# Real time acquisition and processing of strong motion data in Northern Italy: the RAIS network.

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**SUMMARY:**
This work summarizes the characteristics of a strong motion network (RAIS, in Italian: "Rete Accelerometrica in Italia Settentrionale", Strong Motion Network in Northern Italy) installed in northern Italy since 2006. The main goal of the RAIS is both to collect data with a wide range of magnitude, allowing us to increase the knowledge of the covered area, and to assure real time high quality data in case of strong events. For each recorded earthquake data are automatically processed in order to fast disseminate the most important ground motion parameters (peak ground acceleration and velocity, 5% damped acceleration, pseudo-velocity and relative response spectra, Arias and Housner intensities). Moreover, for each event, at each recording site, the Horizontal to Vertical Spectral Ratio are calculated. The analysis and metadata related to each event are collected in a web site (http://rais.mi.ingv.it) while the waveforms are distributed at different data center.

*Keywords: strong motion, seismic networks, data acquisition system, data processing, Northern Italy*

## 1. INTRODUCTION

In Italy, the national strong motion network was designed and installed, in the 1970's, by the Italian Joint Commission on seismic problems, involving ENEA (Ente Nazionale Energie Alternative) and ENEL (Ente Nazionale Energia Elettrica). This network was mainly designed to evaluate the seismic risk related to the nuclear power plants and it was the first example of a strong motion monitoring system on national scale (Gorini et al., 2010). At the end of 1997, the ENEL strong motion network, including all instruments and strong motion data, was taken over by the Italian national seismic agency, now incorporated into the Seismic Office of the Italian national emergency management department (Dipartimento della Protezione Civile, hereinafter DPC). After this acquisition, an extensive program of implementation and technological updating began; hence, the project of a permanent strong motion network started (RAN, in Italian: "Rete Accelerometrica Nazionale", Italian Strong-Motion Network). In spite of the relevant number of stations, 464 stations with GSM (272) or GPRS (192) modem links (http://www.protezionecivile.gov.it, last update 21/04/2011), RAN does not homogeneously cover the whole Italian territory. Moreover, the archived waveforms are sent to users on request (Gorini et al., 2010) and not in real time.
As is only right, the great number of RAN stations are installed in the areas characterized by high level of seismicity, such as the central and southern Apennines, the Friuli and Sicily regions. But the occurrence of the 24$^{th}$ November 2004, $M_L$ 5.2 (Mw 5.0) Salò earthquake (Augliera et al., 2006) showed us that strong motion stations are needed also in areas characterized by a low level or sporadic seismicity. In particular, this event that was one of the strongest earthquake that shocked the Northern Italy region in the last 35 years, triggered in the epicentral area only one analogue strong-motion station on the S-phase (GVD, see http://itaca.mi.ingv.it). The peak ground horizontal acceleration, recorded at 14 km epicentral distance, was 71 cm/s$^2$. The absence of others near field strong-motion stations and the saturation phenomena, involving the velocimetric sensors for distances up to 90 km, does not allow to collect other relevant data in the epicentral area. With the aim to assure high quality near-source recordings in the case of future Northern Italy earthquakes, since June 2006, the INGV

(Italian National Institute for Geophysics and Volcanology), and in particular the department of Milano-Pavia (hereinafter INGV MI), started up with the installation of a dense strong-motion network (RAIS, in Italian: "Rete Accelerometrica in Italia Settentrionale", http://rais.mi.ingv.it) in the area surrounding the 24th November 2004 epicenter (Figure 1.1).

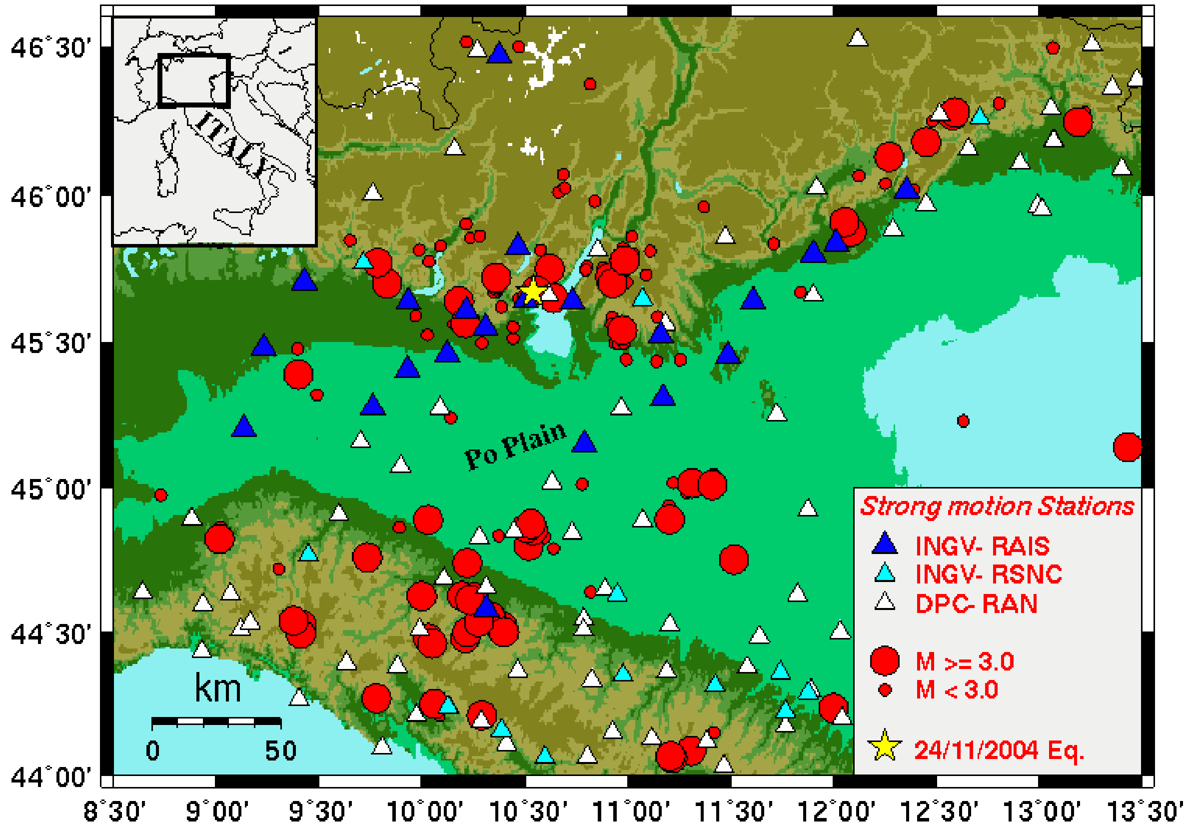


**Figure 1.1** INGV and DPC strong motion stations in Northern Italy and seismicity recorded by INGV-RAIS from June 2006 to March 2012. The yellow star indicates the 24th November 2004, $M_L$ 5.2, Salò earthquake.

The necessity of the strong-motion monitoring in this areas is moreover justified by the occurrence of some relevant historical earthquakes, such as the 1117 Mw 6.69 Verona earthquake, the 1222 Mw 5.84 Brescia earthquake, the 1695 Mw 6.48 Asolo earthquake and the 1901 Mw 5.70 Salò earthquake (CPTI11 catalogue, Rovida et al., 2011). Since 2008, the Italian National Earthquake Center of INGV (INGV-CNT) began to install accelerometric sensors in selected site where velocimetric stations of the INGV National Seismic Network (INGV-RSNC, Amato and Mele, 2008) already operated. At present RAIS forms a part of the INGV strong motion network, composed by a total of 127 stations, distributed in the whole Italian territory.

The first phase of installations, the main features of the first-generation RAIS network (mainly based on a dial-up transmission system) and the detection capability were already described in a previous paper (Augliera et al., 2010). The developments of the system with the description of the procedures for the ShakeMaps generation were discussed in a successive paper (Augliera et al., 2011).

In this paper we assess the first 6 years of installation, focusing on the last developments and the actual configuration of the network, considering site selection, acquisition system, data transmission, data processing and real-time dissemination.

## 2. RAIS: SITE CHARACTERIZATION

RAIS arose in the framework of the 2004-2006 INGV-DPC agreement. The first installation were founded by the project "Stazioni Accelerometriche" (in English "Strong-Motion stations",

http://accel.mi.ingv.it/progettoaccel/). Further developments were made thank to the 2007-2009 INGV-DPC S3 project “Fast evaluation of the parameters and effect of strong earthquake in Italy and in the Mediterranean areas”.
The main goals of the “Stazioni Accelerometriche” project were to improve the earthquake detection in the central area of North Italy and to provide high-quality records in the case of strong events. The first phase of this project concerned the selection of sites suitable for seismic installations. In this way three main aspects were considered: the spatial coverage of others networks operating in the same region, the distribution of the epicenters related to the events occurred in the area in the last 30 years and the municipalities characterized by the highest values of seismic hazard (Gruppo di Lavoro MPS04, http://esse1.mi.ingv.it/), in terms of maximum expected peak ground horizontal acceleration with 10% probability of exceedance in the next 50 years (return period of 475 years).
In Figure 1.1 only RAIS, INGV-RSNC (the Italian National Earthquake Center strong motion station, managed by INGV-CNT) and DPC-RAN stations are reported. However others network like RAF (Friuli Venezia Giulia Accelerometric Network), RSFVG and RSV (the short-period seismometric regional networks of Friuli Venezia Giulia and of Veneto, managed by Centro di Ricerche Sismologiche of the OGS), RSNWI (the Regional Seismic Network of Northwestern Italy, managed by Dip.Te.Ris., Genoa University) operate in this area.
For each RAIS installation site, the final selection represented generally a compromise between the network geometry, which depends on the monitoring purposes, and the characteristics that a given site presents in order to be suitable for installation. Considering the high degree of urbanization and industrialization of North Italy regions, all installations were preceded by microtremors analysis (Nakamura, 1989). Taking into account that a low level of noise (Peterson, 1993) is difficult to achieve in the considered area, the measures was carried out in particular with the aim to avoid very unfavorable situations. For each site horizontal to vertical spectral ratio (HVSR) and probability density functions of the noise power spectra (McNamara and Buland, 2004) were computed by following the procedure presented in Marzorati and Bindi (2006). At present all site where a RAIS station is installed are characterized both from a geological and a geophysical point of view: concerning geology, all information come from the 1:25.000 geological maps provided by Lombardia region (CARG project, 2003) or the 1:100.000 Italian geological maps (SGI, 1984), while from a geophysical point of view, for each site an averaged horizontal to vertical spectral ratio is available considering the earthquake recordings from June 2006. For each recorded waveform an automatic procedure allows to update step by step the actual averaged amplification function calculated for a single site. Finally, for each station installed inside building (e.g. ASOL, BAG8, see Tab. 3.1) careful study about soil-structure interactions are summarized in Massa et al., 2010. It is worth noting as high quality strong-motion data represent the input for each advanced structural analyses that combine ground-motion records with detailed structural models.

## 3. RAIS: INSTRUMENTATION AND DATA PROCESSING

At present the RAIS network is composed by 22 stations (Table 3.1): the strong motion sensors are Episensors FBA ES-T (http//:www.kinemetrics.com) characterized by a dynamic range of 155 dB. Generally the full-scale is set to ±2.0 g (except for MILN at ±1.0 g) . In each site the accelerometer is housed in ad-hoc built concrete basement and anchored to it. Close to the concrete basement a plastic-box, 80 cm long, 60 cm wide and 40 cm high is located. The box contains the digital recorder, a router for data transmission (TCP/IP protocol) and a stabilized power supply connected to a 12V battery in order to avoid possible lacking of electricity. The time synchronization of the recorded signal is assured by a GPS antenna installed near the station. At present the network is characterized by 2 different type of digital recorders: 10 strong-motion sensors are coupled with 24 bits Reftek 130-01 (http://www.reftek.com) while the other 12 sensors are coupled with 24 bits GAIA-2 (Rao et al., 2010), a digital recorder designed and produced directly by the laboratory of the Italian National Earthquake Center (INGV-CNT).
At present all stations record signals in-continuous-mode with a sampling frequency of 100 Hz. The processing of the recorded strong-motion data included the following steps: removal of the mean and linear trends, 5% cosine tapering, application of an acausal 4-pole Butterworth band-pass filter

between 0.2 Hz and 25 Hz. For each event, the Fourier spectra were computed considering different time windows (5 s and 10 s starting 0.5 s before the S-phase onset). To investigate the differences between differently polarized horizontal components, directional spectral ratios were obtained by applying different rotation angles (Augliera et al., 2011). Finally, taking into account both the geological and geophysical remarks, all stations were classified following the provision of the Italian seismic code for building (NTC, 2008).

**Table 3.1.** Main features of RAIS strong-motion stations

| Code | Latitude (N) | Longitude (E) | Elevation (m) | Site Class | Since | Real Time from | Recording System |
|---|---|---|---|---|---|---|---|
| MERA | 45.672 | 9.418 | 350 | B | 25/10/2005 | 25/03/2009 | Gaia2 |
| MILN | 45.480 | 9.232 | 125 | C | 01/06/2006 | 22/04/2009 | Gaia2 |
| EUCT | 45.201 | 9.135 | 82 | C | 26/06/2006 | 31/07/2009 | Gaia2 |
| OPPE | 45.308 | 11.172 | 20 | C | 24/09/2009 | 24/09/2009 | Gaia2 |
| MNTV | 45.149 | 10.790 | 36 | C | 29/07/2009 | 15/10/2009 | Gaia2 |
| CNCS | 45.606 | 10.217 | 126 | B | 03/05/2006 | 22/10/2009 | Gaia2 |
| BOTT | 45.549 | 10.395 | 200 | A | 27/10/2009 | 27/10/2009 | Gaia2 |
| CTL8 | 45.276 | 9.762 | 60 | C | 22/07/2009 | 22/01/2010 | Gaia2 |
| BAG8 | 45.823 | 10.466 | 807 | A | 15/06/2006 | 24/02/2010 | Gaia2 |
| ZEN8 | 45.638 | 10.732 | 596 | A | 30/06/2006 | 03/03/2010 | Gaia2 |
| CAPR | 45.637 | 9.934 | 215 | B | 31/05/2006 | 15/03/2010 | Reftek |
| ORZI | 45.406 | 9.931 | 83 | C | 24/04/2008 | 15/03/2010 | Reftek |
| LEOD | 45.458 | 10.123 | 92 | C | 18/07/2007 | 15/03/2010 | Reftek |
| FRE8 | 46.015 | 12.355 | 543 | A | 31/03/2011 | 31/03/2011 | Reftek |
| VOBA | 45.643 | 10.504 | 292 | B | 28/06/2006 | 08/04/2011 | Reftek |
| SANR | 45.640 | 11.610 | 51 | C | 19/12/2007 | 07/09/2011 | Reftek |
| ZOVE | 45.454 | 11.488 | 376 | A | 28/06/2007 | 07/09/2011 | Reftek |
| TREG | 45.523 | 11.161 | 342 | C | 07/09/2011 | 07/09/2011 | Gaia2 |
| BORM | 46.469 | 10.376 | 1235 | A | 29/11/2006 | 15/09/2011 | Gaia2 |
| CRND | 45.836 | 12.013 | 159 | B | 04/11/2011 | 04/11/2011 | Reftek |
| ASOL | 45.800 | 11.902 | 181 | A | 17/11/2011 | 17/11/2011 | Reftek |
| NEVI | 44.581 | 10.313 | 522 | A | 23/12/2008 | 11/04/2012 | Reftek |

## 4. RAIS: ACQUISITION SYSTEM AND DATA TRANSMISSION

After a first test phase during which only local recordings were obtained, since June 2006 until the end of 2008, the installed Episensors were equipped with 20 bits Lennartz Mars88 Modem Control (http://www.lennartz-electronic.de/) or 24 bits Reftek 130 digital recorders. In both cases the remote stations sent data to the INGV MI acquisition center via GSM modems. The GSM data transmission and Mars88 Modem Control digital recorder (without a TCP/IP support) represented in the first period a relevant technological limitation, that prevented the continuous mode data transmission and forced us to disseminate data with a time-delay of the order of hours. This acquisition system, of consequence, did not allow real-time waveforms metadata of the engineering interest, that actually represents one of the main goal for a strong-motion network. Since 2009, many efforts were made to replace the GSM stations with a system able to record in continuous mode and to transmit data in real-time. The technological evolution of the network leads to the replacement of the Mars88 Modem Control digital recorder with only 24 bits digital recorders (Reftek 130 and Gaia2). At the same time the replacement of the GSM technology with TCP-IP connections started.
At present all stations are connected to the acquisition center of Milan in real-time via SeedLink protocol, a robust data transmission system intended for use on the Internet or private circuits that support TCP/IP (Hanka et al., 2000). The protocol is robust in that clients may disconnect and reconnect without losing data, as the transmission is started where it ended. Requested data streams may be limited to specific networks, stations, locations and/or channels. All data packets are 512-byte Mini-SEED records. The data, previously recorded in binary format (both Reftek or Lennartz formats) and then stored in SAC format, are now acquired in MiniSEED format. We use the SeedLink system

for real time communication using TCP/IP protocol and a SeisComP platform (Hanka et al, 2000) for disk recording and station management. Acquisition and analysis are performed on a HP-Proliant Server DL380G7 (Dual Quad-Core processors, with 6 GB RAM and 3 TB disk space, running with Debian 6.0 operating system). For earthquake data acquisition a procedure for automatic download of waveforms was developed. The locations are provided by the Italian National Earthquake Center (INGV-CNT, http://cnt.rm.ingv.it) and any new event location represents a warning for the RAIS download automatic system. In particular every five minutes the file of event locations (revised by the seismologist which is in charge for the seismic surveillance activity in Rome) is automatically downloaded. Every time a new event is present in the earthquake list, the theoretic spectral amplitude of the earthquake is compared (in a fixed frequency band) with the average noise levels for each station of the network and the corresponding waveforms are downloaded if the theoretical signal to noise ratio exceeds a fixed threshold for at least 3 stations. The synthetic spectrum is computed by considering the omega-square source model (Brune, 1970) and the source spectrum is propagated to each station considering the 1/R geometrical spreading term. In order to avoid data loss the procedure is intentionally conservative (Augliera et al., 2010). At the end of the process the RAIS waveforms are available in our acquisition center and ready to be processed by the automatic system (Figure 4.1).

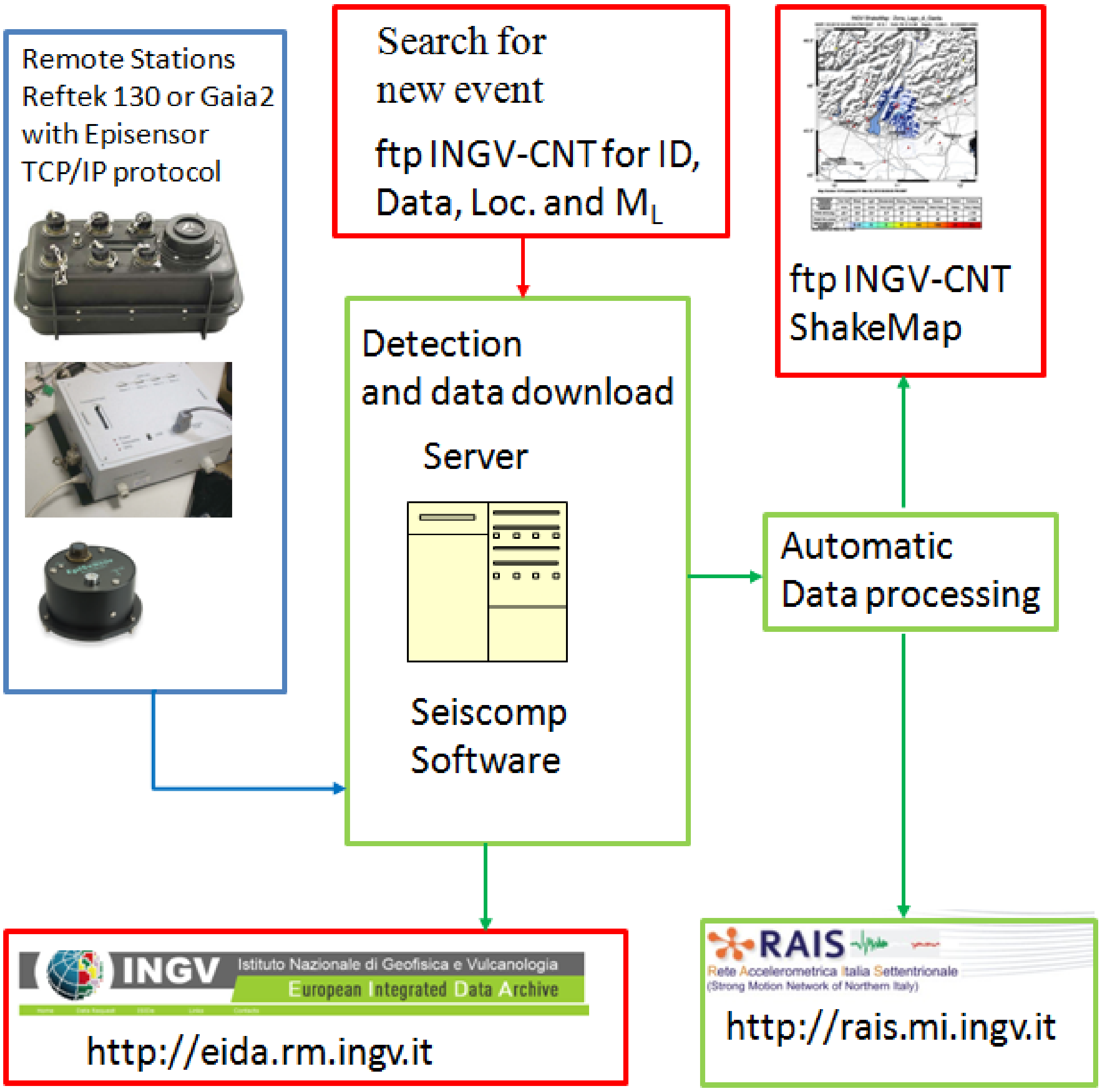


**Figure 4.1** Flow chart representing the RAIS acquisition system, data processing and transmission.

## 5. RAIS: DATA PROCESSING AND DISSEMINATION

The last step is represented by the data processing and their dissemination. The analyses on recorded data are made using codes ad-hoc, developed both in fortran77 and C languages and in bash-script. Each strong-motion waveform is processed using a procedure (Massa et al., 2010b) that include the baseline correction, performed by a least square regression, the mean removal considering the whole signal, the application of a cosine-taper function (usually 5%) and a filtering performed by an acausal 4th order Butterworth digital filter. At first the filtering is automatically applied in the range 0.2–30 Hz, but then manually revised considering the magnitude of the event. For all processed waveforms PGA (peak ground acceleration) and SA (acceleration response spectra, 5% damped) for periods up to 4 s are calculated. Moreover the automatic system provides also PSV (pseudo-velocity response spectra), Sd (displacement response spectra), IA (Arias Intensity; Arias, 1970) and IH (Housner intensity; Housner, 1952) values. Finally, after the integration of acceleration time series, also the peak ground velocity (PGV) is calculated.

In order to fast evaluate the site response, for each recorded event, the HVSR (Horizontal to Vertical Spectral Ratio) at each single site is calculated considering both 5 s and 10 s of S phase. All performed analysis, together the earthquakes and waveforms metadata are collected in the RAIS web site (http://rais.mi.ingv.it). The waveforms for each event with ML equal or higher than 2.5 are included in the ITalian ACcelerometric Archive (ITACA) and downloadable at the web site http://itaca.mi.ingv.it.

Moreover, since 2009, for each event with ML higher or equal than 3.0, PGA, PGV and SA (for periods of 0.3 s, 1.0 s and 3.0 s) are sent to INGV-CNT acquisition centre of Rome, where they are merged with the ground motion parameters provided by others network in order to improve the ShakeMaps calculation (http://earthquake.rm.ingv.it/shakemap/shake/) for Northern Italy events (Fig. 4.1).

ShakeMaps are a very useful tool in the first minutes to hours after an earthquake has occurred, but their relevance progressively decreases as information about actual damage becomes available. For this reason it is fundamental to have data in real-time. At INGV MI we have installed this package, developed by the U.S. Geological Survey (USGS) Earthquake Hazards Program (Wald et al, 2006) and we use this tool in agreement with the procedures developed by INGV-CNT for the ShakeMap implementation in Italy (Michelini et al., 2008). A dense and uniform spatial distribution of stations in the field is essential to produce reliable ShakeMaps (Douglas, 2007; Moratto et al., 2009) minimizing the uncertainties associated with ground motion prediction equations (Wald et al,. 2008).

In order to appreciate the role of RAIS in the ShakeMaps calculation, an example is reported in Augliera et al., 2011 for the 14th July 2008 ML 3.5 earthquake (occurred near 2004 Salò epicenter), by considering the same Shakemap generated with and without RAIS stations.

The results shows that the ground motion prediction equation implemented in the INGV-CNT Shakemaps package for the area under study (Morasca et al., 2006) tends to underestimate the ground shaking in near source and overestimate the same one in far field. This evidence points out both the importance of real data availability and, at the same time, the influence of regional variability in the calibration of empirical predictive models (e.g. Massa et al., 2008, Bindi et al., 2010).

Concerning data dissemination, another improvement has been achieved on November 2011. From then on, RAIS seismic waveforms, recorded in continuous mode, are sent in real time to the European Integrated Data Archive (EIDA, http://eida.rm.ingv.it). In this seismological data portal waveform broad band and strong motion data from European seismic stations are available from INGV and many others European Institutions, using ArcLink, a data exchange protocol developed by Helmholtz Centre Potsdam (GFZ, German Research Centre for Geosciences).

## 6. 2006-2012 RAIS DATA SET

In the period June 2006-March 2012 the RAIS network allowed us to collect a relevant strong motion data set, in term both of number of earthquakes and quality data (Fig. 6.1), for an area (North Italy) characterized by a low seismicity level. After 6 years of recordings, in the acquisition centre of Milan, are stored 200 events (about 4300 3-components waveforms) with $M_L$ ranging from 0.7 to 5.4 (the 27$^{th}$ January 2012 Frignano earthquake, Massa et al., 2012). Considering the events recorded in the distance range 5-300 km, as shown in Fig. 6.1 (bottom panel), in general the highest number of recorded events are included in the magnitude range 2.0-4.0. In this range the records homogeneously cover the hypocentral distance between 10 and 220 km. It is worth noting that the recordings with magnitude lower than 2.0 are related to stations located in A ($Vs_{30}$ > 800 m/s) and B ( 360 <$Vs_{30}$ < 800 m/s) lithological classes, as described in the Italian seismic code for building (NTC, 2008). The stations classified in A or B categories are generally installed on reliefs bordering the Po plain, in general characterized by a lower level of background noise if compared to those detectable for RAIS stations installed in the central part of the plain (classified in C class of NTC, 160 <$Vs_{30}$ < 360 m/s).

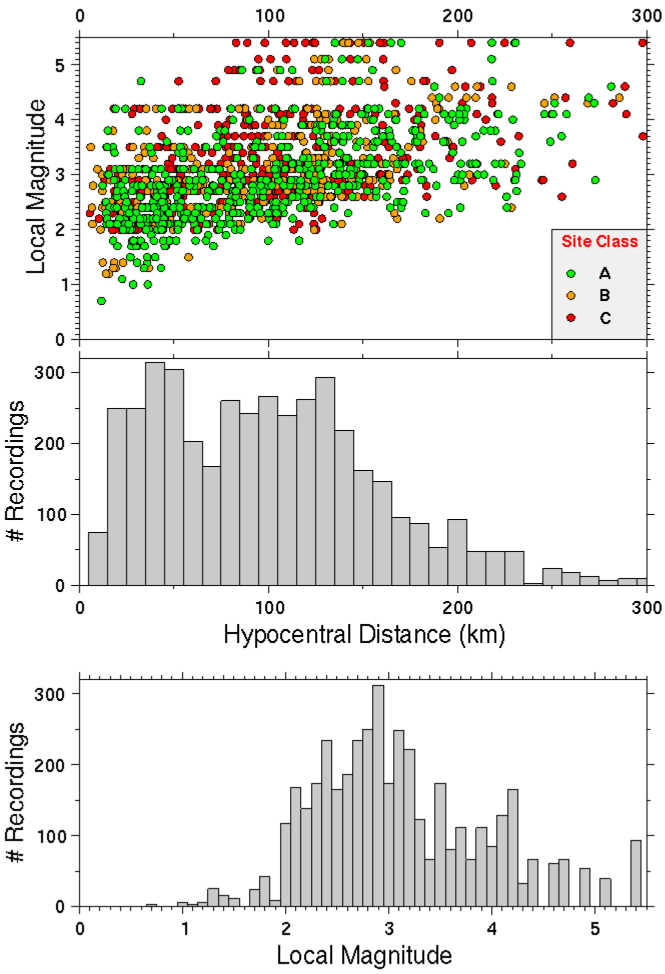


**Figure 6.1.** June 2006 - March 2012 RAIS data set. Top: local magnitude versus hypocentral distance for different NTC (2008) lithological classes (A: 43%, B: 25%, C: 32%); number of waveforms versus hypocentral distance (centre); number of waveforms versus local magnitude (bottom).

In Fig. 6.2, PGA versus hypocentral distance are shown for events with $M_L$ higher (red) and lower (grey) then 3.0. It is possible to observe the presence of anomalous peaks for hypocentral distances closed around 100 km. This phenomenon is due, as demonstrated in Castro et al. (2008) and Bragato et al. (2011) to the meaningful contribution of the Moho S-waves reflection that occur in the East region of the Po Plain even if it is not possible to exclude the contribution of local site effects, in particular for stations installed in sites classified in C category, see Table 3.1.
Concerning the recorded accelerations, the highest PGA value (69 cm/s$^2$) was recorded at NEVI station (Tab. 3.1) for the 23$^{th}$ December 2008, Mw 4.9 Parma event. Focusing on weak motion (local magnitude in general lower than 4.0), that represent the higher percentage of events that occurred in the area, it is worth noting as the VOBA station (Tab. 3.1) recorded a PGA value of 33 cm/s$^2$ during the 14$^{th}$ July 2008 $M_L$ 3.5 earthquake.

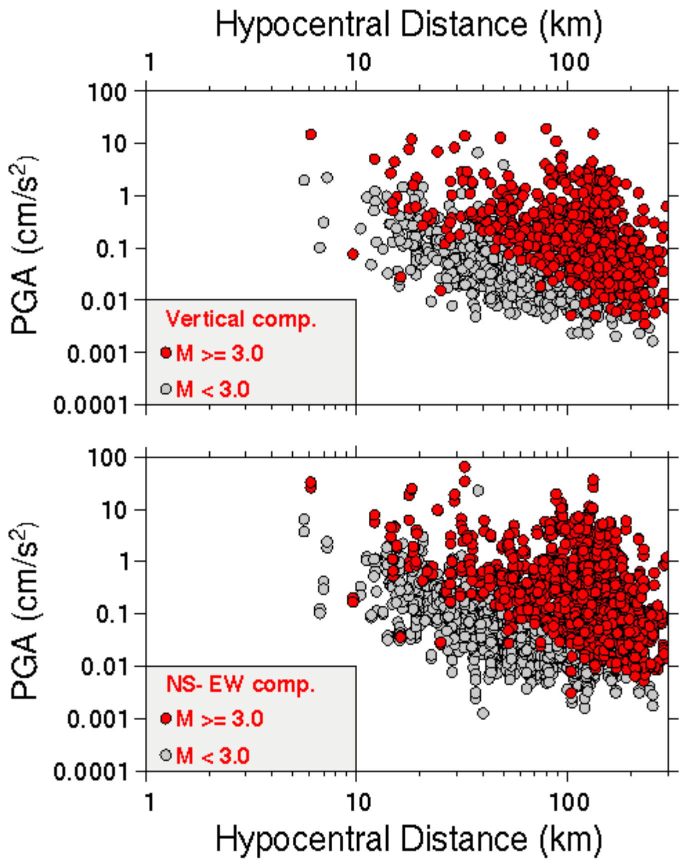


**Figure 6.2.** - June 2006 - March 2012 RAIS data set. On the top, peak ground acceleration for vertical components. On the bottom, peak ground acceleration for horizontal (North-South and East-West) components.

To strengthen the benefit produced by the RAIS network on the strong-motion monitoring of the area under study, in Augliera et al. (2010) a theoretical example was made considering some of the strongest historical events (CPTI11 catalogue, Rovida et al., 2011) occurred in Northern Italy regions. In the case of a "re-occurrence", the 12$^{th}$ May 1802, Maw 5.64, Oglio Valley earthquake (maximum macroseismic Intensity, Imax of VIII MCS degrees) currently would have been recorded by 5 strong-motion stations (4 belonging to RAIS) in the first 30 km. Similarly, the 7$^{th}$ June 1891, Mw 5.86, Illasi Valley earthquake (Imax IX MCS) and the 19$^{th}$ February 1932, Mw 5.08, Mount Baldo earthquake (Imax VIII MCS) currently would have been recorded in the first 30 km by 7 stations (6 belonging to RAIS) and 12 stations (7 belonging to RAIS), respectively (for a detailed explanation see Augliera et al., 2010). In particular, considering a hypothetical “twin event” of the 24$^{th}$ November 2004, $M_L$ 5.2 Salò earthquake (yellow star in Figure 1.1), it is possible to suppose that it would be recorded by at least 11 strong-motion stations (6 belonging to RAIS) in the first 30 km.

## REFERENCES

Amato, A. and Mele, F. (2008). Performance of the INGV National Seismic Network from 1997 to 2007, *Annals Of Geophysics* **51:2/3**, 417-431.

Arias, A. (1970). A measure of earthquake intensity, in Seismic Design of Nuclear Power Plants, R. Hansen (Editor), M.I.T. press, Cambridge.

Augliera, P., D’Alema, E., Marzorati, S., Massa, M., De Gori, P. and Marchetti, A. (2006). 2004 Garda dataset: data processing, installation of seismic stations, Convenzione ProCiv-INGV 2004-2006 - Progetto DPC-S3: scenari di scuotimento in aree di interesse prioritario e/o strategico, DPC-S3: Deliverable12, DVD, (in

Italian).
Augliera, P., D’Alema, E., Marzorati, S. and Massa, M. (2010). A strong motion network in Northern Italy: detection capabilities and first analyses, *Bulletin of Earthquake Engineering* **8:5**, 1091-1104.
Augliera, P., Massa, M., D'Alema, E. and Marzorati, S. (2011). RAIS: a real time strong-motion network in northern Italy. *Annals Of Geophysics* **54:1**, 23-34.
Bindi, D., Luzi, L., Massa, M. and Pacor F. (2010). Horizontal and vertical ground motion prediction equations derived from the Italian Accelerometric Archive (ITACA). *Bulletin of Earthquake Engineering* **8:5**, 1209-1230.
Bragato, P. L., Sugan, M., Augliera, P., Massa, M., Vuan, A. and A. Saraò (2011). Moho Reflection Effects in the Po Plain (Northern Italy) Observed from Instrumental and Intensity Data. *Bulletin of the Seismological Society of America*, **101:5**, 2142-2152.
Brune, J.N. (1970). Tectonic stress and the spectra of seismic shear waves from earthquakes. *J. Geophys. Res.*, **75**, 4997-5009.
CARG Project (2003). Progetto di cartografia geoambientale (Regione Lombardia) alla scala 1:25000, Rel. 1.0. Base cartografica CTR 1:10000. Cd-Rom (in italian).
Castro, R.R., Massa, M., Augliera, P. and Pacor, F. (2008). Body wave attenuation in the region of Garda, Italy. *Pure and Applied Geophysics* **165**, 1351-1366.
Douglas, J. (2007). Inferred ground motion on Guadaloupe during the 2004 Les Saintes earthquake, *Bull. Earthquake Eng.* **5**, 363-376.
Gorini, A., Nicoletti, M., Marsan, P., Bianconi, R., De Nardis, R., Filippi, L., Marcucci, S., Palma, F. and Zambonelli, E. (2010). The Italian strong motion network, *Bulletin of Earthquake Engineering* **8:5**, 1075-1090.
Gruppo di Lavoro MPS04 (2004). Redazione della mappa di pericolosità sismica prevista dall’ordinanza PCM 3274 del 20 Marzo 2003, Rapporto conclusivo per il Dipartimento della Protezione Civile, INGV, Milano-Roma, 65 pp. (in italian).
Hanka, W.A., Heinloo, A. and Jäckel, K.-H. (2000). Networked Seismographs: GEOFON Real-Time data distribution, *ORFEUS Electronic Newsletter* **2:3**, http://www.orpheus-eu.org.
Housner, G.W. (1952). Spectrum intensities of strong-motion earthquakes, in: Proc. Symp. on Earthquake and Blast Effects Structures, C. M. Feigen (editors), Univ. California, Los Angeles, 21-36.
McNamara, D.E. and Buland, R.P. (2004). Ambient noise levels in Continental United States, *Bull. Seism. Soc. Am.* **94**, 1517-1527.
Marzorati, S. and Bindi, D. (2006). Ambient noise levels in North-central Italy, *Geochem. Geophys. Geosyst.* **7**, Q09010.
Massa, M., Morasca, P., Moratto, L., Marzorati, S., Costa, G. and Spallarossa, D. (2008). Empirical ground motion prediction equations for Northern Italy using weak and strong motion amplitudes, frequency content and duration parameters, *Bulletin Seismological Society of America* **98:3**, 1319-1342.
Massa, M., Marzorati, S., Ladina, C. and Lovati, S. (2010). Urban seismic stations: soil-structure interaction assessment by spectral ration analyses, *Bulletin of Earthquake Engineering* **8**, 723-738.
Massa, M., Pacor, F., Luzi, L., Bindi, D., Milana, G., Sabetta, F., Gorini, A. and Marcocci, C. (2010b). The Italian Accelerometric Archive (ITACA): processing of strong motion data, *Bulletin of Earthquake Engineering* **8:5**, 1175-1187.
Massa, M., Ameri, G., Lovati, S., Puglia, R., Franceschina, G., Pacor, F., Luzi, L. and Augliera, P. (2012). What can we learn from the January 2012 northern Italy earthquakes?. *Annals Of Geophysics* **55:1,** 1-3.
Michelini, A., Faenza, L., Lauciani, V. and Malagnini, L. (2008). ShakeMap implementation in Italy, *Seismological Research Letters* **79**, 688-697.
Morasca, P., Malagnini, L., Akinci, A., Spallarossa, D. and Herrmann, R. B. (2006). Ground-motion scaling in the western Alps. *Journal of Seismology* **10**, 315–333.
Moratto, L., Costa, G. and Suhadolc, P. (2009). Real-time generation of ShakeMaps in the Southeastern Alps, *Bull. Seism. Soc. Am.* **4**, 2489-2501.
Nakamura, Y. (1989). A method for dynamic characteristics estimations of subsurface using microtremors on the ground surface, *Quarterly Rept. RTRI Japan* **30**, 25-33.
NTC (Nuove Norme Tecniche per le Costruzioni) (2008). Part 3: Categorie di sottosuolo e condizioni topografiche, *Gazzetta Ufficiale* **29** del 4 febbraio 2008 (in italian)
Peterson, J. (1993). Observation and modeling of background seismic noise, *U.S. Geological Survey Open File Report* **93-322**, USGS, Albuquerque, New Mexico.
Rao, S., Salvaterra, L. and Acerra, C. (2010). Software per l'installazione e la configurazione della stazione sismica GAIA2, *Rapporti Tecnici INGV* **130**, 1-52 (in italian).
Rovida, A., Camassi, R., Gasperini, P. and Stucchi, M. (eds.), 2011. CPTI11, the 2011 version of the Parametric Catalogue of Italian Earthquakes. Milano, Bologna, *http://emidius.mi.ingv.it/CPTI*
SGI (Società Geologica Italiana) (1984). Carta geologica d'Italia 1:100000. Base cartografica IGM 1:25000.

Wald, D.J., Quitoriano, V., Heaton, T.H. and Kanamori, H. (2008). Quantifying and Qualifying USGS ShakeMap Uncertainty, *U.S. Geological Survey Open File Report* **2008–1238**.

Wald, D.J., Worden, C.B., Quitoriano, V. and Pankow, K.L. (2006). ShakeMap Manual, Technical Manual, Users Guide, and Software Guide, http://pubs.usgs.gov/tm/2005/12A01/pdf/508TM12-A1.pdf