Although earthquakes cannot be anticipated to avoid disasters, an efficient and rapid real-time monitoring system is fundamental to reducing the loss of human lives and leading the rescue teams quickly to the right place. Since 2001, INGV has developed a new integrated seismic network and monitoring system, thus drastically increasing the number and quality of seismic stations and promoting the development of new tools for earthquake location, visualization and reporting. Response time from INGV to the Civil Protection Department (DPC) has improved from 10-20 minutes to 1-2 minutes. The present network is also a powerful tool for scientific research in earthquake source and structure.

Monitoring room of INGV. The new digital system (in front) and the old one (back)
La salle de contrôle de l'INGV : au premier plan, le nouveau système numérique ; en arrière plan, l'ancien système.
Source : INGV

The real-time earthquake monitoring system in Italy

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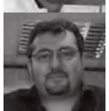

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Italy is one of the most seismically active regions of the Mediterranean, with thousands of earthquakes occurring each year. A glance at an epicentral map of Italy *(figure 1)* reveals that most of the country frequently experiences earthquakes [Chiarabba *et al.* (2004)], and that only a few regions are relatively stable, namely Sardinia and the southern part of Puglia. In addition, except for Sardinia that is located far from major active faults, the entire Italian territory can also feel the effects of earthquakes occurring in adjacent countries. This explains why the most recent seismic classification of Italy (2003-2004) includes all of the 8,101 municipalities.

Although the largest-documented historical earthquakes barely exceed magnitude 7, moderate shocks of magnitude 6 to 7 can nevertheless produce extensive damage and fatalities.

In 1980, a M6.9 earthquake struck southern Italy, causing destruction in several towns and about 3,000 deaths over a large area of the Apennines. The true picture of what had happened only became clear after several days due to the extent of the affected area and the inadequateness of the monitoring system. Many steps forward have been made since then in terms of the rapid evaluation of ground shaking:

Italy is one of the most seismically active regions of the Mediterranean, with thousands of earthquakes occurring each year.

▲ **The town of Conza della Campania (southern Italy) after the M6.9 earthquake in 1980.**
La ville de Conza della Campania (Italie du Sud) après le séisme de 1980 (de magnitude 6,9)
© INGV

today the first estimate of hypocenter parameters is available in less than a minute, as described later.

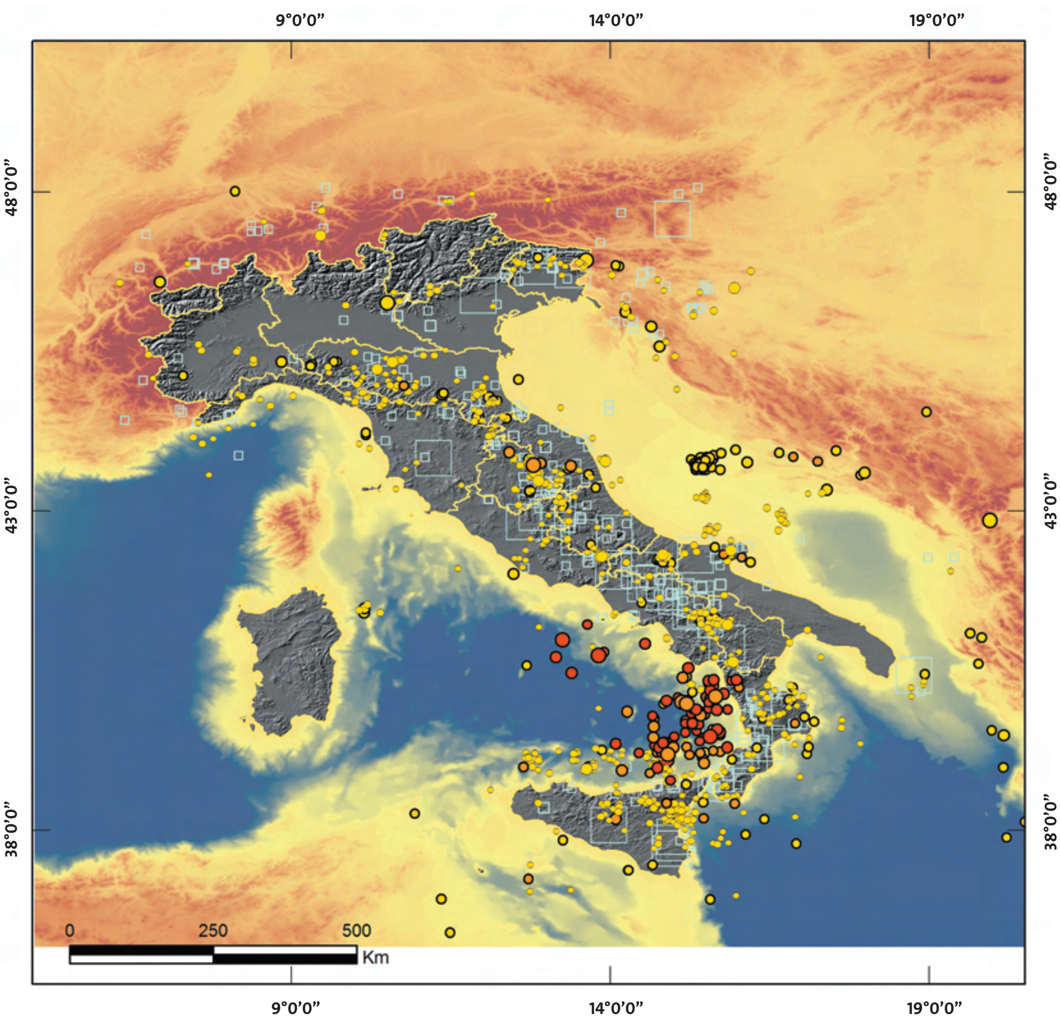
The intense renewal process of the whole Italian monitoring system started in 2001, mainly thanks to support from DPC and, for southern Italy, to the PROSIS project funded by the Ministry of Research. There were three main objectives:

- speed up and improve the real-time determination of earthquake parameters;
- lower the detection threshold of the network to be able to study small earthquakes and accumulate data useful for hazard evaluation, and possibly for future earthquake prediction research;
- accumulate high-quality data from broadband seismometers to study the earthquake source, deep structure and deformation.

We will now present the basic steps involved in building the new monitoring system, starting from the network, then the acquisition system and the GIS-based automatic and interactive information procedures.

The new italian seismic network

In 2001, the National Seismic Network consisted of 92 short-period, mostly vertical, seismometers, connected with low dynamic range telephone lines. The main problems encountered were: difficulty in computing magnitudes due to saturated signals, large areas with sparse coverage, slowness of the location process, unavailability of high-quality data for research purposes. A strong effort has since been made to solve these problems and today, the National network



◄ **Fig. 1: Seismicity of Italy. Historical earthquakes of (equivalent) M>5.5 before 1980 (□) and instrumentally located events of M>3.5 for the period 1981-2005 (● = 0-35 km; ● = 35-200 km; ● = 200-600 km). Data: Gruppo di Lavoro CPTI (2004) and Castello *et al.* (2005)**
Fig. 1 : La sismicité de l'Italie. Sur la carte ont été reportés les séismes historiques de M(équivalent) > 5,5 avant 1980 (□), et les événements de M > 3,5 localisés à partir d'enregistrements pour la période 1981-2005 (● = 0-35 km ; ● = 35-200 km ; ● = 200-600 km). Données : Gruppo di Lavoro CPTI (2004) et Castello et al. (2005)
Source: INGV

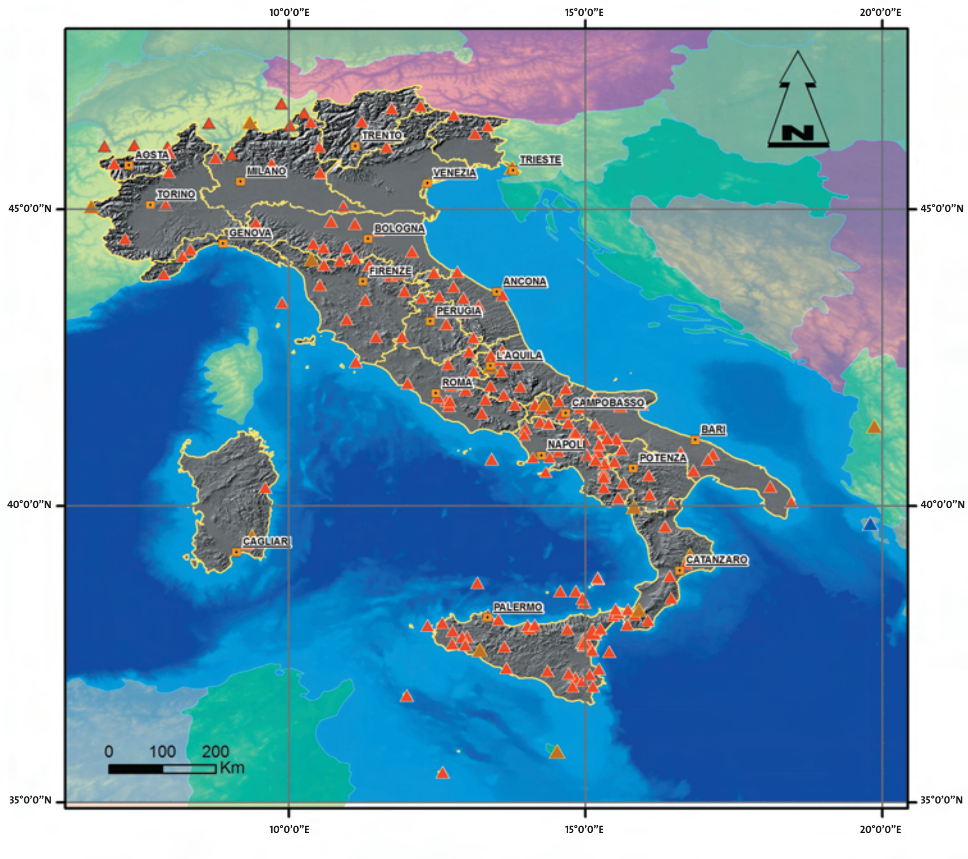


Fig.2: The Italian National Seismic Network consists of more than 200 stations, most of which are equipped with digital 3-component broadband seismometers, linked in real-time to the acquisition center in Rome. Note the stations in the surrounding countries, either belonging to MedNet or to cooperating institutions, those on the islands and one on the Ionian sea bed (SN1).

Fig. 2 : Le réseau sismique national italien se compose de plus de 200 stations dont la plupart sont équipées de sismographes à trois composantes et à large bande passante, transmettant les données en temps réel vers le centre d'acquisition à Rome. Sont également à noter les stations dans des pays limitrophes qui appartiennent à MedNet ou à des organismes coopérants, ainsi que celles situées dans les îles et une dans les fonds de la mer Ionienne (SN1).

Source: INGV

consists of more than 200 stations, most of which are equipped with three-component broadband sensors, digitized at 24 bits at the remote site, and connected with either satellite or telephone links (figure 2).

The main features of the new seismic network are:

- use of both commercial and INGV-developed hardware (GAIA digitizers);
- high dynamic range of the whole acquisition chain;
- broadband of seismic frequencies correctly recovered;
- robustness of the acquisition system, in particular that of the transmission;
- real-time data availability.

As regards the transmission vectors – one of the most critical points of a seismic network – we adopted a mixed strategy: half of the stations are connected through satellite links, and half through cable links. The use of satellite transmission presents several advantages: the link is very robust, the constraints for site selection are weak, and the cost is lower than telephone lines. As regards the terrestrial cable links, we use INGV digitizers (named GAIA), protected IP connections of the Italian Public Administration Network (RUPA): site selection is more delicate, and a compromise must be found between low environmental noise and availability of network infrastructures.

A seismic network must operate continuously on a 24-hour basis: in order to increase the safety of the system, a high level of redundancy is introduced. For instance, the signals coming from the stations connected through satellite links are acquired both in the master hub of Rome, and in secondary hubs (Grottaminarda and Catania). In case of failure of the master hub, the secondary hubs take control of the transmission, and the data flow to Rome is redirected through cable links. For the seismic monitoring of Etna and the volcanoes of the Aeolian Islands, INGV Catania acts as the master hub and Rome as the backup hub.

Another recent development in Italian seismic monitoring is real-time data sharing between different acquisition centres, both with other Italian institutions and the surrounding countries. INGV also manages the Mediterranean very broadband network MedNet (http://mednet.ingv.it/) whose data are integrated into the real-time monitoring system.

Current developments include the co-installation of accelerometers and geodetic GPS instruments at most of the seismic network sites in order to guarantee non-saturated waveforms in the event of strong, close shocks, and to accumulate data for active tectonics and hazard studies.

The new real-time acquisition system

Since 1984 an automatic system, operating on a Digital VAX microcomputer, was able to analyze the signals of the Italian National Seismic Network in quasi-real-time. This system operated up to about 100 mostly vertical stations connected through analogue telephone lines. The automatic location of an earthquake ranged between 4 minutes for small local earthquakes and about 20 minutes for earthquakes exceeding magnitude 5. Today, the new acquisition system operates a complex network of about 80 vertical and 150 three-component stations linked through a variety of connections *(figure 2)*.

“The large number of three-component instruments installed over the last few years ensures the fast computation of reliable magnitudes for all earthquakes in Italy and its surrounding regions.”

The design concept of the new seismic acquisition system, named "Tellus", relies on three combined basics: object-oriented programming (OOP), the multithreading technique, the "mediator-worker" (MWDP) and the "bridge" (BDP) design patterns (DP). Tellus is layered as a three-stage process. The first deals with raw data from remote stations adapting them in a uniform format *(frontnet)*. It defines the characteristic frequency imprint of background noise and declares a detection when the power spectrum of the signal exceeds a threshold in one out of eight pre-defined frequency bands. The second stage gathers all data from the previous process to yield seismic phases and records *(backnet stage)*, and sends arrival times to the last stage *(locator stage)*. The locator stage receives all phases and after a consistency check in the space-time domain, it tries to find a solution as a geographical point, first as a local or regional event. Each location is then checked, leading to three possible results: accept the location, refuse the location as a false association, or attempt a teleseismic location, using world-wide dromochrones. As long as new phases come in, the association/location process starts again every 10 seconds until no new phases are available, or after 150 seconds from the origin time.

The large number of three-component instruments installed over the last few years ensures the fast computation of reliable local magnitudes for all earthquakes in Italy and its surrounding regions. An exact local magnitude is computed at each channel of the three-component broadband stations after checking each signal for completeness and non-saturation to avoid false magnitudes. An event magnitude is only accepted if computed by averaging at least three station magnitudes. This condition is almost always fulfilled at the third iteration of the location process, that is, about 40 seconds after the origin time of an event. Current developments include the automation of moment tensors and magnitudes Mw estimation.

More data, more knowledge

The advantage of the improved national network became evident in 2005, when analysts began the systematic reviewing of earthquakes using the new acquisition system. Comparing the seismicity recorded in Italy during 260 days of years 2004 and 2005, during which activity is comparable, a strong increase in the number of located events is observed. The completeness of the catalogue reached ML=1.6 in 2005, with an improvement of two tenths of magnitude, when compared to seismicity recorded in 2004. The minimum magnitude of located events in 2004 is ML=1.1, compared to ML=0.0 in 2005.

Figure 3 shows the number of located earthquakes per magnitude class for the two test periods (2005 vs. 2004) and reveals the strong improvement in 2005, particularly at low magnitudes (note that the Y axis in the figure is logarithmic). The number of located events more than doubled (+130%) in one year due to the improved capability of the network to locate small earthquakes. This is of great importance in characterizing active faults, particularly in areas where complex geology tends to conceal them [Chiaraluce *et al.* (2005)]. Revised data are available on the Web: http://www.ingv.it/~roma/reti/rms/bollettino/index.php

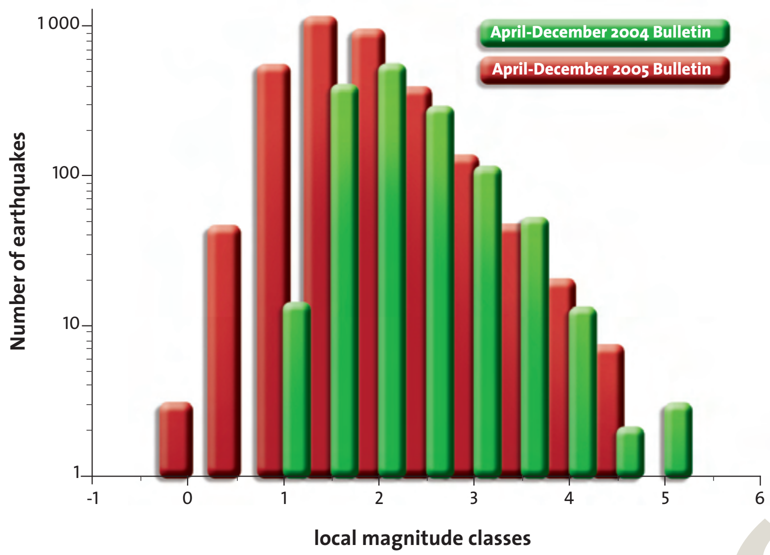


Fig. 3: Number of earthquakes per magnitude class (0.5 intervals) recorded over 9 months during 2004 and 2005, i.e. old versus new network. For every magnitude range, the number of earthquakes recorded in 2005 is higher than in 2004 (note that the Y axis is logarithmic). The total number of located earthquakes increased by as much as +130%. Small earthquakes are important in mapping active faults at depth.

Fig. 3 : Nombre de séismes par tranche de 0,5 degré de magnitude, enregistrés sur une période de neuf mois en 2004 et en 2005, respectivement par l'ancien et par le nouveau réseau. Dans chaque gamme de magnitudes, le nombre de séismes en 2005 dépasse celui de 2004 (N. B. l'axe des ordonnées est logarithmique). Le nombre total d'événements localisés a augmenté jusqu'à + 130 %. Les petits séismes sont importants pour cartographier les failles actives en profondeur.

Source: INGV

SisMap: the real-time mapping system

SisMap was introduced in 2002 to provide those on 24-hour duty at the INGV monitoring center with a rapid overview of the ongoing seismicity. It is an interactive application connected in real-time with the automatic monitoring system so as to receive the alert as soon as an event is identified. SisMap acts as a dashboard by running several other applications to revise seismic waveforms [Bono and Badiali (2004)], insert data in a relational database, send e-mails, and update Web pages. SisMap is a GIS application, suitable for multi-thematic mapping, spatial and attributes querying, image exporting and printing.

Figure 4 reports three out of six automatically produced screen shots after a recent small earthquake in Central Italy. The upper one reports the first automatic location, determined with the first 12 triggered stations and available after 24 seconds from the earthquake origin time. In the left panel all the relevant information is shown, together with the rapid access to the GIS database, which allows comparison between ongoing seismicity and previous earthquakes, mapped faults, geographical and administrative information, etc.

The second panel shows the third automatic location, obtained with data from 38 stations 45 seconds after the origin time, and with the first local magnitude estimate (3.5±0.3). The lower panel reports the final automatic location, determined with 62 stations after 2.5 minutes. The local magnitude has now been recomputed with data from more than 60 horizontal seismograms (3.3±0.3).

> *"The number of located events more than doubled (+130%) in one year due to the improved capability of the network to locate small earthquakes. This is of great importance in characterizing active faults, particularly in areas where complex geology tends to conceal them."*

Following this, the personnel on duty at the INGV center in Rome informs the DPC in three successive steps, within 2, 5 and 30 minutes, each providing increasingly accurate information for every potentially felt earthquake (generally above M2.5). The third step (<30') is made after analysis of seismograms and relocation. Several hundred earthquakes are communicated every year.

Data are then made available through the Web (http://www.ingv.it/~roma/webterrNew/last/month.php) while automatic pickings are sent to national and international agencies.

In the Mediterranean, a real-time monitoring system is an important first step for tsunami alert. INGV uses stations from both the National network, MedNet and connected networks, to determine locations, magnitudes and moment tensors. For instance, the location of the recent M6.8 earthquake in Greece (8 January 2006) was available only 2 minutes after earthquake occurrence. Similarly, data for the May 21, 2003 earthquake in Algeria (M6.8), which generated a small tsunami, was available after 2.5 minutes. Real-time data sharing among countries in the Mediterranean still has much room for improvement. This is one of INGV targets for the coming years, also within the framework of the European Union project "NERIES", starting in June 2006.

Fig. 4: Three screenshots for a recent earthquake (13/1/06 10:20 UTC, M3.3) using SisMap, the automatic GIS-based tool adopted by INGV to map and revise earthquake locations. The upper panel shows the first automatic location, obtained with 12 triggered stations 24 seconds after the origin time. The second shows the third location (38 stations, 45 seconds) with the first magnitude estimate. The last one shows the final automatic location (62 stations, 150 seconds).

Fig. 4 : Trois copies d'écran SisMap, le logiciel automatique issu du SIG et utilisé par l'INGV pour cartographier et réviser les déterminations hypocentrales, relatives à un séisme récent (13/1/06 10:20 UTC, M 3.3). En haut, une détermination préliminaire automatique calculée avec 12 stations déclenchées, 24 secondes après l'heure d'origine. Au milieu, la troisième détermination (après 45 secondes, prenant en compte 38 stations) avec la première estimation de magnitude. En bas, la détermination automatique définitive (après 150 secondes, prenant en compte 62 stations).

Source: INGV

> *In the Mediterranean, a real-time monitoring system is an important first step for tsunami alert.*

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Le dispositif de surveillance sismique en temps réel en Italie

L'Italie est située dans l'une des zones sismiques les plus actives du bassin méditerranéen. Malgré la magnitude modérée des séismes qui dépasse rarement 7, la grande vulnérabilité du bâti sur le territoire italien, édifié pour sa majeure partie avant l'introduction des normes de construction parasismiques, place l'Italie parmi les pays à haut risque, même pour des magnitudes qui avoisinent 6.
La communauté scientifique internationale a désormais acquis la conviction que la prédiction des événements sismiques à des fins de protection civile, permettant de sauver des vies humaines, relève de l'impossible. Il est donc impératif, d'une part, d'investir dans une politique de prévention efficace consistant à :

- *construire selon les normes parasismiques,*
- *renforcer le patrimoine existant,*
- *éduquer et sensibiliser la population,*

et d'autre part de développer un système de surveillance efficace.
Le premier point a été réévalué par la communauté scientifique nationale, suite au tremblement de terre d'octobre 2002 du Molise, et a conduit à l'élaboration d'un nouveau zonage sismique ainsi qu'à des normes de construction plus rigoureuses.
Pour ce qui concerne le système de surveillance territorial, l'INGV, encouragé et financé par le Département de la Protection Civile, a entamé depuis 2001 une phase de mise en œuvre et de modernisation du réseau sismologique national.
De grands efforts ont été déployés ces dernières années pour la réalisation d'un système de surveillance et de détection en temps réel avec des résultats très probants. Ces résultats, exprimés en terme de rapidité et de précision de la détermination hypocentrale et de la magnitude à travers tout le territoire italien, sont disponibles dans les 20 à 60 secondes qui suivent le tremblement de terre.