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2012 EMILIA EARTHQUAKES

**Rapid response to the earthquake emergency of May 2012
in the Po Plain, northern Italy**

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1. Introduction

Rapid-response seismic networks are an important element in the response to seismic crises. They temporarily improve the detection performance of permanent monitoring systems during seismic sequences. The improvement in earthquake detection and location capabilities can be important for decision makers to assess the current situation, and can provide invaluable data for scientific studies related to hazard, tectonics and earthquake physics. Aftershocks and the clustering of the locations of seismic events help to characterize the dimensions of the causative fault. Knowing the number, size and timing of the aftershocks or the clustering seismic events can help in the foreseeing of the characteristics of future seismic sequences in the same tectonic environment.

Instrumental rapid response requires a high degree of preparedness. A mission in response to a magnitude (M_L) 6 event with a rupture length of a few tens of kilometers might involve the deployment within hours to days of 30-50 seismic stations in the middle of a disaster area of some hundreds of square kilometers, and the installation of an operational center to help in the logistics and communications. When an earthquake strikes in a populated area, which is almost always the case in Italy, driving the relevant seismic response is more difficult. Temporary station sites are chosen such as to optimize the network geometry for earthquake locations and source study purposes. Stations have to be installed in quiet, but easily reachable, sites, and for real-time data transmission, the sites might need to have optical inter-visibility. The operational center can remain in a town if there is one within the damaged area, and it should coordinate the actions of the field teams and provide information to colleagues, the Civil Protection Authorities and the general public. The emergency system should operate as long as the seismic rate remains high; the duration of any mission might also depend on the seismic history of the area involved. This study describes the seismic response following the May 20, 2012, M_L 5.9 earthquake in northern Italy, which included rapid deployment of seismological stations in the field for real-time seismic monitoring purposes, the coordination of further instrumental set-ups according to the spatial evolution of the seismic sequence, and data archiving.

2. The INGV rapid response system

Since 1990, the Istituto Nazionale di Geofisica e Vulcanologia (INGV; National Institute of Geophysics and Volcanology) has had an emergency structure ready to face the occurrence of damaging earthquakes. Temporary seismic networks have been usually deployed for $M_L \geq 5.0$ crustal earthquakes that have occurred in the Italian territory; these have been important monitoring and scientific tools to better understand the last major seismic sequences (e.g., Carlentini in 1990, Umbria-Marche in 1997-1998, Forlì in 2000 and Molise in 2002). In 2008, a new emergency structure was



Figure 1. INGV centers in the Italian territory. Differently colored stars, availability of both personnel and instruments or personnel only for emergency network deployments; white stars, other Italian Institutes that generally deploy temporary stations (e.g., Prato Ricerche, OGS and Genova University).

co-founded with the Civil Protection Department (DPC; Dipartimento di Protezione Civile; see 2012-2021 decennial Agreement between the DPC and the INGV; <http://istituto.ingv.it/l-ingv/progetti/allegati-convenzioni-dpc/accordo-quadro-2012-2021>). This was tested for the first time during a regional seismic emergency simulation that was organized by the Civil Protection of the Marche Regione. This structure is composed of three operational units: (i) a real-time temporary seismic network; (ii) a stand-alone temporary seismic network; and (iii) the Seismic Emergency Operational Centre (COES; Centro Operativo Emergenza Sismica) [Govoni et al. 2008]. The COES is the INGV facility that is devoted to seismic emergency management in an epicentral area [Moretti et al. 2010a]: it is a mobile office equipped with satellite internet communication that can be rapidly installed in a disaster area. The COES supports the INGV staff operative needs, and helps in the coordination with other national and international Institutes. It cooperates with the DPC by providing updated information 24 hours a day, which contributes to the decision-making stages during an emergency. Furthermore, the COES serves as a reference information center for all of the people involved in the crisis management, and thus provides important practical, and also psychological, support [La Longa and Crescimbeni 2010] to the rescuers and to the population affected by an earthquake.

The experience of the L'Aquila earthquake in 2009

taught us that coordination between national and international Institutes in the deploying of seismic stations is fundamental to optimize material, human and management resources and scientific results [Margheriti et al. 2011, Chiarluce et al. 2011].

Today the INGV structure for rapid response to seismic emergency [Moretti et al. 2010b] is based on the one that operated during the L'Aquila earthquake, but with an increased number of temporary seismic networks. The different sets of temporary seismic stations (networks) that belong to different INGV centers can either be independently deployed or coordinated into a unique network. This integrated seismic network is composed of: 1. Real-time stations equipped with both radio-satellite (Re.Mo.Tel.) [Abruzzese et al. 2011] and universal mobile telecommunications system transmission (Re.Mo.-UMTS), which then become part of the National Seismic Network (RSN; Rete Sismico Nazionale) [Amato and Mele 2008]. This ensures substantial improvements in the real-time monitoring systems. 2. Standalone recording stations (Re.Mo.-STANDALONE and EMERSITO) [Bordoni et al. 2012, this volume] that guarantee the acquisition of high resolution data devoted to the improvement of our scientific knowledge (e.g., seismic hazard, seismotectonics, earthquake physics, site response, wave propagation studies).

The INGV seismic stations and the people involved in the emergency deployment are distributed in different centres in the Italian territory (Figure 1: Ancona, Arezzo, Bologna, Catania, Gibilmanna, Irpinia, Milan, Naples, Pisa and Rome). In the last year, an internal INGV project was launched, named as 'Sismiko', to coordinate the activities during these emergencies and to establish common procedures for station deployment, network maintenance and data archiving. After the emergency alarm to all Sismiko participants, the deployment is coordinated by one central office that designs the possible network geometry and assigns the installation sites to the different groups in the field, according to the instrument availability and the achievable group reaction time. Station installation and maintenance can be performed by teams composed of staff coming from different centers, to guarantee knowledge of the area, and of the instruments and their interchangeability. The data are archived in Standard for the Exchange of Earthquake Data (SEED) format, and need to be available to the scientific community as soon as possible (they can be restricted up to 3 years duration for specific projects). In the case of the May-June 2012 Emilia seismic sequence, the Sismiko effort resulted in a much faster reaction than in the past for all of the INGV components, and in an easier management of the intervention.

At the European level, within the framework of the 'Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation (NERA)' European project, a European Rapid Response Network (ERN) is being developed [Margheriti et al. 2011]. Four European Institutes (INGV, Italy;



Figure 2. Photographs of the seismic deployments in the Po Plain, showing the standalone recording stations and the stations connected in real-time to the seismic monitoring center in Rome. Top to bottom: the seismic stations (digitizer, GPS, battery and cables) are transported and installed inside a plastic case. The case is covered by a tarpaulin and a sign explains the instrument scope and gives contact information. Most of the stations are powered with solar panels; the sensor is buried inside a plastic bag close to the station. Stations transmitting data in real-time are equipped with antennas.

GFZ, German Research Centre for Geosciences, Germany; ETH, Eidgenössische Technische Hochschule, Switzerland; CNRS, Centre National de la Recherche Scientifique, France) are combining their efforts under the one umbrella, to set up a common European framework for the coordination of future post-seismic initiatives. This on-going project has facilitated the exchange of information at the European level (http://www.nera-eu.org/content/mm_files/do_798/NERA-WP4-Webpage-Update.pdf), and the coordination of station deployment with European colleagues during the May-June 2012 Emilia seismic sequence.

3. The Emilia seismic sequence and the rapid response timing

At 02:03 UTC (04:03 local time) on Sunday, May 20, 2012, an earthquake of M_L 5.9 hit northern Italy (44.89°N, 11.23°E, 6.3 km in depth) which resulted in casualties and severe damage to the historical buildings and to the economical activities of the region. In the following 72 hours (May 20-22, 2012) the RSN located about 300 events, 68 of which had $M_L \geq 3.0$ (including 13 events with $M_L \geq 4.0$) (data source: 2005-2012 ISIDe-Italian seismological instrumental and parametric data-base) [Mele et al. 2011]. After few minutes, the mainshock was followed by a M_L 5.1 event, and after a few hours, by a second M_L 5.1 earthquake (origin time, 13:18 UTC). After the mainshock struck, contact among the different INGV centers started immediately, and early in the morning of May 20, 2012, the first INGV emergency rapid-response group was heading to the meizoseismal area. The first real-time station started operating (i.e.,

sending real-time data to the INGV monitoring system) at about 10:30 a.m. on May 20, 2012. The INGV groups from Ancona, Arezzo, Bologna, Milan, Irpinia, Pisa and Rome installed 16 seismic stations (eight with real time transmission) within the first 48 hours (Figure 2). The whole meizoseismal area is characterized by the presence of the Po Plain sediments, which did not allow the deploying of the stations on rock outcrops. In the meantime, the INGV group started the coordination with other Italian and foreign Institutes (Prato Ricerche; OGS, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale; DPC; NERA project participants).

During the first days of the sequence, the rate of seismicity remained high, with more than 60 events per day. On May 29, 2012, at 07:00 UTC, a new large earthquake, of M_L 5.8, struck the area at the western edge of the ongoing seismic sequence (44.85°N, 11.09°E, 10.2 km in depth). This was followed by several earthquakes, including M_L 5.2 and M_L 5.3 events, at 10:55 UTC and 11:00 UTC, respectively, of May 29, 2012. The emergency seismic network continued to improve under the central coordination of the INGV. As soon as further stations became available, the network was expanded, following the spatial evolution of the seismic sequence (details and timing of the installation are described in Moretti et al. [2012]). When a 5.1 magnitude event occurred on June 3, 2012, at 19:20 UTC, about 70 seismic stations were operating for the emergency (Figure 3), including stations managed by French groups. The 10 real-time stations (Re.Mo.Tel and Re.Mo.-UMTS) integrated into the RSN contributed to the INGV event locations for monitoring purposes. The 15 DPC strong-motion stations made use of the

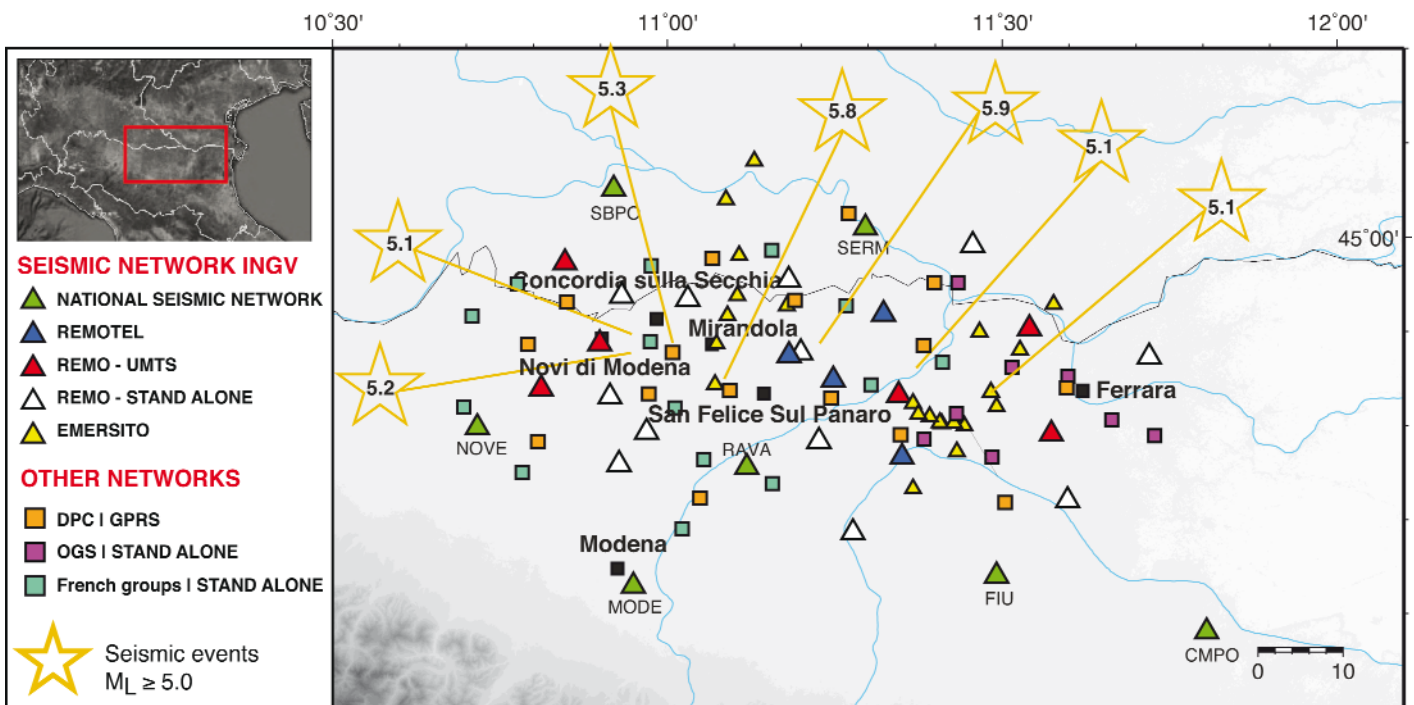


Figure 3. Map of the seismic stations deployed after May 20, 2012. Triangles, INGV permanent (green) and temporary stations; squares, stations from other Institutes; stars, earthquakes with magnitude > 5.0 .



Figure 4. Photograph of the COES room in Bologna.

General Packet Radio Service data transmission to the DPC acquisition center [Zambonelli et al. 2011]. The ca. 50 remaining stations, which were recording as standalone, from the INGV (Re.Mo.-STANDALONE and EMERSITO) and other Institutes (OGS; Università di Ferrara; French IPGS-EOST stations coordinated by INSU, Institut National des Sciences de l'Univers/CNRS) will provide excellent datasets for scientific studies.

After this 5.1 magnitude earthquake on June 3, 2012, the seismicity was characterized by a progressive decrease in the seismic rate and seismic moment release (<http://ingvterremoti.wordpress.com/category/i-terremoti-della-pianura-padana-emiliana/aggiornamento-sismicita/>).

The formal COES was activated at the Agenzia della Protezione Civile Regionale dell'Emilia-Romagna in Bologna

relatively late, on June 8, 2012, because the INGV center in Bologna was previously fulfilling the COES tasks. The COES (Figure 4) ensured continuous and direct communication with the DPC officers present in the epicentral area, 24 hours a day, providing formal updates on the seismic sequence twice a day. At the same time, the structure helped in providing education and information services to support the affected populations, and for the Civil Protection operators and rescue volunteers (<http://ingvterremoti.wordpress.com/category/informazione/>).

The duration of this rapid response mission will depend on the trend of the seismic rate and the seismic moment release, along with information drawn from historical seismic catalogs. The historical seismic catalogs indicate a relatively moderate seismicity in this area, as well as in neighboring

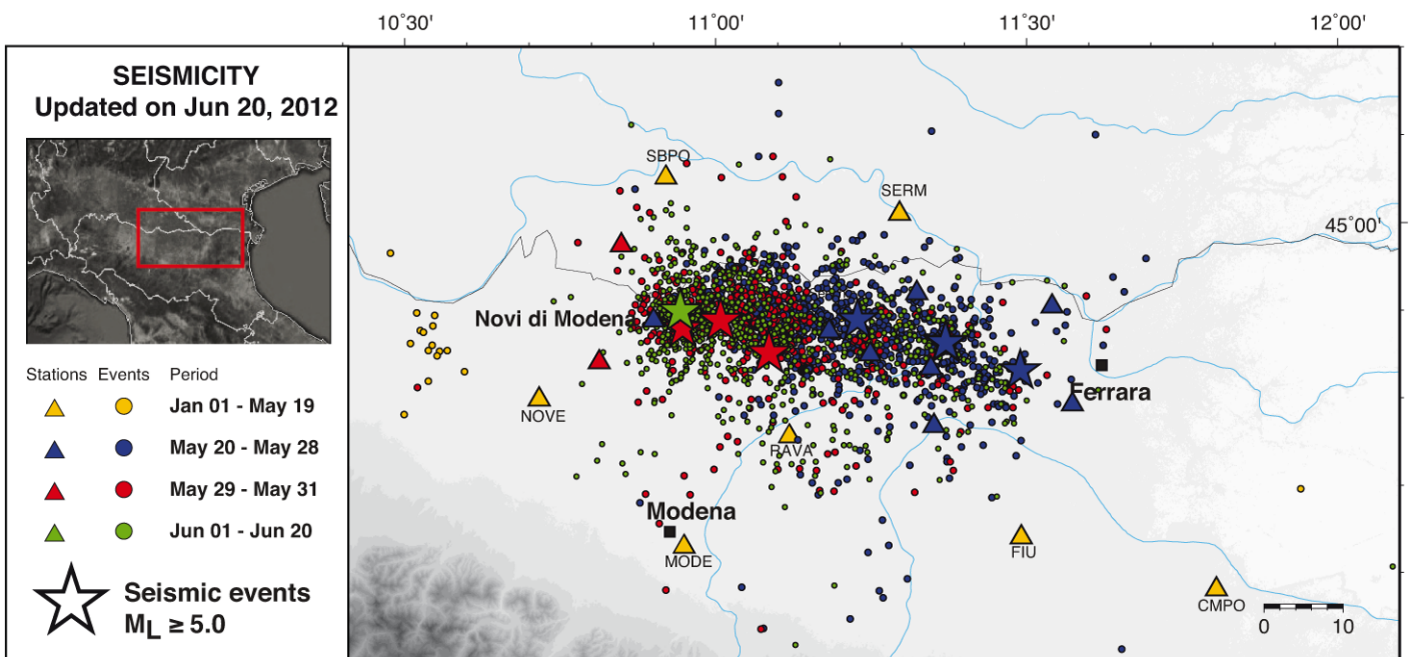


Figure 5. Earthquakes located by the INGV monitoring system for the period January to June, 2012. Black circles, towns and villages; colored triangles, seismic stations; circles and stars, earthquakes with magnitude >5.0 . Earthquakes and stations are color-coded according to occurrence/deployment time relative to the scale on the legend.

areas in the Po Plain, which have been characterized by earthquakes with maximal estimated magnitudes close to 5.5 [i.e., Selvaggi et al. 2001]. It is interesting to note that the seismic sequence that struck the city of Ferrara (estimated magnitude of M_W 5.5) on November 17, 1570, was a sequence of four strong shocks [DBMI11; Locati et al. 2011]. It was a complex and long sequence, and it including an event on March 17, 1574, that produced damage in Finale Emilia (estimated magnitude of M_W 4.7), one of villages most damaged by the 2012 seismic sequence.

4. Data archives and preliminary results

The INGV temporary network data, as defined in the Sismiko agreement, are being stored within the European Integrated Data Archive (EIDA; <http://eida.rm.ingv.it/>) waveform archive, to make it available to the scientific community [Mazza et al. 2011, Moretti and Govoni 2011, Mazza et al. 2012, this volume]. The continuous data are archived in SEED format and can be requested by the scientific community in SEED or SAC format. Data from the Re.Mo. and Re.Mo.Tel stations (22 stations, named as T0800-T0828) are available on EIDA at the time of writing (July 2012). All of both the real-time and standalone INGV stations are, or are going to be, registered at the International Seismological Centre (ISC; <http://www.isc.ac.uk/>). Some restrictions on data access will be applied to the EMERSITO network. OGS colleagues will share their continuously recorded data, without restrictions, through the OASIS portal (<http://oasis.crs.inogs.it/>) [Priolo et al. 2012, this volume]; French colleagues will do the same through the RESIF portal (<http://www.resif.fr/portal>). DPC data consists of triggered events; the two mainshocks are available on the official Department website, and other events recorded within the DPC-Rete Accelerometrica Nazionale (RAN; National Accelerometer Network), with magnitudes >5.0 will be released soon.

A first report on the quality control procedures applied to the temporary network data, and to the very preliminary results obtained by an automatic analysis of the continuous waveforms, has been prepared by Marzorati et al. [2012, this volume]. Overall the station operation scores were satisfactory: by the end of June, the real-time stations had contributed to the location of about 2000 earthquakes by the RSN, by providing more than 5000 P-wave and more than 4000 S-wave pickings, allowing thus for enhanced completeness and accuracy of the earthquake list distributed by the INGV through ISIDe (Figure 5). Refined magnitude estimations and earthquake location procedures need to take into account that all of the temporary stations were installed on the soft sediments of the Po Plain, an aspect that has not been rigorously dealt with in real-time monitoring due to the obvious lack of time. In Figure 5, the aftershocks located by the real-time INGV monitoring system, and the stations in real-time, are colored according to their temporal evolution;

this allows for a comprehensive view of the seismic sequence spatio-temporal evolution and the parallel rapid-response seismic network development. On the whole, the epicenter distribution was elongated about 50 km in the E-W direction, from the town of Ferrara to the village of Novi di Modena. Most of the seismic events and all of those with magnitude >5.0 were thrust events [Scognamiglio et al. 2012, Pondrelli et al. 2012, this volume], in agreement with the well-known geological structures buried under the sediments of the Po Plain [Boccaletti et al. 2011] and with the ca. N-S compressional stress regime in the region [Mariucci et al. 1999].

Currently, several research groups are in the process of analyzing the continuous data stored in EIDA [e.g., Marzorati et al. 2012, Scognamiglio et al. 2012; Govoni, personal communication] for the improvement of the locations, the magnitude estimations, and understanding of the seismic sequence.

5. Conclusions

Rapid earthquake response is very challenging and requires a high degree of preparedness. The coordination projects launched within Sismiko at a national scale and inside NERA at the European level constitute an important first step towards being prepared. The contacts established in these projects significantly helped the rapidity and coordination of the seismic deployment. The national and European protocols established for data transmission and data archiving have succeeded in improving the real-time monitoring system and the data availability to the scientific community.

Further improvements are foreseen: at least once every year, there will be the organization of a seismic-risk emergency simulation, which will allow enhanced technical and scientific exchange among the groups, to lubricate the communication and coordination skills.

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