accelerometers and Seismometers* is an information system aimed at organizing, archiving and accessing to seismological data of coupled surface-borehole stations. In Europe in general and in Italy in particular there is a lack of couple accelerometers and/or seismometers at the surface and in boreholes. Other countries as Japan are more advanced in this sector, with hundreds of surface-boreholes stations. USA and Turkey are recently improving the number of this kind

ISTITUTO NAZIONALE
 DI GEOSCIENZE E
 GEOFISICA SPERIMENTALE

imaa
 Istituto Nazionale della Ricerca
 in sismologia e in geofisica per l'Emilia Romagna

Homepage
Sites
Event Waveforms
Continuous Waveforms
Jump to Gallery...
Log-in to nisbas Version 1.0 (May 2015)

Stations search

Network Type

Network Code -- select network --

Station Code

Station Name

Latitude (e.g. 45.27) from [≥]: to [<]:

Longitude (e.g. 12.7) from [≥]: to [<]:

Region

Province

EC8 -- Any value --

Sensor -- Any value --

Depth

Installation type -- Any value --

Housing -- Any value --

Morphology -- Any value --

Number of Recordings

Search

Map data ©2015 GeoBasis-DE/BKG (©2009), Google, Inst. Geogr. Nacional, Mapa GISraet ORION-M

Network Code	Stat. Code	Station Name	Latitude	Longitude	Elev [m.a.s.l.]	Municipality	EC8	Sensors (*)=out of service	Housing	# of records	Station recordings
BA (Temp)	IMAA	Tito Scalo CNR-IMAA	40.601000	15.724000	828	TITO	D	SM(*)		8	
BA (Temp)	MSN	Marsico Nuovo CNR-IMAA	40.425000	15.730000	791	MARSICO NUOVO	B	SM	Building Borehole	46	
NI (Perm)	MIRB	Mirandola Borehole	44.877455	11.062789	17	MIRANDOLA	C	SM	Borehole Borehole	0	
NI (Perm)	FERB	Ferrara Borehole	44.900000	11.540000	7	FERRARA	C	BB,SM(*)	Borehole	0	
NI (Perm)	STIN	SAN STINO	45.714830	12.771910	1	SANTO STINO DI LIVENZA		BB(*),SP		0	
NI (Perm)	TOPP	PIAN DEL TOPPO	46.198488	12.817060	258	TRAVESIO		SM	Borehole	0	
EV (Perm)	ED01	SUSEGANA S. LUCIA	45.834582	12.289224	54	SANTA LUCIA DI PIAVE	B	BB(*),SP(*)	Borehole	0	

Fig. 1 – Station search page of the NISBAS website.

of installation. In Italy there were very few experiments in the past and at the moment there are some sparse attempts to produce this kind of valuable data. Our purpose aimed to start to fill this gap in Italy by improving the existing installations, providing uniform recording site characterization and offering a common web portal for the public dissemination of data derived from different owners. The availability of this kind of seismological data, together with the description of the recording site, is essential for the studies on site response analysis in the case of lack of a suitable outcrop rock reference site, but it could also improve the understanding of ground motion attenuation and site effects with implications for ground-motion prediction equation, seismic code provisions and seismic PSHA studies. NISBAS was developed following the same structure of OASIS - The OGS Archive System of Instrumental Seismology (<http://oasis.crs.inogs.it>, Priolo *et al.*, 2015a), which in turn is inspired by ITACA database (<http://itaca.mi.ingv.it>, Luzi *et al.*, 2008; Pacor *et al.*, 2011). This choice was made in order to make easier the use and helping the interaction among different databases and archives.

The NISBAS data are structured in two parts, i.e. *Sites*, a database that manages all the information of the seismological instrumented sites, and *Waveforms*, a double archive of waveforms, for the continuous and extracted data, respectively. Access to the site information and data downloads is made through the web portal <http://nisbas.crs.inogs.it>.

Sites. The characterization of the recording site, from the geographical, geological and geophysical point of view is essential for a correct use and interpretation of the data recorded by that station. The NISBAS database archives all the information needed to describe both the instrumentation and the characterization of the sites that host the stations. Station metadata are displayed within the area *Sites* of the website. The *Station search* page (Fig. 1) allows to search sites according to the different criteria: network type (permanent or temporary), network code, station code, station name, geographical location (geographical coordinates, region, province) and other information such as soil type (EC8 code), housing, morphology, etc. The *Search* operation provides a list of stations matching the request. By selecting a station from the list, one can access to the *Station detail* page, where the station main characteristics are given and its location is shown on a Google Earth map. Below the station description, the active and/or old instrumentations are listed and a link leads to the *Sensor-Channel* detail, where details on digitizers and sensors are reported. The whole information about stations is also gathered in a *Station Monography*, downloadable in pdf printable format. The *Station Monography* describes all the features and shows, when available, a photo of the site, the geological map, the topographic or regional technical maps, the microtremor H/V spectral ratios curve, the site classifications according to the seismic norms, the EC8 (CEN, 2003) or the NTC-08 (NTC, 2008).

Three institutions (the National Institute of Oceanography and Experimental Geophysics - OGS, the Geological Seismic Soil Survey of Emilia-Romagna Region RER, and the Institute of Methodologies for Environmental Research (IMAA) of the National Council of Research (CNR) CNR-IMAA) cooperated in the installation and maintenance of the NISBAS stations. The stations included within NISBAS (and listed in Tab. 1) belong to three different networks: the North-East Italy Regional Broad Band Seismic Network NI (Priolo *et al.*, 2005; Bragato *et al.*, 2011), the University of Basilicata (UNIBAS) network BA (Attolico *et al.*, 2010), and the Collalto permanent network EV (Priolo *et al.*, 2015b). The stations are the following:

1. ED01. The station ED01 - Susegana S. Lucia (TV) belongs to the Collalto permanent network EV, which aims at monitoring the natural and the induced seismicity of a gas storage activity in Veneto Region. The station is a 3-channel DM24-Guralp data logger, equipped with a compact seismometer (Guralp CMG-SP1, T=10 s, fmax=100 Hz) installed at 153 m depth. The data are acquired in continuous mode from December 2011, with a sampling rate of 200 Hz.
2. FERB. The station FERB - Casaglia (Ferrara) Borehole, managed by OGS in co-operation with INGV, has been reinstalled following the May 2012 Emilia sequence. It is equipped with a Guralp CMG-3T (360 s) Very Broad Band seismometer (with a CMG-DM24 digitiser) installed at 135 m depth. The data are acquired in continuous mode and the sampling rate is 100 Hz.
3. IMAA. The IMAA - Tito Scalo station is located in the Saint Loja Plain in southern Italy, along the axial zone of Southern Apennines. The station is a 6-channel K2-Kinematics data logger, equipped with a surface accelerometer (1g FBA ES-DECK Episensor) and a shallow borehole accelerometer installed at 35-m depth (1g shallow borehole Episensor). The data acquisition started on 28 November 2005. All triggered events were recorded with a sampling rate of 100 Hz.
4. MIRB. The station MIRB - Mirandola Borehole, is located in the epicentral area of the May 2012 Emilia sequence close to the RAN station, which recorded the maximum acceleration (a PGA value of 0.9 g on the vertical component of the 29 May shock). It is equipped with three Sara Force Balance accelerometers SA10, one at the surface, another one at 31 m depth, and the third at 126 m depth, respectively. The sensor at 126 m lies within a rock formation. The data are acquired in continuous mode with a sampling rate of 100 Hz.
5. MSN. The MSN - Marsico Nuovo station is located in the High Agri Valley, a Quaternary NW-SE trending intermontane basin located in the axial zone of the Southern Apennines

thrust belt (southern Italy). The station is a 6-channel K2-Kinometrics data logger, equipped with a surface accelerometer (1g FBA ES-DECK Episensor) and a borehole accelerometer (1g shallow borehole Episensor) installed on the seismic bedrock at the bottom of a 70 m deep borehole. The data acquisition started on 18 February 2011. Most of the triggered events were recorded with a sampling rate of 250 Hz, and only few events were recorder at 100 Hz.

6. STIN. The STIN- San Stino di Livenza (VE) station is a new borehole seismic station installed by OGS in the alluvial plain of Veneto region. The station is a 6-channel RefTek rt130 data logger, equipped with a surface (Lennartz - LE-3DLite 1s) and a borehole velocimeter (Sara - SSBHV) installed in a 100 m deep borehole. The data are acquired in continuous mode and the sampling rate is 100 Hz.
7. TOPP. The TOPP station is located in Piana del Toppo, Travesio (PN), an area where OGS realized an instrumented site for the experimental study of borehole and surface geophysics. The station is a 6-channel Sara SL06 data logger, equipped with two Sara Force Balance accelerometers SA10 installed at the surface and in a 150 m deep borehole, respectively. The data are acquired in continuous mode from March 2015 and the sampling rate is 100 Hz.

Tab. 1 - Stations stored in NISBAS database.

Station code	Station name	Network code	Lon	Lat	Borehole depth (m)	Data Download
ED01	Susegana S. Lucia (TV)	EV	12.289	45.834	153	Continuous
FERB	Ferrara borehole (FE)	NI	11.540	44.900	130	Continuous
IMAA	Tito Scalo	BA	15.724	40.601	35	Event
MIRB	Mirandola borehole (MO)	NI	11.063	44.877	31, 126	Continuous
MSN	Marsico Nuovo (PZ)	BA	15.730	40.425	76	Event
STIN	San Stino	NI	12.772	45.715	100	Continuous
TOPP	Pian del Toppo (PN)	NI	12.817	46.198	150	Continuous

Waveforms. The NISBAS webpage *Waveforms* manage the archive of waveforms and it is divided into two sections, i.e. continuous (*Continuous Waveforms*) and the extracted (*Event Waveforms*) waveforms. The archive of continuous waveforms contains the entire record acquired by each station. Extracted waveforms refer, instead, to seismic events that have been detected by the network and contain data that have been processed by applying a standard processing procedure. *Continuous Waveforms* section implements the search and download functions of generic pieces of waveforms within the stream of continuous recordings. This functionality allows searching and retrieving any piece of signal, with some limitations about the overall size of the resulting files. Before downloading the data, the user can check the data availability for the selected time period. At this point data can be downloaded as compressed files, in miniSEED (Ahern *et al.*, 2007) or SAC (Goldstein *et al.*, 2003) format. *Event Waveforms* section implements the search and download of waveform records concerning seismic events. In this section, the user can retrieve all the waveforms recorded by a station and related to a seismic event. Moreover, the main ground motion parameters (i.e. Peak Ground Acceleration PGA, Peak Ground Velocity PGV, Peak Ground Displacement PGD, Housner and Arias intensities,

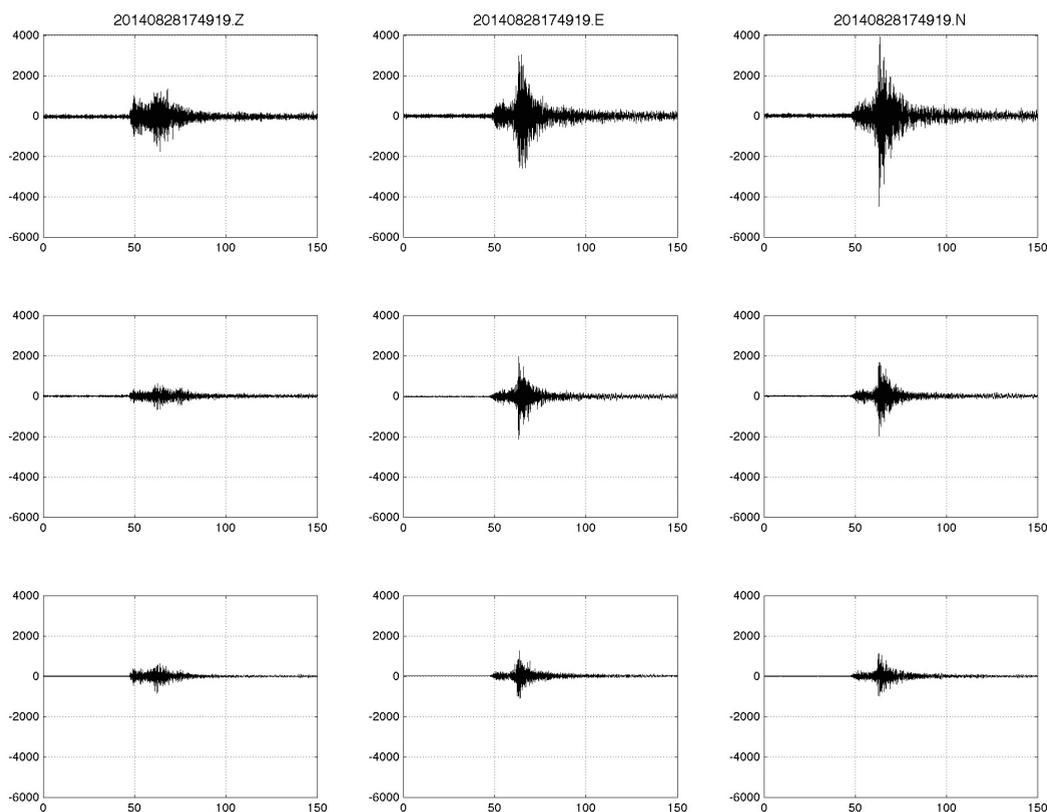


Fig. 2 – Recordings of the M=3.6, 20140828174919 event at different depths (from top to bottom: $z=0$, 31 and 126 m). From left to right: vertical, EW and NS components. Values are reported in counts.

etc.) are calculated and listed in the web page. Two kinds of data are considered: unprocessed and processed data. Both kinds of data are in physical units. Processed data are obtained by applying a standard processing procedure including: baseline correction, cosine taper function of 2-5% width in the time domain, pass-band filtering, calculation of Fourier spectrum and signal-to-noise ratio, integration and/or differentiation in order to obtain the displacement, velocity and acceleration time-series, computation of acceleration response spectrum. By selecting the *Export Data* button, the user downloads a *zip* file that contains, for each component, the unprocessed data as well as the processed displacement, velocity and acceleration time series, the acceleration Fourier spectra and the 5% damped acceleration response spectra, for a total of 19 files. Files are in ASCII format with a header of 43 commented rows that reports the most relevant information about station, event and waveform parameters [the 43 fields are the same adopted in ITACA and described in Pacor *et al.* (2011)].

As can be seen in Tab. 1, data belonging to networks NI and EV are provided in *Continuous Waveform* mode while stations belonging to networks BA provide *Event Waveforms*.

In Fig. 2 we show as an example the recording of the M=3.6, 2014-08-28 17:49:19 event at the Mirandola (MIRB) vertical array station (from top to bottom, $z=0$, 31 and 126 m depth). It can be seen as the amplitude and the duration of signals increase significantly from the bottom upwards, as the effect of surface soil amplification. Recently, both Mirandola (MIRB) and Casaglia (FERB) stations data have been used in studies for the evaluation of the local geophysical model and of the spectral amplification in the lack of a real reference site on rock in alluvial plain areas (Laurenzano *et al.*, 2013, 2015).

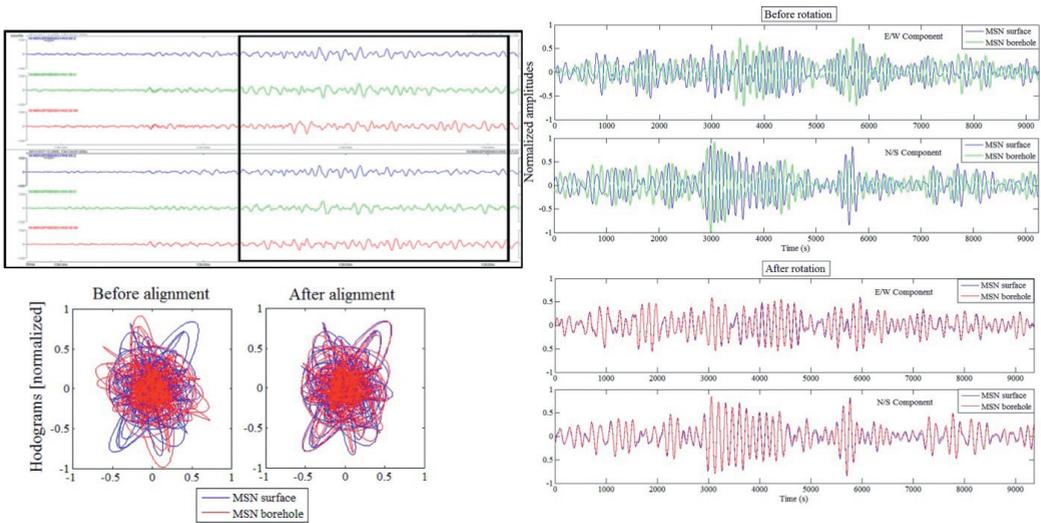


Fig. 3 – Correction of the azimuthal rotation of the borehole sensor at Marsico Nuovo (MSN). Top left: example of traces used for the horizontal alignment calculation. Seismograms refer to Mw 6.4 Greece earthquake recorded by the station (MSN surface and MSN borehole sensors, respectively). The black box indicates the part of the waves used to represent the seismograms and hodograms shown in the following panels. Right: Comparison of the seismograms before (top) and after (bottom) misalignment correction. The blue traces always correspond to the reference surface sensor, while the green and red colours correspond to the original traces and those obtained after misalignment correction. Bottom left panel: particle motion (hodograms) related to station pairs before (left) and after (right) misalignment correction. The reference MSN surface sensor is represented in blue, while the MSN borehole sensor is represented in red.

Misalignment angle correction of borehole seismic sensor. Despite all precautions, rotation may occur during installation of the sensors in the boreholes and therefore the orientation of borehole stations is unknown. An attempt was made in order to evaluate the misalignment angle correction of borehole seismic sensors of ED01, IMAA, MIRB, and MSN stations. The goal is to calculate the relative misalignment angles between sensors installed at depth, taking as a reference the sensor installed on surface, and considering that this instrument can be oriented by traditional methods, i.e. with compass. To determine the correction angle sensor in these stations we used a method developed and described by Grigoli *et al.* (2012). As mandatory requirement, the distance between sensors must be much smaller than the dominant wavelength of the signal used. Taking into account this condition, we selected the seismograms used for the determination of the rotation angles on the base of the following conditions: 1) teleseismic events with epicentral distances of at least 5000 km from the station; 2) regional events with epicentral distances up to 1000 km from the station; 3) magnitude of at least 6 degrees (Mw) and enough energy to be recorded simultaneously by all sensors. In all cases, the signal was pre-processed in the following way. First of all, it was down-sampled by decimation to 1 Hz sampling; secondly, static offset and linear trend were removed, and 5% tapering was applied. Third, the signal was pass-band filtered in the band 0.08-0.15 Hz by a Butterworth 4th order band-pass filter.

Fig. 3 shows, as an example, the correction of the azimuthal rotation of the borehole sensor at Marsico Nuovo (MSN). The top left panel shows the traces of the Mw=6.4, 2013-10-12 13:11:54, Crete event recorded from MSN surface and MSN borehole sensors, respectively. The borehole sensor appears quite misaligned, with the respective influence on the quality of the recorded data. Essentially the effect of this error is that the amplitudes of the traces recorded by borehole sensor are strongly modified in relation with trace recorded at the surface (Fig. 3, top right). The same effect is observed in the particle motion before and after correction (Fig. 3, bottom left). Results show that misalignment angles range from some tens up to hundred

degrees, and they are not necessarily correlated to the sensor depth. The values obtained for MIRB using the sensor at the surface as a reference, show that the misalignment angle for the sensor located at $z=31$ m is quite large (120°), probably because its sensor was not aligned at all, while surprisingly, a good value of 7° is obtained for the deeper sensor, if we consider that the sensor lays at 126 m of depth. MSN borehole showed quite misaligned, with an angle of about 135° , while IMAA borehole sensor appears rotated in an opposite position of almost 180° respect to the surface sensor. Finally, ED01 showed a small misalignment angle of about 8° (Diez Zaldivar *et al.*, submitted). Considering the obtained values, the misalignment angle correction was applied on the recorded data of IMAA and MSN, so that the extracted waveforms (downloadable on NISBAS *Event Waveforms* site) are already corrected. For MIRB and ED01 stations, instead, the correction has to be applied after downloading the data from the *Continuous Waveforms*, in order to reduce errors in the analysis procedure.

Conclusions. NISBAS was created with the aim of organizing, archiving, and providing access to seismological data recorded by coupled seismological accelerometers/seismometers installed at the surface and in boreholes. They represent a valuable resource of data that may be of interest for the scientific community. Through a web interface (<http://nisbas.crs.inogs.it>), the user can retrieve detailed information about the seismological stations as well as either download generic pieces of waveforms taken from the stream of continuous recordings or seismograms related to specific events.

Acknowledgements. Version 1.0 of June 2015 was realized within the research project entitled “Progetto S2-2014, Constraining Observation into Seismic Hazard. The project is the 3rd S2 Project funded in the frame of DPC (Dipartimento di Protezione Civile Nazionale) – INGV (Istituto Nazionale di Geofisica e Vulcanologia) agreements. It concerns the mid-long term Seismic Hazard Assessment in Italy, focussing in betterment that can be reached on two priority areas.

References

- Ahern, T., Casey, R., Barnes, D., Benson, R., and Knight, T.; 2007. SEED Standard for the Exchange of Earthquake Data Reference Manual Format Version 2.4, http://www.fdsn.org/seed_manual/SEEDManual_V2.4.pdf.
- Attolico, A., Gallipoli, M.R., Harabaglia, P., Lapenna, V., Mucciarelli, M., Rosa, A.B.; 2010. A review of the activity of two accelerometric networks in Basilicata (Italy), *Bulletin of Earthquake Engineering*, 8(5) 1131-1140
- Bragato, P.L., di Bartolomeo, P., Pesaresi, D., Linares, M.P.P., Saraò, A.; 2011. Acquiring, archiving, analyzing and exchanging seismic data in real time at the seismological research center of the OGS in Italy. *Annals of Geophysics*, 54(1), 67-75. DOI 10.4401/ag-4958.
- CEN (Comité Européen de Normalisation); 2003. prEN 1998-1-Eurocode 8: design of structures for earthquake resistance—part 1: general rules, seismic actions and rules for buildings. Draft No 6, Doc CEN/TC250/SC8/N335, January 2003, Brussels
- Diez Zaldivar E.R., Priolo, E., Grigoli, F., Cesca, S. Misalignment angle correction of borehole seismic sensors – The case study of the Collalto Seismic Network. Submitted to *Seismological Research Letters*
- Goldstein, P., Dodge, D., Firpo, M., and Minner, L.; 2003. SAC2000: Signal processing and analysis tools for seismologists and engineers. In Lee, W., Kanamori, H., Jennings, P., and Kisslinger, C., editors, *The IASPEI International Handbook of Earthquake and Engineering Seismology*. Academic Press, London.
- Grigoli, F., Cesca S., Dahm, T. and Krieger, L.; 2012. A complex linear least-squares method to derive relative and absolute orientations of seismic sensor. *Geophysical Journal International*, 188(3), 1243-1254.
- NTC; 2008. Norme Tecniche per le Costruzioni, DM 14/01/2008, GU n.29 del 04/02/2008, Suppl. Ord. 30 (in Italian)
- Laurenzano G., E. Priolo, C. Barnaba, M.R. Gallipoli, P. Klin, L. Martelli, M. Mucciarelli, e M. Romanelli; 2013. Studio sismologico per la caratterizzazione della risposta sismica di sito ai fini della microzonazione sismica di alcuni comuni della Regione Emilia-Romagna. Atti del 32 Convegno Nazionale GNGTS, Tema 2, pp. 247-252.
- Laurenzano G., Priolo E., Barnaba C.; 2015. Site response estimation at Mirandola by virtual reference station. Convegno finale Programma Sismologico DPC-INGV, Poster Session, 4-5 giugno, Bologna (Italy)
- Luzi, L., Hailemikaël, S., Bindi, D., Pacor, F., Mele, F., and Sabetta, F.; 2008. ITACA (Italian ACcelerometric Archive): A Web Portal for the Dissemination of Italian Strong-motion Data. *Seismological Research Letters*, 79(5), 716–722, doi: 10.1785/gssrl.79.5.716
- Pacor F., Paolucci, R., Luzi, L., Sabetta, F., Spinelli, A., Gorini, A., Nicoletti, M., Marcucci, S., Filippi, L., and Dolce, M.; 2011. Overview of the Italian strong motion database ITACA 1.0. *Bulletin of Earthquake Engineering*, 9(6), 1723–1739, doi: 10.1007/s10518-011-9327-6.

- Priolo E., Barnaba C., Bernardi P., Bernardis G., Bragato PL, Bressan G., Candido M., Cazzador E., Di Bartolomeo P., Duri G., Gentili S., Govoni A., Klinc P., Kravanja S., Laurenzano G., Lovisa L., Marotta P., Ponton F., Restivo A., Romanelli M., Snidarceig A., Urban S., Vuan A., and Zuliani D.; 2005. Seismic monitoring in north-eastern Italy: A ten-year experience. *Seismological Research Letters*, 76, 446–454
- Priolo, E., Laurenzano, G., Barnaba, C., Bernardi, P., Moratto L., and A. Spinelli; 2015a. OASIS: The OGS Archive System of Instrumental Seismology. *Seismological Research Letters* 05/2015; 86(3):978-984. DOI:10.1785/0220140175
- Priolo E., M. Romanelli, M. P. Plasencia Linares, M. Garbin, L. Peruzza, M. A. Romano, P. Marotta, P. Bernardi, L. Moratto, D. Zuliani, and P. Fabris; 2015b. Seismic monitoring of an underground natural gas storage facility: the Collalto Seismic Network. *Seismological Research Letters*, 86 (1), 109-123 + esupp, doi: 10.1785/0220140087.