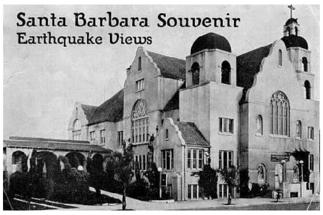

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SITE RESPONSE AND AMBIENT NOISE CHARACTERISTICS AT THE NORTHEAST ITALY BROADBAND SEISMIC NETWORK

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ABSTRACT

The characteristics of the background seismic noise recorded at the NorthEast Italy (NI) broadband seismic network have been analyzed. The network, managed by Centro di Ricerche Sismologiche (CRS) - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) is composed of 14 broadband deployed on 25000 Km^2 wide area.
The instrumentation is installed in caves, bunkers and in boreholes to improve the signal-to-noise ratio; the sensors have been isolated against fast changes in temperature and air flow by covering them with sealed steel caps anchored to the ground.
The data quality check is performed through standard seismological tools: PQLX, McNamara & Boaz, 2005, using Power Spectral Densities for frequencies ranging from 0.01 to 16 Hz. Continuous data of the former day and all the 24 hours is considered, without eliminating seismic events (both local or teleseismic) or anomalous transient phenomena. Probability Density Functions provide a useful tool for characterizing the performance of broadband stations and for detecting operational problems. The noise level at all stations is contained within the Peterson New Model limits. In particular, we observed the amplitude of the noise is higher and the dominant peak frequencies are shifted toward lower period in wintertime. In summer, the amplitude is lower with a maximum at shorter periods.
Our observations play an important role to the future siting for the NI Network growth. The noise maps at body wave frequencies should be useful for estimating the magnitude threshold or conversely for optimizing the distribution of regional network stations.

INTRODUCTION

It is well known that although the magnitude and distance are first-order factors that control ground motion, site condition can generate significant changes in earthquake effects on buildings. Therefore, site characterization is one of the most important goals of earthquake engineering and it is an important ingredient in accurate empirical ground-motion prediction relations. However, a good quantification and understanding of the site response starts from the noise knowledge of each site. It has long been known that the reduction, quantification and understanding of seismic background noise are the first step to provide high quality data. The background noise is a limiting factor since it can mask seismic signal, especially in the low-frequency band. The importance of noise level reduction on seismic data is strongly linked to quantify the detection level of the network, that reflects directly on the completeness magnitude of an area and indirectly on the calibration of attenuation relations through regression analysis, which may be biased by non-triggering stations (McLaughlin, 1991; Bragato and Slejko, 2005).
The noise affecting the seismic signals that reducing the signal-to-noise ratio is interpreted like the sum of electronic noise, atmospheric fluctuations (pressure, temperature and humidity) and seismic noise. Here, our attention is focused only on the seismic noise, while the electronic noise, mainly produced by seismic sensors self-noise, datalogger self-noise or near-field electric cabling, and the atmospheric turbulences are not investigated in detail.

Seismic noise has been extensively studied in the past. A detail bibliography is available in Bonnefoy-Claudet et al. (2006). The conclusions of these observations at different sites all over the world are consistent with each other and may be summarised as follows: i) at long periods (below 0.3 to 0.5 Hz), seismic noise is caused by ocean waves long distances away; ii) at intermediate periods (between 0.3-0.5 Hz and 1 Hz), it is mainly generated by both close coastal sea waves and wind; iii) beyond 1 Hz, it is linked to human activity, and therefore reflect the human cycle.
In this study, we have carried the noise level at NI stations in order to quantify the quality of stations from 0.01 to 16 Hz. The power spectral density curves presented here are a useful tool for selecting stations as a function of signal-to-noise ratio in the frequency band of interest. The noise level of the different stations is studied as a continuous function of time.
We also present horizontal-to-vertical-spectral ratios (Nakamura, 1989) test performed for both noise and two local earthquakes. The receiver function (Langston, 1979) on strong motion records is at the moment suspended because of the very low frequency band of the sensors needs more detailed studies.
The previous studies on ground motion on the NI sites were limited to some sites (Siro, 1984; Castro et al., 1997). On the other hand, some recent improvements have been performed through all sites (Barnaba et al., 2008), but precise site classification with geotechnical characterization down to 30 m depth are almost nonexistent.

TECTONIC SETTING

The seismic history of the Friuli Venezia Giulia (FVG) put in evidence its geological complexity. The region is situated in central Europe, in the northeastern corner of Italy, and it is part of the eastern Southern Alps, on the edge of Adria microplate. From satellite views, the Alps show as a crescent-shaped series of folds in the earth from southern France to eastern Austria. Some 100 million years ago Africa began moving northward, and the present state of stress is a consequence of the Adria microplate's progressive motion and its anti-clockwise rotation with respect to the Eurasian plate (Anderson and Jackson, 1987), with accommodation by complex mechanism of crustal shortening and indentation against the Southern Europe edge (Mantovani et al., 1996).
The structural framework is mainly characterized by two indented tectonic wedges, in which the outer surrounds the inner wedge; these wedges are outlined by NE–SW and NW–SE orientated paleo-fault systems (Venturini, 1991). They were formed from Paleozoic to the middle Eocene times by syn-sedimentary tectonic movements and they were re-activated during the compressional Cenozoic tectonic phases. The Mesoalpine (Dinaric) NE–SW compression was the earliest tectonic phase and generated NW–SE-orientated thrusts during the Middle late Eocene, mainly in Slovenia and in the south eastern part of the Friuli area (Faccenda et al., 2007). Therefore Friuli represents a key area in the Alps, where superimposion of several Cenozoic tectonic phases (Castellarin et al., 1992) reflects on present-day seismic activity (Bressan et al., 2003).
Although this area is one of the most tectonically active in the Alpine Chain, it is characterized by moderate seismicity, with magnitude 6, exceeded only three times in the past centuries: 1348 Villach; 1511 Gemona and 1976 Gemona (Slejko et al., 1989) and with magnitude 5.5 exceeded other few times, 1928 Tolmezzo; 1936 Cansiglio; (Slejko et al., 1989); 1998 Bovec (Bajc et al., 2001). The main activity affects the central part of FVG region with localized clusters in the northern and western parts of the area and the western Slovenia. The seismotectonic characteristics are heterogeneous. The fault plane solutions are mainly of thrust type, even if with different nodal plane orientations, with significant number of strike-slip and minor normal faulting events (Gentile and Slejko, 1990; Bressan et al., 2003; Poli and Renner, 2004). The seismicity pattern and the various types of focal mechanism suggest the present stress field is characterized by different stress patterns, with variations in principal stress orientation and stress regime (Bressan and Bragato, 2009).

NETWORK AND STATIONS DESCRIPTION

Instrumental seismological observation in the Northeastern Italy started at the end of the 19-century with few observatories in Italy and the former Hapsburg Empire. The reference station was that of Trieste (Finetti & Morelli, 1972); now it is part of the Mednet network (MN). After the 1976 Friuli earthquake, the OGS installed the first five short-period vertical seismometers in the area. Since then, the network has been enlarged and currently comprises 19 short period stations (18 three-component) called Friuli-Veneto network (FV). Since 2006, the OGS have been installing the first broadband and now running 14 stations equipped with broadband and accelerometer sensors that belong to the NI network. For more details in the development of the NI network see Priolo et al., 2005. To increase the coverage of the western site of the area we have included the Trento network stations (TN).
Locations, equipment and installation details of the all stations are summarized in Tab. 1, Tab. 2 and Fig. 1. Further logistic settlement and improvements are still running on for some site (CLUD and DRE for these reasons they are not considered in this study). In general, all short period stations are of a similar physical design and include a vault, equipment hut, radio link, GPS time and solar panels. The vaults are a solid concrete constructions with additional insulation and a steel lid, far 5-30 m away the radio-solar panels pylon. The sensor is set on a thick glass sheet. The equipment hut, usually mounted on the radio pylon, houses the digitizer, the communication equipment and the power supply. The broadband stations are deployed in caves, bunkers or, more recently, in small

boreholes to reduce the ambient noise and improve the signal-to-noise ratio. In addition the broadband sensors are covered with a polyurethane foam box or sealed steel caps to protect them against fast changes in temperature and airflow (Fig. 2).
All the stations are telemetered and real time acquisition is available since 1994. Since 2002, real time continuous data exchange is available with the Antelope software (BRTT, 2004), waveform and parametric data are transmitted in real time to the FVG, Veneto and Trento Civil Defense agencies, to the Italian National Institute for Geophysics and Volcanology (INGV), to the Earth Science Department (DiGeo) of the Trieste University – Italy, to the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) in Vienna, and to the Environment Agency of the Republic of Slovenia (ARSO) in Ljubljana.

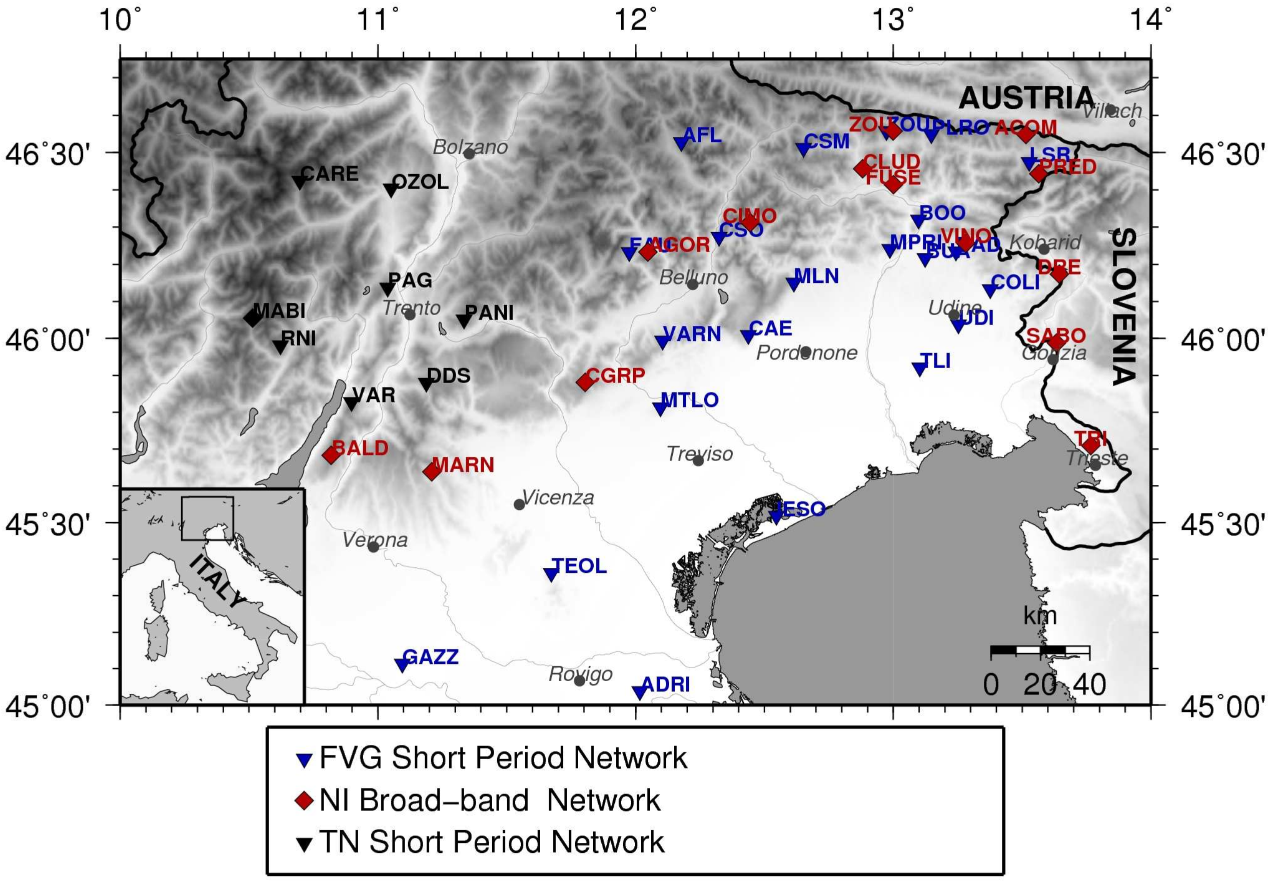

Fig. 1. Northeast Italian stations map: blue triangle down represents the short period FV network, black triangle down represents the Trento network (TN), and red and blue diamond represents the broad band NI network.

Table 1. Broadband Stations list running in the NI network, MN network; Qxxxx stand for Quanterra; STS-x stand for Streckeisen broadband sensor, Epi stand for Episensor. For housing: MB, military bunker; C, shallow cave; CC, deep carsic cave; SB, shallow borehole; BB, building basement; M, mine

Code	Lat (°N)	Long (°E)	H (m)	A/D	BB	ACC	Rock -Housing	Net	Name
ACOM	45.5479	13.5149	1715	Q330	STS-2	Epi	Limestone – MB	NI	Acomizza
AGOR	46.2829	12.0472	631	Q680	STS-2	-	Limestone – C	NI	Agordo
BALD	45.6830	10.8187	1911	Q330	Trillium40	Epi	Limestone – BB	NI	Mte. Baldo
PRED	46.4428	13.5650	902	Q330HR	STS-2	Epi	Dolomite – M	NI	Cave Predil
CGRP	45.8806	11.8047	1757	Q330	STS-2	Epi	Limestone – C	NI	Cima Grappa
CIMO	46.3116	12.4448	610	Q4120	STS-2	Epi	Dolomite – C	NI	Cimolais
CLUD	46.4569	12.8814	635	Q330	Trillium120	Epi	Dolomite – M	NI	Cludinico
DRE	46.1729	13.6432	810	Q330	STS-2	-	Sandstone – SB	NI	Drenchia
FUSE	46.4142	13.0011	520	Q330	Trillium40	Epi	Dolomite – SB	NI	Fusea

MARN	45.6378	11.2099	785	Q330	Trillium40	-	Porphyrite – SB	NI	Marana
SABO	45.9875	13.6337	575	Q330	STS-2	Epi	Limestone – MB	NI	Sabotino
TRI	45.7090	13.7642	161	Q4126	STS-1	5T	Limestone – CC	MN	Trieste
VARN	45.9933	12.1048	1270	Q330	Trillium120	Epi	Limestone – SB	NI	Varnada
VINO	46.2560	13.2810	608	Q4120	CMG-3T	Epi	Limestone – CC	NI	Villanova
ZOU2	46.5584	12.9729	1896	Q330	Trillium120	Epi	Porphyrite - SB	NI	Zouf Plan

Table 2. Short period stations operating in the FV network.

Code	**Lat**	**Long**	**H (m)**	**A/D**	**SP**	**Rock**	**Net**	**Name**
ADRIA	45.0378	12.0166	1	Mars88	LE-3Dlite	Alluvium	FV	Adria
AFL	46.5283	12.1755	2235	Mars88	LE-3Dlite	Dolomite	FV	Alpe Faloria
BAD	46.2340	13.2438	590	Mars88	LE-3Dlite	Limestone	FV	Bernadia
BOO	46.3195	13.0984	444	Mars88	LE-3Dlite	Limestone	FV	Bordano
BUA	46.2167	13.1227	320	Mars88	LE-3Dlite	Flysch	FV	Buja
CAE	46.0090	12.4379	870	Mars88	LE-3Dlite	Limestone	FV	Caneva
CSM	46.5125	12.6515	1635	Mars88	LE-3Dlite	Sandstone	FV	Mimoias
CSO	46.2724	12.3228	1060	Mars88	LE-3Dlite	Limestone	FV	Casso
COLI	46.1322	13.3770	250	Mars88	LE-3Dlite	Flysch	FV	Colloredo
FAU	46.2322	11.9753	1430	Mars88	LE-3Dlite	Shales	FV	Forc. Aurine
GAZZ	45.1134	11.0950	12	Mars88	LE-3Dlite	Alluvium	FV	G. Veronesse
IESO	45.5178	12.5464	1	Mars88	LE-3Dlite	Alluvium	FV	Jesolo
LSR	46.4750	13.5269	1755	Mars88	LE-3Dlite	Diabases	FV	Lussari
MLN	46.1495	12.6154	814	Mars88	LE-3Dlite	Limestone	FV	Malnisio
MPRI	46.2408	12.9877	762	Mars88	LE-3Dlite	Limestone	NI	Monte Prat
MTLO	45.8136	12.0991	350	Mars88	LE-3Dlite	Molasse	FV	Montello
PLRO	46.5491	13.1481	1410	Mars88	LE-3Dlite	Flysch	FV	Paularo
TLI	45.9209	13.1032	74	Mars88	LE-3Dlite	Alluvium	FV	Talmassons
TEOL	45.3617	11.6740	370	Mars88	LE-3Dlite	Marls	FV	Teolo

SEISMIC NOISE ANALYSIS

The quality of the raw seismic data is checked using the Power Spectra Densities (PSD) analysis. It is systematically estimated for all broadband stations and it is statistically analyzed to compute Probability Density Functions (PDF) (McNamara and Buland, 2004) using the PASSCAL Quick Look eXtended (PQLX) software package (McNamara and Boaz, 2005). The computed PSDs are stored in a MySQL database, allowing to access specific time periods of PSDs.
The method used for estimating the PSD for stationary random seismic data is the direct Fourier transforms (Cooley and Tukey, 1965), the method computes the PSD through a Fast Fourier Transform (FFT) of the original data, the instrument response is removed for obtaining accelerations, for details of calculations see McNamara and Buland, 2004. The obtained PSD are directly compared to the standard New Low and High Noise Models (NLNM and NHNM, Peterson, 1993, reported in Fig. 3). The principal application for a PDF measurement of physical data is to establish a probabilistic description for the instantaneous values of the data (Bendat and Piersol, 1971). Statistical analysis (mean, mode, median, PDFs) is performed in each station. Here we show only the Mode curves, and these represent the significant noise level, as they correspond to the highest probability power level at each frequency bin.

NI SEISMIC BACKGROUND NOISE CHARACTERIZATION

Prior to the NI network installations the sites was selected and checked for about two months of continuous recordings. Peterson analysis was used to discard the sites with high general noise levels; at the end, the quietest sites resulted those located into the caves and discarded military bunkers.
Nowadays the OGS performs the quality control of broadband data through daily inspections of the PDF plots; they are generated using the continuous data of the former day and all the 24 hours is considered. This control is useful to check the instrumental troubleshooting, gaps, spikes etc.

From Fig. 3 we can see that the power limits (mode) at high frequency varies between -110 dB and -145 dB, while at low frequency it varies between -150 db to -175 dB. For periods longer than the primary micro seismic peak (12 sec), the horizontal components are much noisier, due mainly to tilting effects associated with the physical installation settings (Bormann, 2002).

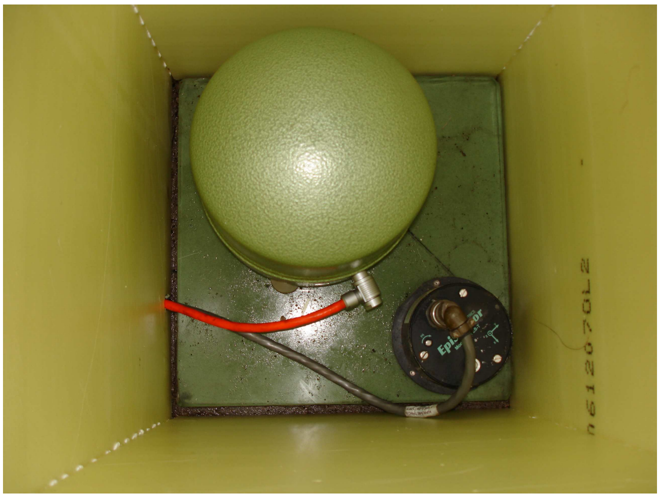

Fig 2. Broadband Streckeisen and accelerometer Episensor set in the thermic insulation box at SABO station. The box is filled with polystyrene pearls to prevent airflow.

In general all stations show seasonal variations. In winter, both during daytime and nigh time, the amplitude of the noise are higher and the dominant peak frequencies are shifted toward lower values. In summer, the amplitude is lower with a maximum at shorter periods, these variations have been also observed by Stutzmann et al. (2000) for the GEOSCOPE network, and they have been interpreted as the consequences of an increase of the intensity of storms over oceans in autumn and winter. In our case, they could be the result of the North Atlantic storms, as observed by Steiman et al. (2003) in Rhine Graben. Some differences arise for TRI station, which is set into the touristic cave of "Grotta Gigante". The summer daytime time history, shows higher noise level and the maximum peak is shifted to higher frequencies.
The noise level at all stations is contained within the limits of the Peterson model; both for day/night and summer/winter periods, the results are shown in Fig. 3. The high level noise is appreciated at coastal sites and those stations installed in the basins.

HVSR ANALYSIS

For all stations we analysed ambient vibration recordings with horizontal to vertical spectral ratio (HVSR). Significant peaks in HVSR allow us to identify the presence of underground discontinuities. A strong impedance contrast between sediment and hard bedrock is required for the formation of a significant peak in the HVSR spectral ratio. The general shape of a HVSR can be considered a fingerprint of the local structure. As it can be seen in Tab. 1, all the stations are set on rock, and deployed in caves in the mountains. We aspect to have some topographic effect for those site settled on crest and slopes and an average decrease of amplitudes with respect to the data recorded at the surface for those site settled in deep carsic caves, as observed by Amoruso et al. (1997) in the underground physics laboratories of Gran Sasso - Central Italy.
We calculated the HVSR both for ambient noise and local selected earthquakes (Fig. 4). The selected earthquakes are those recorded by the NI Italy seismic network; they are high quality data with local magnitude higher than 3.0, and recorded by all the stations.
The HVSR have been computed using the SESAME Software (WP03, 2003) and they consist in the classical polarization analysis in the frequency domain, where the polarization is defined as the ratio between the quadratic mean of the Fourier spectra of the horizontal components and the spectrum of the vertical component. For noise tests, we selected 15 minutes long window of continuous data, removing eventually non-stationary parts.
The sites in deep carsic caves (TRI and VINO) have flat response. The same can be observed at CIMO station, even though the bunker in which the station is set is not so deep. No particular amplifications are present at sites ACOM, ZOU2; the site FUSE, excluding the peak at 3-4 Hz, probably related to human activity, shows quite flat HVSR amplification. Clear peak are present at site AGOR and SABO, while sites BALD, CGRP and VARN exhibit significant amplifications at low and/or intermediate frequencies (0.7-10 Hz).
Because of the very low significant (Ml>3.0) seismicity of the last two years in this sector of the Alps, two events only have been selected for earthquake analysis: the 2011-07-04 04-44-02 UTC, M_L=3.1 (local ev. 1), and the 2010-03-07 04-27-20 UTC, M_L=3.3 (local ev. 2). A satisfactory similarity between the different tests is obtained. Flat responses are obtained at sites TRI, VINO, CIMO,

ZOU2 and FUSE; at AGOR site, the amplification peak shifts to lower frequencies; sites ACOM, VARN, BALD and CGRP record an increase of amplification, with some specific frequencies well constrained (eg. 1.5 Hz at SABO station).

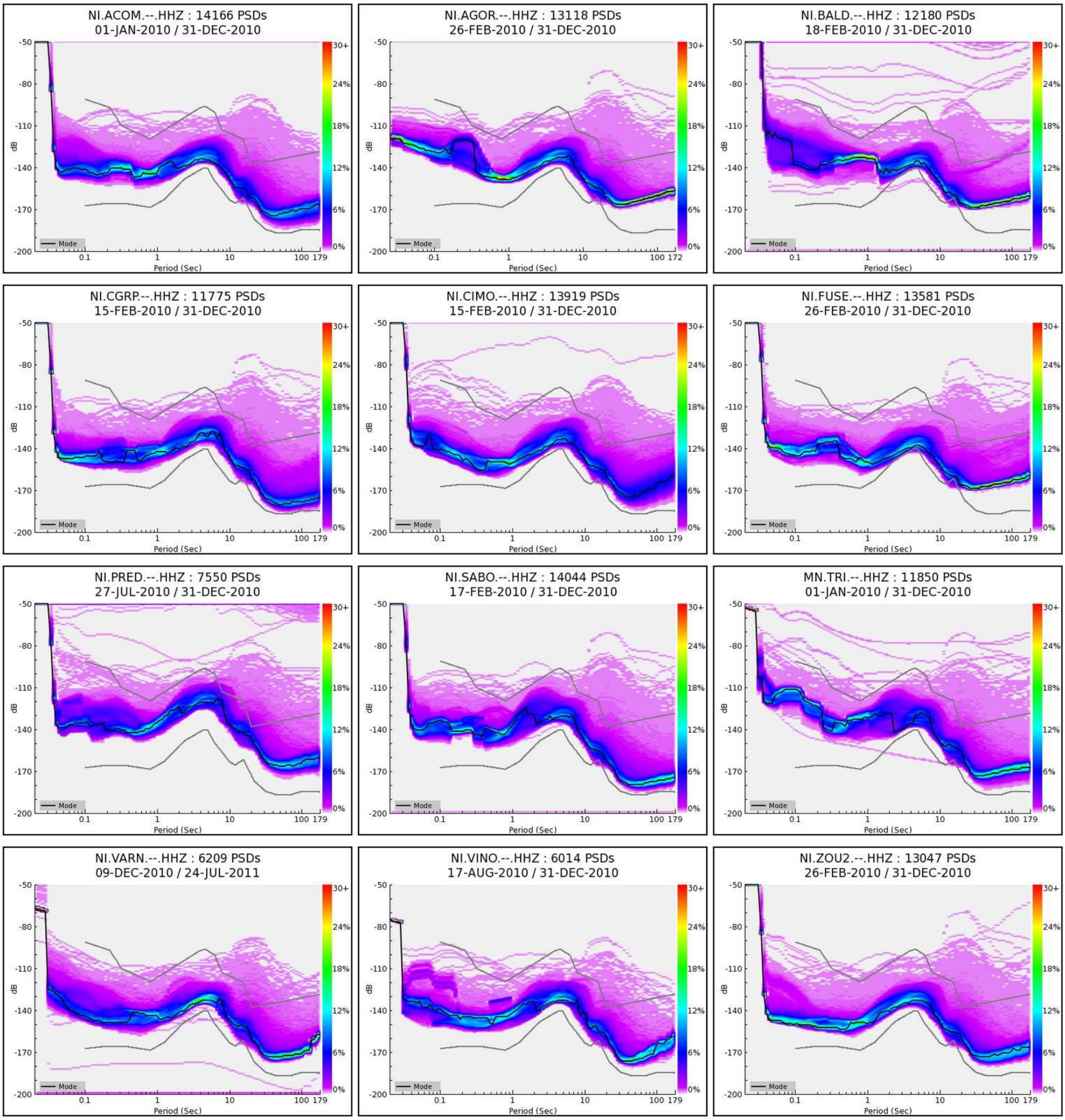

Fig.3. Probability Density Functions (PDF) during 2010 for the HHZ channels of the broadband stations that operate in the NI network. The gray lines represent the New High and New Low Noise Model (Peterson, 1993) and the black line plot indicate the highest probability power levels.

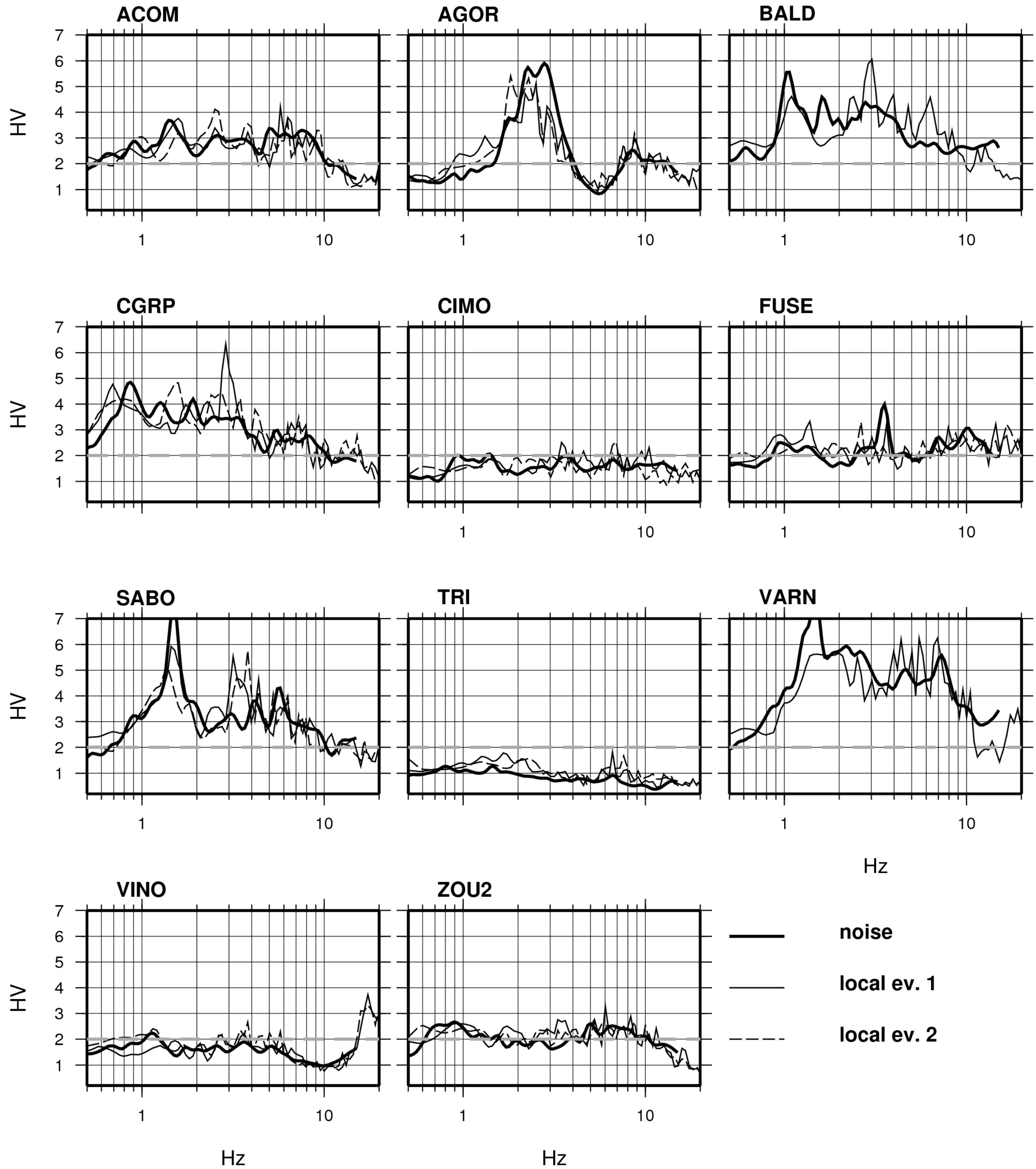

Fig.4. Horizontal to Vertical Spectral Ratio (HVSR) plots for broadband data, obtained for different test, noise represented by black line, local earthquake 1 by gray line and local earthquake 2 by gray dashed line.

CONCLUSIONS

We have presented a study on the seismic background noise spectra for the Northeastern Italy (NI) broadband seismic network. Born as a short period network in 1977, it was substantially improved and grown in the years, and since 2006 the first broadband sensors started to work. The quality of the recordings at each station has been evaluated by computing the PSD and its statistical analysis. Mode PSD levels lie between the NHNM and NLNM of Peterson (1993) for all stations; the PDF plots indicates in general the goodness and consistency of our installations, improved in the years.
Precise site classification with geotechnical information down to 30 meters deep are not existent for any site yet; however, it has been shown that pure surface geological observations are very poor in assessing the real response of the sites (e.g. Zarè et al., 1999), and HVSR is a better method to give a site classification. Considering the HVSR diagrams on noise and local events, we can observed that, although all the site are set on concrete rock, only 5 sites exhibit flat response. The other sites show some amplification, with well constrain peaks at specific frequency band and put in evidence the structural complexity of the study area.

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