Agreement INGV-DPC 2007-2009

Project S5 : "High-resolution multi-disciplinary monitoring of active fault test-site areas in Italy"

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Scientific Report - I phase

May 1st, 2008 – April 30th, 2009 (delayed to May 22nd)

Section 1: Report on the S5 project by Lucia Margheriti and Aldo Zollo

1.1 Progress of the project: general

S5 project is aimed at supporting and integrating the ongoing research on selected Italian test sites (the Alto Tiberina Fault (ATF), the Messina Strait and the Irpinia fault system) where advanced multi-parametric monitoring infrastructures are available or under construction.
The main objective of the project is to improve the understanding of earthquake generation processes in Italy and to characterize the earthquake source and medium properties in the three selected test sites by developing and applying innovative methodologies aimed at the massive processing, analysis and modelling of multi-parametric geophysical data available in real-time and off-line data banks.
According to the original workplan the research activities of project S5 during the first year concerned 1/ the development of methods for seismic and geodetic data analysis in continuous and off-line modes, code implementation and testing on real and synthetic data: 2/ the collection, formatting and archiving of seismic and GPS data from test-site areas and their publication on web-accessible relational data-bases 3/ collection, analysis and interpretation of geological data on the ATF fault and 4/ the instrument deployment, in particular the sea-bottom array of seismographs installed off-shore of Sicily.
A detailed description of activities, products and results can be found in the UR reports. However we point out some important progresses concerning :

- the improved imaging of fault structures through the refined analysis of background seismicity and microearthquake source parameters;
- the integration of seismic and geological methods to reconstruct subsoil images
- the monitoring of fault structures through high frequency continuous GPS
- determination of stress orientation from seismic anisotropy and focal mechanisms (moment tensor from waveform amplitude inversion for M down to M 2.5-3)
- methodological development aimed at the detailed 3D images integrating travel time tomography, reflected/converted wave imaging and Green's function extraction from ambient noise cross-correlation and stacking

The occurrence of the Mw 6.3 earthquake near L'Aquila on April the 6th introduced a new scientific priority in the working program of the INGV staff , and more in general of the whole Italian seismological community. The emergency management also benefited of the work done in S5 specifically concerning the rapid determination of aftershock location and mechanisms and GPS data analysis and modeling. The seismic, GPS and SAR data acquired for L'Aquila mainshock and related aftershock sequence represent a very rich data-bank useful to set procedures and methodologies for the high-resolution multi-disciplinary monitoring of active fault.
A recent lesson from the Central Italy earthquake is the importance to integrate multi-parametric, real-time observing system of active faults including seismic, low- and high frequency ground deformation monitoring (GPS and SAR). Furthermore, dense accelerometric arrays deployed around active faults provide unsaturated seismic waveforms which are relevant for peak ground motion estimation, rapid fault rupture modeling and elaboration of accurate ground shaking scenarios. We believe that a partial re-orientation of S5 (and may be of other S-projects) including the results and lessons from the analysis of data acquired during the L'Aquila earthquake sequence can be of primary importance for the project objectives.

1.2 Progress of the project by task

Task 1 Alto Tiberina Fault monitoring site (responsible: Lauro Chiaraluce)

As a reminder here, this test site area is under construction through the AIRPLANE project, funded by Italian Minster of Universities and Research, for a very dense seismic (at surface and at depth) and geodetic network. Thus, all of the activities of the RU are focused on performing a series of multidisciplinary studies to complement and integrate the AIPLANE project, in terms of the dataset, approach and knowledge produced. For this reason, and going beyond their scientific significance, all of the studies performed will help to better define earthquake generation potential of the Alto Tiberina Fault (ATF). In this context, the investigators of (hereinafter named with their working package acronym) wp_1.1 have build a procedure to successfully detect and associate microseismic events down to M_L 2.0. Then, for the recovered events, a process to semi-automatically pick the P- and S-wave arrival times. They show here the testing of the procedure on data collected during the L'Aquila sequence. Wp_1.2 efficiently located a cross-section profile along the west Tiber river margin where next autumn they will be able to perform the seismic experiment. Wp_1.3 has collected in collaboration with the Perugia RU all of the available information from the Labtopo GPS stations, archiving the data in the INGV system. They also started with some processing of the merged-time series, producing preliminary but important observations, such as the unambiguous concentration of the tectonic strain along the High Tiber Valley, together with the likelihood of identification of a deficit in the seismic moment release rate relative to the tectonic strain of the area. Wp_1.4 went through the re-interpretation of the seismic data, successfully reconstructing and restoring the subsurface geology of the first two vertical cross-sections located across the ATF. The sections have got going with the improving of the resolution of the geometry of the extensional system, providing stronger constrains to compute the cumulative displacement of the ATF and to determine the kinematic interaction between the ATF and secondary faults. Finally, wp_1.5 is carrying on with the geomorphological mapping and aerial-photograph interpretation of the Quaternary deposits of the High Tiber Valley. They have started also with the field survey of part of the area, to reconstruct the Late Pleistocene-Holocene flight of inset terrace surfaces of the valley, producing a preliminary (1:10,000) map of ≈500 km^2 that is mainly focused on the spatial distribution of the continental deposits in-filling the Tiber basin and their connection with the tectonic activity. The map has been improved through the reconstruction of the fault system and the deformation pattern affecting the continental deposits at the surface, paying attention to the drainage pattern analysis and the reconstruction of the Late Pleistocene-Holocene flight of inset terrace surfaces.

Task 2 Messina Strait monitoring site responsible Lucia Margheriti

We are proud to say that in December 2008 the Messina 1908-2008 project received a special award from the cultural group "Antonello da Messina" (http://www.sat8.tv/tag/geofisica/). In the framework of project Messina 1908-2008, the working packages relating to task2 realized the working plan described in the following. WP1 deployed 5 ocean-bottom seismometers produced by the INGV-Gibilmanna laboratory, for about 4 months. WP2 collected the continuous seismic signals coming from the permanent networks in the Messina Strait area (INGV National seismic Network and Peloritani seismic network) and from the temporary deployment (Land and OBS temporary stations) into a unique database, with the conversion of all of the data in Seed format in progress. The event detection and location is not yet at the expected stage, but the first locations completed testify to the decrease in uncertainty in the hypocentral parameters, better constraining the depth of the events located in the Ionian sea. WP4 collected GPS data in a campaign in 2008 and analyzed it together with all of the available data, to obtain a detailed spatial resolution of the ongoing crustal deformation. At least three different research groups are working on the definition of the velocity field in the area, and last March general agreement on the different solutions was reached. Data coming from temporary GPS campaign belonging to different groups will be shared during this coming year.

Two different automatic procedures to evaluate seismic anisotropy (WP3) where refined: after sharing the strategies for selecting the events and the analysis window, the two codes produce very similar results. The codes are ready to analyze the Messina1908-2008 events and will also be applied on the data of the L'Aquila seismic sequence and to selected data from ISnet (see Management). Focal mechanism computation and integration of the computed FMs in the available database was carried out in WP5, and data of the first months of the temporary deployment have been exchanged between WP2.1 (INGV) and WP 2.5 (Messina University). The studies carried out for this task will promote progress for our knowledge of stress accumulation mechanisms and the consequent processes of seismogenic faulting in the area of interest.

Task 3 The Irpinia Fault System monitoring site (responsible: Aldo Zollo)

The activity for Task3 during the first year of the project has pursued the planned objectives, with minor changes relative to the planned schedule. The cross-correlation and stacking tools for analyzing long-period time windows of ambient noise recordings at the Irpinia Seismic network (ISNet) have been implemented and tested, with the main purpose of extracting high frequency (0.5-1 Hz) Green's functions for the shallow crust beneath the array. The procedures for automatic noise data recovery, formatting and cross-correlation processing have been completed for all of the possible couples of broad-band stations for ISNet, while the analysis of dispersion for the retrieval of the dispersion curves for surface waves has just started.

We have developed and implemented procedures for automatic event detection and analysis of local earthquakes (http://lxserver.ov.ingv.it/cgi-bin/isnet-events/isnet.cgi) with the aim of obtaining refined estimates of micro-earthquake source parameters that are initially collected in the delivered product D21. The manual re-picking of 640 local earthquakes recorded by ISNet and the nearby INGV stations has been performed for the period 2005/08/22 – 2008/09/28 (44703 traces), for a total number of 4705 P picks and 2916 S picks. After earthquake location using a probabilistic method, the non-linear inversion of attenuation corrected, P- and S-wave displacement spectra provided average estimates and uncertainties of the source parameters: seismic moment, moment magnitude, corner frequency, source radius, seismic energy, and static and apparent stress releases. The S-wave corner frequencies decrease with the seismic moment, according to a constant Brune stress-drop model (self-similarity), down to Mo about 1e12 Nm (Mw ~ 1.9). At smaller seismic moments, there appears an abrupt slope change that is the evidence for violation of the self-similar scaling at very small magnitudes (Mw < 1.5). The radiated seismic energy increases with seismic moment, but with a slope greater than expected from theory, which implies the dependency of apparent stress on seismic moment. Whether this effect is due to the frequency bandwidth limitation or to rupture source dynamicswill be explored during the second year by specific tests. A calibrated moment vs local magnitude scale for the test site is an additional product of this activity.

Local micro-earthquakes are also used to image the crustal structure beneath the seismic array using re-adapted reflection processing, array beam-forming and migration techniques applied to reflected/ converted phase waveforms. The first year of activity consisted in data collection, and pre-processing, gathering and identification of event clusters. Related software have been developed and applied for initial imaging tests.

Since 2003, INGV has deployed in Italy a continuous GPS network, with several high-rate (30s and 1s) stations in the Irpinia region. These 1s data are stored in Rome and Grottaminarda, with a ring-buffer strategy spanning a period of 1 week, thus assuring a sufficient amount of data to retrieve co-seismic and immediately successive post-seismic signals. In case of an event, the ring-buffer is turned off and the data are stored in the hard disk. All of the RING sites located in the Irpinia area are now transmitting data in real or quasi real time. All of them transmit data 1 epoch every 30s by satellite telemetry and most of them (5 of the 7 sites) transmit data also at 1 Hz, by GPRS/UMTS technology. Advances in the epoch by epoch GPS data analysis have been made by using non-commercial geodetic-quality software developed at JPL (Zumberge et al., 1997). At present, a kinematic solution in post-processing is performed to obtain the variation of the position of each site with respect to its nominal *a-priori* precise position.

1.2 Deliverables

Deliverable D1 (not declared for phase 1, but presented in a preliminary stage) Title: Standard modular automatic procedures for the management and analysis of a continuous seismic data stream

Deliverable D6 (not declared for phase 1, but presented in a preliminary stage) Title: Balanced geological sections, derived from depth converted seismic profiles at ATF test site.

Deliverable D8 (not declared for phase 1, but presented in a preliminary stage) Title: Geological and geomorphological map of the High Tiber Valley from Perugia to Città di Castello.

Deliverable D11 (30%) Title: Preliminary integrated data bank of continuous recordings for the period October 2007-October 2009 at the Messina strait test-site.

Deliverable D12 (1%) Title: Preliminary earthquakes locations in the Tyrrhenian and Ionian regions around Messina Strait to define seismogenic structures.

Deliverable D16 (100%) Title: Database of focal mechanisms of earthquakes in the Messina Straits over the time period between 1988 and 2007.

Deliverable D20 (50%) Preliminary re-picking arrival-time catalogue and earthquake locations in the Irpinia test site.

Deliverable D21 (50%) Parametric catalogue of micro-earthquakes including source parameters in the Irpinia test site.

1.4 Management

In the first year of activities, project S5 had some plenary meetings and several working group workshops. The presentations at the meetings and the programmes of the workshops are archived in the project website:
http://dpc-s5.rm.ingv.it/ in the Meeting link.
The kick-off meeting was held on the 4th July 2008 in Rome, and those responsible for all of the Working Packages presented their working plans to the others.
In October 2008, each research group met to prepare the presentations for the International Evaluation Committee; preliminary results were presented to the CIV in November (19-21).
With the reprise, in 2008, of the centennial of the 1908 Messina earthquake (Mw=7.1), a conference promoted by the Dipartimento Protezione Civile was organized in collaboration with INGV and Messina University, in Reggio Calabria in December 2008. General aspects of each Seismological DPC-INGV project and many of the research activities of S5-Task2 were presented there. In March 2009, the velocity fields of the Messina Strait area that were obtained by the different groups were discussed in a joint workshop between projects S5 and S1. A general consensus was reached. WP 2.3 is selecting a data base from the ISNet (Irpinia fault system monitoring site Network) and from the National Seismic Network (INGV) to evaluate seismic anisotropy in the region of the 1930 Irpinia earthquake. The results will be discussed and interpreted together with Daniela Di Bucci in the framework of a collboration

with DPC (Interscambio di professionalita' nell'ambito della convenzione DPC-INGV 2007-2009) .

1.5 Problems and difficulties

We are generally satisfied of the results obtained problems encountered by each UR are discussed in the UR reports in the following; here we want to mention only one noteworthy point.

In 2008 one of the areas of cost-cutting action of the Italian government is the scientific and technological research. For this reason, many researchers on temporary positions working in S5 project were worried about loosing their jobs. The problem is not yet solved.

As a consequence of the efforts and involvement of INGV staff in the emergency management following the 2009 Mw 6.2 L'Aquila earthquake some of the work planned at the three test sites (Alto Tiberina Fault, Messina Strait and Irpinia) by S5 in April was indeed slightly delayed

1.6 Main key publications

Web sites

http://portale.ingv.it/l-ingv/progetti/progetti-finanziati-dal-dipartimento-di-protezione-civile-1/progetti-dpc-convenzione-2007-2009/progetti-s/progetto-s5

http://dpc-s5.rm.ingv.it/

http://lxserver.ov.ingv.it/cgi-bin/isnet-events/isnet.cgi

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Barchi M., Mirabella F., Chiaraluce L., Cocco M. and Montone P. (2008) "*An active low-angle normal fault in the Northern Apennines (Italy): a possible site for ICDP drilling*". 33rd International Geological Congress (IGC), Oslo August 6-14th 2008 (Norway).

Cheloni D., N D'Agostino, I Hunstad, G Selvaggi, R Maseroli Strain Accumulation in the Messina Straits (Southern Italy) From Terrestrial Geodetic Measurements and GPS observations AGU fall meeting December 2008.

Chiaraluce L., C. Chiarabba, C. Collettini, D. Piccinini and M. Cocco Anatomy and seismic release of a major normal fault system located along the Northern Apennines of Italy. 27th **ECGS** Workshop 'Seismicity Patterns in the Euro-Med Region'.EUROPEAN CENTER FORGEODYNAMICS AND SEISMOLOGY November 2008

D'Agostino N., D Cheloni, F Bernardi, I Hunstad, B Palombo, G Selvaggi Reassessment of the interseismic and coseismic deformation in the Messina Straits AGU fall meeting December 2008.

D'Amico, S., Orecchio, B., Presti, D., Zhu, L., Herrmann, R. B., Neri, G., 2009. Moment tensor solutions of recent earthquakes in the Messina Straits area, southern Italy. Abstract presented at the Seismological Society of America, Annual Meeting Monterey, CA, (USA), April 8 - 11 2009.

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D'Anna G., G. Mangano, A. D'Alessandro, R. D'Anna, G. Passafiume, S. Speciale, G. Selvaggi, L. Margheriti, D. Patanè, D. Luzio, M. Calò. "Messina 1908-2008" Progetto Di Ricerca Integrato Sull'area Calabro – Peloritana: La Campagna Obs/H Convegno 1908 - 2008 Scienza e Società a 100 anni dal grande Terremoto December 2008

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Festa G. and Zollo A., 2009. Early radiation and final magnitude: insights from source kinematics, The 2nd International Workshop on Earthquake Early Warning, Kyoto, Japan

Gavaruzzi R., Radicioni F. (2008) - "*Attività interregionali per specifiche tecniche per le reti geodetiche: cronaca e integrazioni operative nella predisposizione e realizzazione della Convenzione Lotto 1-2007*". Atti della XII Conferenza Nazionale ASITA, L'Aquila, Ottobre 2008. ISBN/ISSN: 978-88-903132-1-9.

Govoni Aladino Lucia Margheriti, Giuseppe D'Anna, Giulio Selvaggi, Domenico Patanè, Milena Moretti and Luciano Zuccarello Messina 1908-2008: understanding crust dynamics and subduction in Southern Italy AGU fall meeting December 2008.

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Mattia, Mario Valentina Bruno, Mimmo Palano and Flavio Cannavò Crustal motion along the Calabro-Peloritan Arc as imaged by twelve years of measurements on a dense GPS network Convegno 1908 - 2008 Scienza e Società a 100 anni dal grande Terremoto December 2008

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UR Reports - I phase

May 1st, 2008 – April 30th, 2009 (delayed to May 22nd)

Section 2:

Report on the project S5 UR01 by Responsible Lauro Chiaraluce

Within the first year project all the groups followed their specific working packages work flow whose details we report in the following.

2.1 Activity of UR01 in phase 1

WP1.1: Automated seismic data analysis.(*Raffaele Di Stefano)*

Objectives

Following our working package workflow, in this first year of the project we worked on building the procedure to semi-automatically manage and analyse seismic data streams. To do this we set up a modular procedure including

- triggering algorithm and events association routine
- P- and S-wave arrival times and polarity identification
- 1D events location
- local magnitude estimation

Methodologies

Triggering algorithm and events association.

We use only data recorded at three component seismic stations with natural periods (T) 5s or 20s. We first correct signals for the instrumental response, then we apply a band-pass filter to the continuous data streams over the 1–15 Hz frequency band using a 4- pole, 2-pass Butterworth filter. We calculate the magnitude of the ground velocity vector using the trace of the 3-component covariance matrix derived over 1s long time windows sliding with 0.5 s step (Montalbetti and Kanasewich, 1970; all the references are listed in the supplementary material). We use these latter time series for a detection procedure based on the classical STA LTA coincidence-sum algorithm.

Automatic picking of P- and S-wave arrival times

We implemented a recently developed picking software package (MannekenPix) already in use at the INGV (Aldersons, 2004) to automatically identify both P- and S-wave arrival times, and to furnish accurate events locations and magnitudes. For each P- and S-wave onset, related polarities and error estimations are defined, the latter based on a weighting engine rigorously calibrated on a reference data set (see Aldersons 2004 and Di Stefano et al. 2006; Valoroso et al., 2009). The procedure yields preliminary event locations based on a first run of the code, only on the triggered waveforms, by using the Hypoellipse code (Lahr, 1989). Such locations allow to calculate predicted arrival times at unpicked stations. Then MannekenPix searches for accurate P- and S-wave onsets through the whole set of waveforms. Finally, new precise 1D locations are produced by using the high quality picks of the second run.

Activities

In the first year, we applied the detection algorithm over data previously recorded during field experiments simulating a continuous data flow. This step help us in test the stability of the code and defining the proper parameter setup to maximize its performance.

At the same time, to implement the automatic picking procedure, we invited F. Aldersons for one week to improve the calibration and weighting procedure. Soon after Aldersons visit, the L'Aquila sequence started, then we decided to apply the refined procedure to a subset of data that struck the Abruzzi region since April 6, 2009. We analysed waveforms recorded by 20 temporary seismic stations (INGV Emergency Network), installed in the epicentral area soon after the mainshock (Mw 6.3) occurrence. In order to quickly identify seismic events, we skipped the triggering steps and we selected ~1200 P-wave pickings at one station (AQU) seismic station furnished by the Earthworm acquisition system, to be used as reference triggers for the procedure. To locate events, we used a reference 1D velocity model optimized for the area (Bagh et al., 2007). Improved final locations for 1100 events with M_L in the 2.0 and 4.8 range (see Figure 1a and 1b in the D1 deliverable) were obtained by using the doubledifference algorithm (HypoDD; Waldhauser and Ellsworth, 2000). Vertical cross sections through the aftershocks clearly show the geometry of the fault planes activated during the sequence. These results let us foresee the potentiality of the improved procedure.

WP1.2: Imaging the shallower portion of the Tiber basin(Luigi Improta)

Objectives

We focused on the selection of two sites in the Tiber basin suitable for high-resolution (HR) seismic profiling. We benefited of the collaboration with WP1.4, which made available proprietary commercial reflection profiles and surface geologic data.

Methodologies

We investigated a sector of the Tiber basin, about 10 km long, comprised between two SW-trending commercial profiles (L3 and L7, Fig.1a). The Tiber basin is up to 6 km wide (Fig.1a) and reaches a thickness of ~0.9 s TWT, corresponding to about 900 m (Fig.1d). It is bounded to the SW by a system of NE-dipping faults, which displace the substratum and continental deposits. Along the NE margin, continental deposits simply cover a regular SW-dipping substratum with on-lap geometries. More importantly, shallow imaging (< 0.2 s TWT) of the basin is quite poor. Apart from an overall low resolution, stack sections suffer from several acquisition gaps (Fig. 1d).

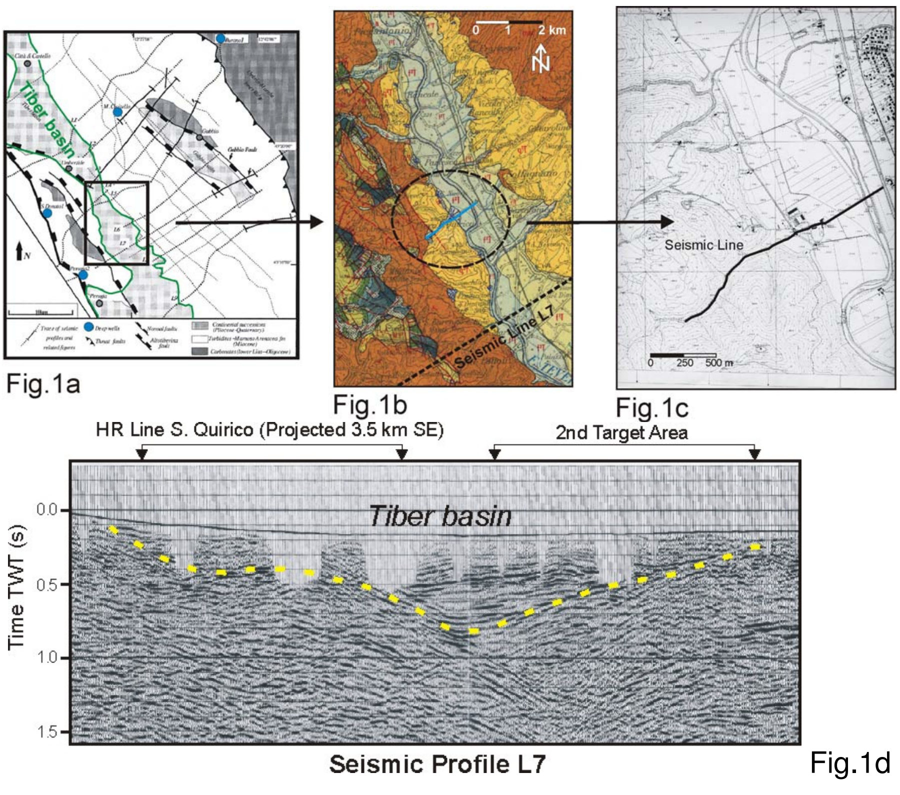


Figure 1: a – Location of seismic profiles investigating the Tiber basin and the ATF (from Mirabella et al., JSG 2004), b – geological map zooming on the Tiber basin with outlined the area selected for the survey, c – trace of the planned HR seismic profile, d - detail of commercial profile L7 zooming on the Tiber basin. Note the frequent acquisition gaps.

Activities

Seismic imaging of the entire basin by HR profiling is out of the purpose of WP.1.2. In addition, the analysis of topographic maps, aerial photos and field surveys have showed that the investigated area presents significant logistic challenges mainly due to the presence of the

Tiber river, that acts as a barrier to surveying, of rough topography, thick vegetation cover and widespread urbanized areas, with a railway and an highway that parallel the valley (Fig.1b). As result, we were able to identify only one potential site on the western side of the basin (Fig.1b-c). At this locale, surveying will satisfy these conditions: collection of a ~2 km long line, tie to outcrops of the substratum, crossing of the basin recent infill and of one splay, at least, of the Alto Tiberina Fault (Fig.1b). Logistic condition allows the use of a Vibroseis source (IVI MiniVib). Further surveys are going on along the eastern side of the valley to select a 2nd site suitable for shallow surveying. Both profiles will be acquired in July 2009.

WP1.3 Velocity and strain rate fields across the fault from integration of regional GPS networks. (Nicola D'Agostino)

Objectives

The aim of this working package is to integrate GPS data from regional GPS networks mainly developed for real-time positioning applications. This integration allows a densification of the existing INGV GPS network and an increase of the spatial resolution needed to investigate the active tectonic deformation in the Alto Tiberina Valley.

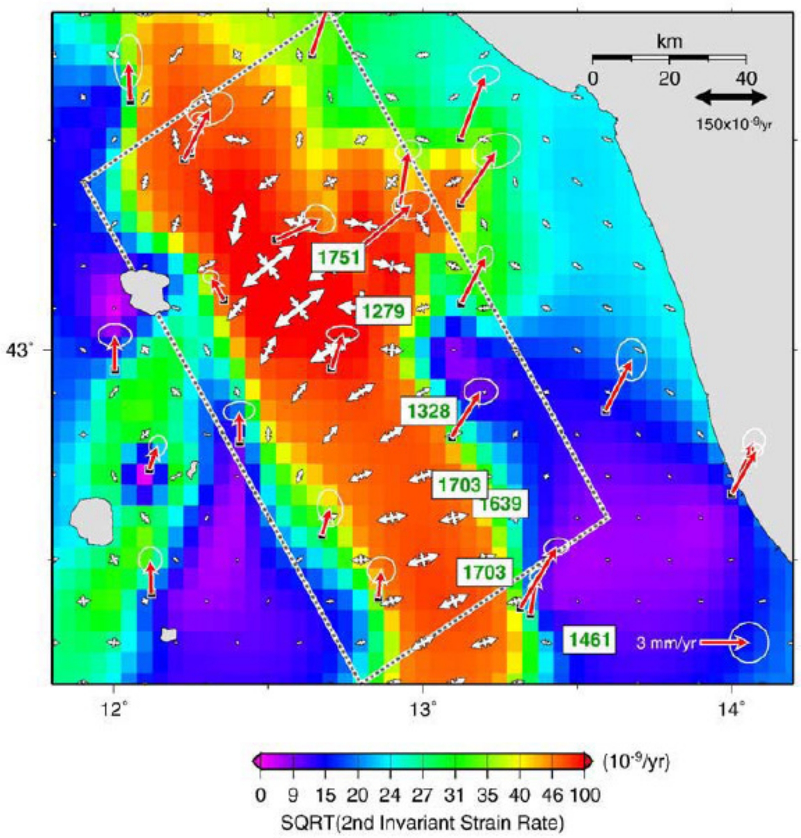


Figure 1. Map of the second invariant and principal axes of the model strain rate tensor obtained from the interpolation of the velocity field using a tensor factor T=0.5. Red arrows: observed GPS velocities with 95% CI ellipse errors. Shaded box: area used for summation of scalar seismic moment for the earthquakes occurred in the last 720 years.

In this project we collaborate with the geodetic WP of the Perugia UR and integrate the daily rinex files of the Labtopo GPS network with the other CGPS sites coming from the INGV GPS (RING) and other GPS networks in a single processing scheme to obtain a homogeneous velocity field in terms of data processing and reference frame alignment. From this velocity field we derive the distribution of the tectonic strain rate and the rate of strain accumulation of known active faults. We emphasize that this products constitute an essential component for an improved seismic hazard assessment.

Methodologies

The raw daily GPS rinex files from the Labtopo network have been processed in an homogeneous processing scheme with the other GPS data coming from the RING and other public available GPS networks for a total amount of circa 350 GPS sites located in the Africa-Eurasia plate boundary and in the stable parts of the Nubia and Eurasian plates. We used the GIPSY-OASIS software together with precise orbits and clock-files from the NASA Jet Propulsion Laboratory. The daily positions time series allow accurate estimates of the velocities and the associated uncertainties.

Activities

In the first year of the project we achieved the following targets:

1) Data collection and archiving. In collaboration with the Perugia UR we collected all of the available data from the Labtopo GPS stations and archived them in the central archiving facility in Rome.

2) Data processing with GIPSY-OASIS II and analysis of the time series.

3) Analysis of the GPS velocity field and derived products (strain rate, geodetic moment rate).

Preliminary results with a reduced number of available GPS stations have been published (see Figure 1) in D'Agostino et al., (in press). The results show a clear concentration of the tectonic strain in the Alto Tiberina Valley and a partially significant deficit in the seismic moment release rate relative to the tectonic strain evaluated from the GPS velocity field.

2.2 Deliverables

No deliverable were expected for Phase I .However, as can be seen in preliminary D1 presented in the following the standard modular automatic procedures for the management and analysis of a continuous seismic data stream (WP1.1) has been tested during the L'Aquila earthquake sequence.

2.3 Problems and difficulties

None

2.4 Key publications

L. Chiaraluce, C. Chiarabba, C. Collettini, D. Piccinini and M. Cocco Anatomy and seismic release of a major normal fault system located along the Northern Apennines of Italy. 27th **ECGS** Workshop 'Seismicity Patterns in the Euro-Med Region'.EUROPEAN CENTER FORGEODYNAMICS AND SEISMOLOGY November 2008

Chiaraluce, L., L. Valoroso, M. Anselmi, S. Bagh and C. Chiarabba. A decade of passive seismic monitoring experiments with local networks in four Italian regions, Tectonophysics (2009), doi:10.1016/j.tecto.2009.02.013.

N. D'Agostino, S. Mantenuto, E. D'Anastasio, A. Avallone, M. Barchi, C. Collettini, F.Radicioni, A. Stoppini, G. Fastellini (2009). Contemporary crustal extension in the Umbria–Marche Apennines from regional CGPS networks and comparison between geodetic and seismic deformation, Tectonophysics, doi:10.1016/j.tecto.2008.09.033.

Piccinini, D., and G. Saccorotti (2008), First observations of non-volcanic, long-period seismicity in the central Apennines, Italy, *Geophys. Res. Lett.*, 35, L12303, doi:10.1029/2008GL034120.

Report of UR02 of the project S5 by Massimiliano Rinaldo Barchi

2.1 Activity of UR in phase 1

The research activity of the Perugia UR is subdivided into two main sub-projects, which were dedicated to: i) the subsurface geology (wp 1.4 resp. F. Mirabella) and to the surface geology and geomorphology (wp 1.5 resp. M. Barchi). The Perugia UR also contributes to other investigations such as the geodetic ones and those on the active state of deformation, which are addressed by the INGV UR (wp 1.3, resp. N. D'Agostino) through a subcontract with the Civil and Environmental Engineering Department of the University of Perugia (resp. F. Radicioni) for the maintenance of the permanent GNSS/GPS stations of the GPSUMBRIA and LABTOPO networks.

WP 1.4, Upper crustal structure and tectonic evolution of ATF (Francesco Mirabella)

The activity of the wp 1.4 was focused on the geological reconstruction of the subsurface of the Altotiberina normal fault (ATF) and on the sequential balancing of geological sections across the ATF. The UniPg people involved in this part are F. Mirabella, M. Barchi and A. Lupattelli who is working on his PhD within this project.

We started collecting the available data, both surface geological data (maps 1:10.000, 1:25.000, 1:100.000), and subsurface data (boreholes and commercial seismic data).

The main topics addressed by this wp concern the coherent re-interpretation of the seismic data, calibration with boreholes and surface geology, estimation of the velocity field through the wells sonic logs for the depth conversion of the reflectors and the sequential restoration of the extensional structures. The data, after being gathered and projected/reprojected into the same geographical reference system with GIS tools, were loaded into the Move^{TM} package which allows the depth conversion and sequential balancing of the geological sections to be made. The sequential restoration and balancing was addressed along two sections (L1 and L2 in figure and in D6 deliverable) which cross the region between the Tiber Valley and the Gubbio anticline. The interpretation of these two sections is tied to the stratigraphy of three boreholes, S.Donato1, M.Civitello1 and Perugia2.

In figure the balancing sequence of L1 and L2 sections is shown. The top of the sections show the present-day geological setting. The sections show the presence of three main extensional structures, from West to East: the Corciano fault (CoF), the Altotiberina Fault (ATF), the Gubbio fault (GuF). The combined effect of the CoF and of the ATF are responsible for the exhumation of late Triassic rocks (Anidriti di Burano fm - Ev) at the ATF footwall. The easternmost segment of the ATF faults borders the Tiber Valley, here infilled by about 1 km thick, upper Pliocene-Pleistocene sediments. The displacement along the major normal faults is to be restored starting from the youngest back to the oldest: we mainly derived the timing of deformation from the ages of the sediments infilling the basins. In the proposed reconstruction, the total amount of extension is about 9.9 km and 8.5 km for sections L1 and L2 respectively, whilst the cumulative displacement of the ATF alone in the order of 7.5 km. The sequential restoration also shows: i) the kinematic interaction between the ATF and the Gubbio fault; ii) the influence of the staircase geometry of the fault on the onset and evolution of the Tiber basin at its hanging-wall; iii) the pre-extensional geometry of the compressional structures of this part of the Umbrian Apennines. On the basis of the work made on the first two sections we moved the interpretation towards NW and started to reinterpret the seismic section corresponding to L3 section in figure 1 and the CROP-03 section (L4). The work on the CROP-03 section was particularly focussed on the ATF footwall. This is due to the fact that at the time of the CROP-03 interpretation, many seismic lines at the ATF footwall, west of Citta' di Castello were not available. These seismic lines are important as they allow to better constrain the depth of the Umbria Marche carbonates below the siliciclastic rocks cropping out at the surface. In order to better calibrate the shallower part of the cross-sections, we involved in the working group F. Brozzetti of the University of Chieti who is one the best experts of the surface geological setting of the siliciclastic rocks which crop out in the ATF test-site area.

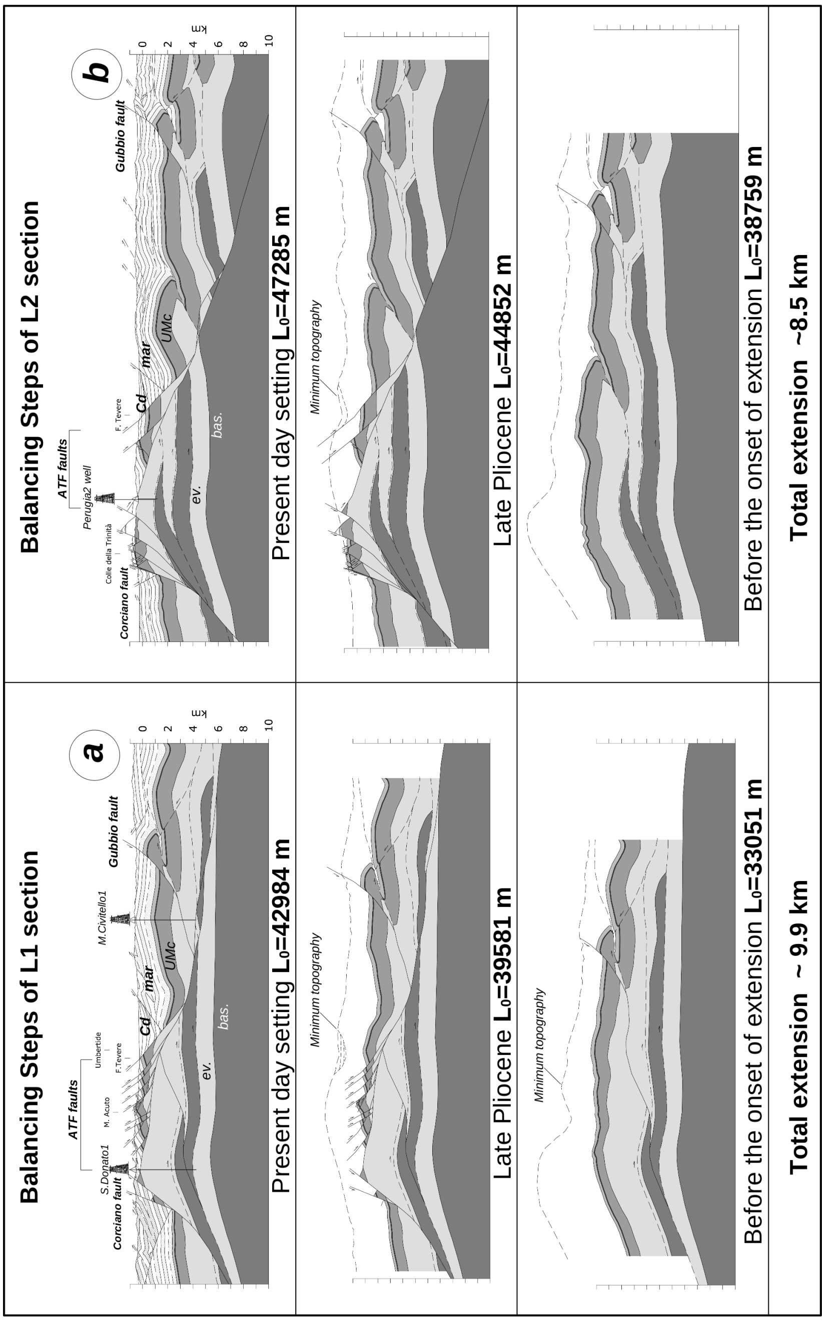


Figure *Schematic balancing steps of the L1 and L2 sections across the ATF structure and related inferred extensional deformation.*

The contribute of F. Brozzetti to this study will be the synthesis of the existing surface geological maps and field controls of critical areas along the sections which are to be balanced. The activity of the next year will be concentrated on the balancing of the L3 and L4 sections in order to evaluate the longitudinal variations of the offset along the Tiber Valley and provide an estimate of the long-term foot-wall uplift to be compared with the short-term, morphological uplift.

The inferred long-term extension-rate will compared with the short-term extension-rates drawn on the basis of geodetic measures (wp 1.3 INGV UR).

After the interpretation and balancing of the sections is completed and revised, we will produce the isobath maps of the ATF and of the top of the basement by the interpolation of the data along the sections. To this aim, also the information provided by all the seismic data of figure 1 of D6 deliverable will be used. In the shallow part of the seismic profiles, the image of the geometry of the basin infill will be compared with the information of the field work made by the wp 1.5.

WP 1.5, Tectonic evolution of the Upper Tiber Valley, from Perugia to Sansepolcro (M.R. Barchi

The activity of wp 1.5 was focused on the geomorphological mapping and aerial photograph interpretation aimed at the mapping of the Quaternary deposits of the Tiber Valley. The people involved in this wp are M. Barchi (UniPg), S. Pucci (INGV), F. Pazzaglia (UniPg), L. Melelli (Unipg) and L. Saccucci who is attending her PhD in the framework of this project.

During this first year of the project we have: i) collected the available geological maps (scale 1:10.000, 1:50.000), the aerial photographs and the Digital Elevation Models (DEMs); ii) performed the geological/geomorphological field survey of the study area (i.e. Upper Tiber Valley from Sansepolcro to Pierantonio (PG); iii) performed the aerial photograph interpretation of the Upper Tiber Valley; iv) reconstructed the Late Pleistocene-Holocene flight of inset terrace surfaces of the valley; v) made some preliminary tests of quantitative geomorphological analysis, based on the 90 m-DEM. All the geological and geomorphological observations have been organized and analyzed in a qualitative and quantitative way using Geographic Information Systems and Remote Sensing software (ArcGis9.2™ and Erdas8.0™).

Extensive 1:10,000-scale geological and geomorphological mapping of about 500 km^2 along the Upper Tiber Valley, from Sansepolcro to Pierantonio (PG), has been carried out, focussed on the continental deposits infilling the Tiber basin. We started from the existing geological maps, produced in the framework of previous national (CARG) and/or regional (Regione Umbria) projects. The field work was aimed at producing an integrated and homogeneous stratigraphic scheme of the outcropping Early Pleistocene to present deposits, and at characterizing the deposits also from a sedimentological and structural point of view. The geological and geomorphological field mapping was integrated also with other data such as: the observations made on 1:33,000 scale aerial photographs (GAI); 10-m-resolution Digital Elevation Model and standard morphometric derivatives (hill-shaded and slope angle maps, Spatial Analyst™). The mapping was conducted in order to understand the spatial distribution and the paleoenvironmental significance of the deposits associated to the tectonic activity. The map was improved through the reconstruction of the fault system and the deformation pattern affecting the continental deposits (see D8 deliverable). Particular attention was paid to the drainage pattern analysis (strong river incisions, valley profiles, paleodrainages) and to the reconstruction of the Late Pleistocene-Holocene flight of inset terrace surfaces, along with their correlation and ordering, that will be useful for further paleogeodetic analysis. The significant geomorphic features related to the setting of the depositional and tectonic landforms, such as paleosurfaces, scarps, slope changes, crests, peaks, landslides and tectonic lineaments are also drawn. An example of synthetic map of a portion of the study area is reported in the deliverable D8.

During the next year, we will extend this work and will pay particular attention to integrate the information coming from the field with those from the seismic profiles (wp 1.4) which show the geometry of the basin infill at depth.

Activity of the sub-contractor DICA sub-UR (resp. F. Radicioni)

The sub-UR of DICA (Civil and environmental engineering department) has made a constant maintainance of the permanent GNSS/GPS stations of the GPSUMBRIA and LABTOPO networks. The people involved are F. Radicioni, A. Stoppini and G. Fastellini (Dipartimento di Ingegneria Civile ed Ambientale – DICA). The work of this sub-UR will be mainly integrated with the INGV UR and in particular with WP 1.3 (Resp. N. D'Agostino).

The maintainance activity was carried on by both remote checks through GPS/GLONASS receivers and field surveys on the stations sites. During the maintainance operations, the

substitution of the local server was needed and the updating of the receivers firmwares was made, in order to make them adeguate with the recently launched GLONASS satellites.
The data acquired by the GNSS receivers of the stations which form the two networks have been constantly archived in a RINEX format and are available at http://www.gpsumbria.it (for the GPSUMBRIA network) and at http://labtopo.ing.unipg.it (for the LABTOPO network). The data have been acquired with 1 second sampling interval and a cut-off angle of 0°. The data have been succesively re-sampled also at 5 and 30 seconds and archived in the standard RINEX data format with Hatanak (compact RINEX or CRINEX) compression and gzip UNIX/LINUX compatible compression. The network undergoes a continuous computation operated by the software which manages the real-time positioning services (GNSMART, Geo++ Hannover, Germany). The computation is made on the basis of the ETRS89 datum. This type of computing provides a powerfull tool of continuos monitoring of the network and is capable to identify possible malfunctionings or consistent deformation effects due to events like earthquakes. The periodic solutions availability allows to perform the temporal series analysis of the tridimensional position of the permanent stations which can be used for the local analysis of the earth crust deformation.

2.2 Deliverables

The UR does not have deliverables at the end of the first year. However, the production of two (D6 and D8) of the three deliverables (a geological and geomorphological map of the High Tiber Valley from Perugia to Città di Castello, and the balanced cross sections) are at a good stage of preparation (about 30%) so we decided to show them. The isobath maps will be made after the final calibration of the cross-sections.

2.3 Problems and difficulties

None

2.4 Key publications

Barchi M., Lupattelli A. and Mirabella F.. (2008) "*Balanced cross-sections across a low-angle normal fault in the Northern Apennines of Italy*". Congresso della Societa' Geologica Italiana, September 15-17 2008, Sassari (Italy).

Barchi M., Mirabella F., Chiaraluce L., Cocco M. and Montone P. (2008) "*An active low-angle normal fault in the Northern Apennines (Italy): a possible site for ICDP drilling*". 33rd International Geological Congress (IGC), Oslo August 6-14th 2008 (Norway).

D'Agostino N., Mantenuto S., D'Anastasio E., Avallone A., Selvaggi G., Barchi M., Collettini C., Radicioni F., Stoppini A., Fastellini G. - "*Contemporary crustal extension in the Umbria-Marche Apennines from regional CGPS networks and comparison between geodetic and seismic deformation*". Tectonophysics, doi: 10.1016/j.tecto.2008.09.033. (in press). ISSN 0040-1951.

Fastellini G., Radicioni F., Stoppini A. (2008) - "*Impact of Local GNSS Permanent Networks in the Study of Geodynamics in Central Italy*". In "Observing our Changing Earth" (M.G. Sideris Editor), IAG Symposia, Vol. 133, Springer Berlin-Heidelberg, 2008. ISBN 978-3-540-85425-8.

Fastellini G., Radicioni F., Stoppini A., Barzaghi R., Carrion D. (2008) "*New active and passive networks for a support to geodetic activities in Umbria*". The Bulletin of Geodesy and Geomatics, IGMI, no. 3/2008.

Gavaruzzi R., Radicioni F. (2008) - "*Attività interregionali per specifiche tecniche per le reti geodetiche: cronaca e integrazioni operative nella predisposizione e realizzazione della Convenzione Lotto 1-2007*". Atti della XII Conferenza Nazionale ASITA, L'Aquila, Ottobre 2008. ISBN/ISSN: 978-88-903132-1-9.

Report on the project S5 UR03 by Responsibles Lucia Margheriti and Giuseppe D'Anna

2.1 Activity of UR03 in phase 1

WP 2.1 Ocean Bottom Seismographs deployment and test (Giuseppe D'Anna – Giorgio Mangano, INGV- CNT)

On the 15th and 17th of July 2008, staff of Gibilmanna OBS Lab of INGV, thanks to the support of the Coastal Guard, deployed five BB-OBS (Broad Band Ocean Bottom Seismometer) in the Tyrrhenian sea, Aeolian area, and in the northern Ionian sea (Tab. 1).

Some hours after the deployment, the OBS named A3 released the ballast because of an electronic issue on the acoustic releaser. The OBS come up, was tracked by a GPS system and recovered after three days. After the replacement of the acoustic releaser, the same OBS was re-deployed on the 2nd of august. All the five OBS's were successfully recovered on the 6th and 7th of November 2008.

The OBS's were equipped with a Nanometrics Trillium 120p seismometer (bandwidth 120s-175Hz) installed in a gimbals for the leveling and a Cox-Webb Differential Pressure Gauge (bandwidth 160s-2Hz); signals from these two instruments were digitalized at 100 Hz and stored by a SEND Geolon MLS data-logger.

At the end of the 2008, at the INGV OBS Lab, the plan of a new version of OBS was completed and on the first months of the 2009 started the production of the prototype. The new OBS, equipped with an acoustic modem and a new data-logger with an ARM microprocessor embedded system, will allow to retrieve waveform segments from the instrument on the seabed, to a ship or a buoy on the sea surface. The test of the prototype and of the acoustic communication will be done within this work-package at the end of the 2009. Details about the data are in the description of the D11 deliverable.

Serial num.	*Lat.*	*Long.*	*Depth (m)*	*Date of deployment (UTC)*
A2	37° 36' 28.2" N	15° 56' 51.6" E	1919	15/07/2008 10:44
A3	38° 28' 10.9" N	15° 16' 37.8" E	1150	02/08/2008 06:22
A4	37° 42' 32.1" N	15° 33' 26.4" E	1585	15/07/2008 12:47
A5	38° 42' 53.2" N	15° 31' 10.1" E	1360	18/07/2008 08:10
A6	38° 20' 38.7" N	14° 44' 50.8" E	1420	18/07/2008 04:11

Table 1: Geographic coordinates and depth of the OBS's deployment locations

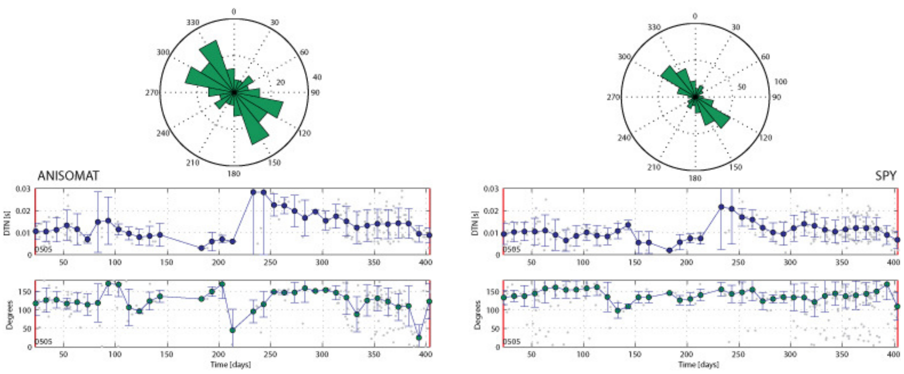
WP 2.2 Integrated seismic data bank and refined earthquake location to define seismogenetic structures(Milena Moretti , INGV-CNT)

One of the goals of the project is the creation of a waveform archive that will collect, in a uniform format (Seed), recordings of all the available seismic stations present in the region. It should be the first example of complete integration of data provided by permanent networks (INGV National Seismic Network; Peloritani Local network), temporary deployments (both mobile network from INGV CNT and INGV CT) and OBS data. The occurrence of the Mw 6.3 earthquake near L'Aquila on April the 6th and the consequent deployment of temporary stations introduced a new priority in the data-base development which benefit of the work done in this working package. At the time we are writing we are building a Seed archive for L'Aquila seismic sequence including INGV National Seismic Network; Abruzzo Local network and temporary station deployed by the INGV-CNT, INGV-CT and LGIT (Grenoble,France).

To build the Messina 1908-2008 archive, we are converting all the continuous seismic recordings (permanent stations, temporary stations and OBS) to a uniform format (SEED).

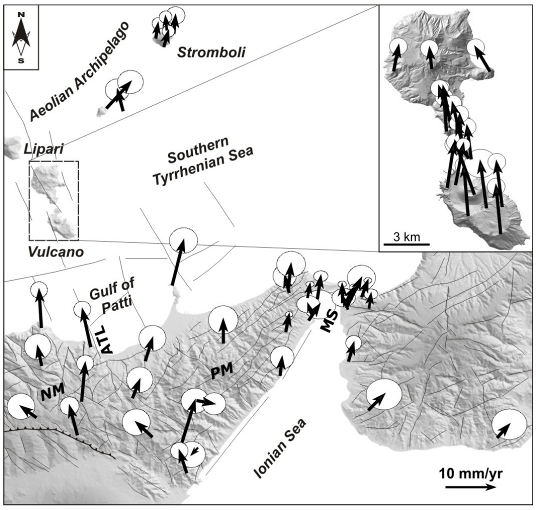
To achieve this goal, the INGV CNT, INGV Catania and INGV Napoli data centers have been connected in real time via seedlink to gather the waveforms from the Peloritani and Eolian Islands Networks starting from February 2008. The temporary stations have been deployed on November 2007 and the data has been collected on a regular basis and the first OBS deployment was realized between July and November 2008.
The data is stored in the original format on the mobile network data server MAYA, then it is going to be converted to SEED data format and fed to the HSL seedlink/arclink server. The data from permanent networks is stored in HSL together with RSN data and is accessible in real-time for 15 days. After this period the data is moved to the CNT SAN and can be retrieved through the arclink interface. The database in the first year was realized for about a 30%, details on data are described in the preliminary deliverable D11. Once the data set will be ready we will compute refined hypocentral locations to define seismogenetic structures inside the Messina Strait and in the surrounding region especially in the Tyrrhenian and Ionian sea. The event detection and location is not yet at the expected stage but the first locations done testify for the decrease of uncertainty in the hypocentral parameters better constraining the depth of the events located in the Ionian sea (see the preliminary deliverable D12 (1%)).

WP 2.3 Seismic anisotropy (Davide Piccinini, INGV-Roma1)
Following our working package workflow, in the first year of the project we worked on building the procedure to semi-automatically analyze near real time seismic data in order to estimate the deformation and fracture field of the crust. We compare two different semi-automatic codes (SPY and ANISOMAT) based on different techniques independently developed under MatLab by two research team. The former uses the covariance matrix decomposition to retrieve the polarization azimuth of the *fast* S wave. Then a cross correlation algorithm is applied over the rotated seismic traces in order to obtain the delay time between the *fast* and the *slow* S wave. The latter is based on the cross-correlation algorithm applied over a time window centered on the S wave arrival time. The two horizontal components are rotated by 1 degree step. For each step a cross-correlation series is computed. The absolute maximum of the cross-correlation series obtained indicates the azimuth and the delay time of the *fast* and *slow* S waves. We test independently the codes over a common dataset recorded during a field seismic survey in Val d'Agri basin (Southern Italy). In this year we worked on common strategies for automatically select events to be used looking for seismic anisotropy. The results after calibrating those strategies show a general agreement between the two codes, although small differences remains and are caused by the different sensitivity of the codes to the S-wave picking accuracy. The figure shows a comparison of the two codes applied on a common dataset.



Anisotropic parameters found by the two automatic codes: the wind-rose plots indicate the mean polarization azimuth for the entire dataset (236 events). The two sub-plot shows the anisotropy parameters estimates during time. Solid dots represent the day average of anisotropy parameters (blue: average normalized delay time; green: average fast direction), while blue bars are the standard deviation for each day.

WP 2.4 Ground deformation pattern of the Calabro-Peloritani area and the Messina Straits from GPS networks and terrestrial data (Mario Mattia, INGV- CT)



Velocity field of the area produced by Mattia et al.

In this first year, we analyzed periodical and continuous GPS data collected between 1996.00 and 2008.21 on three geodetic networks installed both on Peloritani Mts., on Aeolian Islands and across the Messina Strait, in order to obtain a detailed spatial resolution of the ongoing crustal deformation. The dilatation strain-rate pattern is dominated by a clear compression of about 0.65 µstrain/yr on a small area located between the Vulcano and Lipari islands. A compression of about 0.1 µstrain/yr can be recognized also between Stromboli and Lipari islands.

Across the Nebrodi-Peloritani and the Messina Strait areas the dilatation strain pattern is positive. The areas having maximum values of positive dilatation strain-rate (about 0.15 µstrain/yr) are localized in the region containing two main active fault systems: the Messina Strait fault system and the Aeolian-Tindari-Letojanni fault system. In March 2009 all the different groups (including people working in S5 and S1 projects), involved in the geodetic measurements and studies in the Messina Strait area, had a meeting in Rome, the different groups showed the velocity fields results for the area. Results even if come from different data and different analysis are consistent in their general pattern showing a regional divergence of Sicily and Calabria of about 3mm per year. Velocity between Milazzo (Sicily) and the Aspromonte Massif (Calabria) vary linearly, this imply small velocity variations across the Messina Strait but generate a constant stain-rate, the values vary among the different groups between 0.10 and 0.15 µstrain/yr. The next step is trying to understand if this strain rate can be accommodated by one fault structure inside the Strait of should be distributed on different fault systems. Data coming from temporary GPS campaign belonging to different groups will be shared during this coming year.

2.2 Deliverables:

Deliverable D11 (30%) Title: Preliminary integrated data bank of continuous recordings for the period October 2007-October 2009 at the Messina strait test-site
Deliverable D12 (1%) Title: Preliminary earthquakes locations in the Tyrrhenian and Ionian regions around Messina Strait to define seismogenic structures

2.3 Problems and difficulties

We are generally satisfied of the results obtained but we want to mention few noteworthy points.

- We were aware that the deployment of OBS is still in a test phase for INGV so the limited functioning of some of the OBS stations was somehow expected.
- The occurrence of the Mw 6.3 earthquake near L'Aquila on April the 6th introduced a new priority in the working program of the INGV Centro Nazionale Terremoti, the emergency benefit of the work done in S5 but the closing of S5 phase suffers (especially the deliverable D12).

2.4 Key publications and meetings

Publications

D'Anna G., G. Mangano, A. D'Alessandro, R. D'Anna, G. Passafiume, S. Speciale, S. Passarello Progetto "Messina 1908 – 2008". Rapporto preliminare della campagna obs nell'area eoliana e dello stretto di messina. Ingv rapporti tecnici #98 (2009)

Margheriti, L. and Messina 1908-2008 team - Understanding crust dynamics and subduction in southern Italy , Eos Trans. AGU, 89(25), 225–226.

Margheriti L.,D'Anna G., Selvaggi G., Patane D., Moretti M., Govoni A., Alla ricerca di nuovi dati sulla relazione tra subduzione e cinematica crostale nell'arco Calabro-Peloritano. Capitolo del volume Il terremoto e il maremoto del 28 dicembre 1908 Editors: Bertolaso G., Boschi E., Valensise G.,Guidoboni E..Dec-2008 Publisher:SGA

Pastori M., Piccinini D., Margheriti L., Improta L., Valoroso L.,Chiaraluce L. and Chiarabba C. (2009) Stress aligned cracks in the upper crust of the Val d'Agri region as revealed by Shear Wave Splitting. Under revision for GJI

Meetings

Pastori M., Piccinini D., Zaccarelli L., Valoroso L., Bianco F., Margheriti L. Shear Wave Splitting Versus Faults And Stress Field In The Val D'agri (Southern Italy) Analysed With Automatic Procedures. IGC International Geological Congress, Oslo 2008 August 6-14th

Selvaggi Giulio, Lucia Margheriti, Giuseppe D'Anna e Domenico Patane' Il Progetto Messina 1908-2008: Nuovi Dati Per Comprendere Relazione Tra Subduzione E Cinematica Crostale Nell'arco Calabro-Peloritano; Convegno 1908 - 2008 Scienza e Società a 100 anni dal grande Terremoto December 2008

Mattia, Mario Valentina Bruno, Mimmo Palano and Flavio Cannavò Crustal motion along the Calabro-Peloritan Arc as imaged by twelve years of measurements on a dense GPS network Convegno 1908 - 2008 Scienza e Società a 100 anni dal grande Terremoto December 2008

Moretti M.,A. Govoni L. Abruzzese, G. Aiesi, P. Baccheschi, F. Criscuoli, G. D'Anna, R. D'Anna, G. De Luca, D. Franceschi, L. Giovani, F.P. Lucente, G. Mangano, M. Manni, L. Margheriti, M. Moretti, G. Passafiume,D. Patanè, P.R. Platania, S. Rapisarda, G. Selvaggi, L. Scuderi, S. Speciale, L. Zuccarello, A.G. Mandiello, A. Basili, A. Bono, C. Castellano, F. Criscuoli, S. Mazza, O. Torrisi "Messina 1908-2008" Progetto Di Ricerca Integrato Sull'area Calabro – Peloritana: La Campagna Sismica Convegno 1908 - 2008 Scienza e Società a 100 anni dal grande Terremoto December 2008

D'Anna G., G. Mangano, A. D'Alessandro, R. D'Anna, G. Passafiume, S. Speciale, G. Selvaggi, L. Margheriti, D. Patanè, D. Luzio, M. Calò. "Messina 1908-2008" Progetto Di Ricerca Integrato Sull'area Calabro – Peloritana: La Campagna Obs/H Convegno 1908 - 2008 Scienza e Società a 100 anni dal grande Terremoto December 2008

Govoni Aladino Lucia Margheriti, Giuseppe D'Anna, Giulio Selvaggi, Domenico Patanè, Milena Moretti and Luciano Zuccarello Messina 1908-2008: understanding crust dynamics and subduction in Southern Italy AGU fall meeting December 2008

D'Agostino N., D Cheloni, F Bernardi, I Hunstad, B Palombo, G Selvaggi Reassessment of the interseismic and coseismic deformation in the Messina Straits AGU fall meeting December 2008

Cheloni D., N D'Agostino, I Hunstad, G Selvaggi, R Maseroli Strain Accumulation in the Messina Straits (Southern Italy) From Terrestrial Geodetic Measurements and GPS observations AGU fall meeting December 2008

Report of UR04 of the project S5 by Giancarlo Neri

The second semester activity of the UR-Messina consisted in the prosecution of focal mechanism computation and the integration of the computed FMs in the available database. The analyses have been performed using the information collected by the local and national seismic networks. In the third semester, we are going to use also the data coming from the OBS and the on-shore temporary stations installed in the framework of the Messina Project 1908-2008 in the study area.

The UR–Messina, in collaboration with the Earth & Atmospheric Sciences Department of Saint Louis University, has applied in the Straits area the "Cut And Paste" (CAP) method for moment tensor estimation (Zhao and Helmberger, 1994, Zhu and Helmberger, 1996). To obtain the Green's functions we performed the frequency-wavenumber (f-k) integration as described in Zhu and Rivera (2002) for a distance range from 5 to 500km and a focal depth range from 2 to 60km (horizontal and vertical grid spacing is of 5km and 2km, respectively) . One of the advantages of the CAP method is that each waveform is broken up into the Pnl and surface wave segments that are fit using a grid search to obtain the best moment magnitude, source depth and focal mechanism. CAP has been shown to be very stable also for earthquakes of magnitude as small as 2.5÷3. For this reason it is very useful in the Messina Straits area, characterised in the last decades by microearthquake activity.

We started by compiling a list of all earthquakes in the study area from the INGV seismic catalogue (http://iside.rm.ingv.it) with focal depths less than 25 km and magnitudes ML larger than 3. The dataset was restricted to the earthquakes recorded at a minimum of 4 three-component seismic stations equipped with broad-band sensors such as Trillium 40s, STS-2-120s, and Lennartz-3D-20s (www.ingv.it), located within about 200km from the epicenter. Each waveform was corrected for the instrument response, examined to eliminate recordings with spurious transients, double events or low signal-to-noise ratios, and finally reviewed for the picking of P-arrivals. The final data set used consisted of about 1000 waveforms from 23 earthquakes. We relocated these events using the BAYLOC non-linear probabilistic location method by Presti et al. (2004, 2008) and the 3-D seismic velocity model proposed for the study area by Barberi et al. (2004).

The stability of the CAP method is widely accepted (Li et al., 2007; Jost et al, 2002; Zhu and Helmberger, 1996, 1997; Zhu et al., 2006). However, in order to have an additional check of CAP's focal mechanisms in the specific conditions of the Messina Straits area we performed some tests based on variation of parameters like: starting epicenter, number of recording stations and their spatial distribution, number and type of seismic wave segment adopted during the inversion. The results show good stability, see the examples in Figure 1. Furthermore, we note that azimuthal gaps into station distributions as large as 180° do not change significantly the solution for this mechanism.

For some events we also applied the so-called "SLU/USGS" method (Herrmann, 2008) in order to get the moment tensor solution and perform some comparisons. It is a technique of direct inversion of broadband waveforms. In this case as well we used the velocity model derived by Barberi's et al. 2004 model to obtain the Green's functions. The "USGS/SLU" method, like CAP, consists of a grid search technique over the focal mechanisms parameters of strike, dip and rake angles and source depth (Herrmann et al., 2008; Herrmann and Ammon 1997), but it does not perform to break the seismograms into Pnl and surface segments. Figure 2 shows a comparison of source mechanisms from this study using the CAP and the SLU/USGS methods and some focal mechanisms provided by INGV, which were computed using either the Dreger's approach (1990, 1993) (TMTD Solution) or the method described by Ekstrom et al. (1998) and Pondrelli et al. (2006) (QRCMT Solution). The latter usually are determined for intermediate magnitude earthquakes (4.5<M<6), but occasionally they also list events with magnitude less than 4.5 if the station distribution is particularly favourable, the threshold may reach 4.1. (www.bo.ingv.it/RCMT).

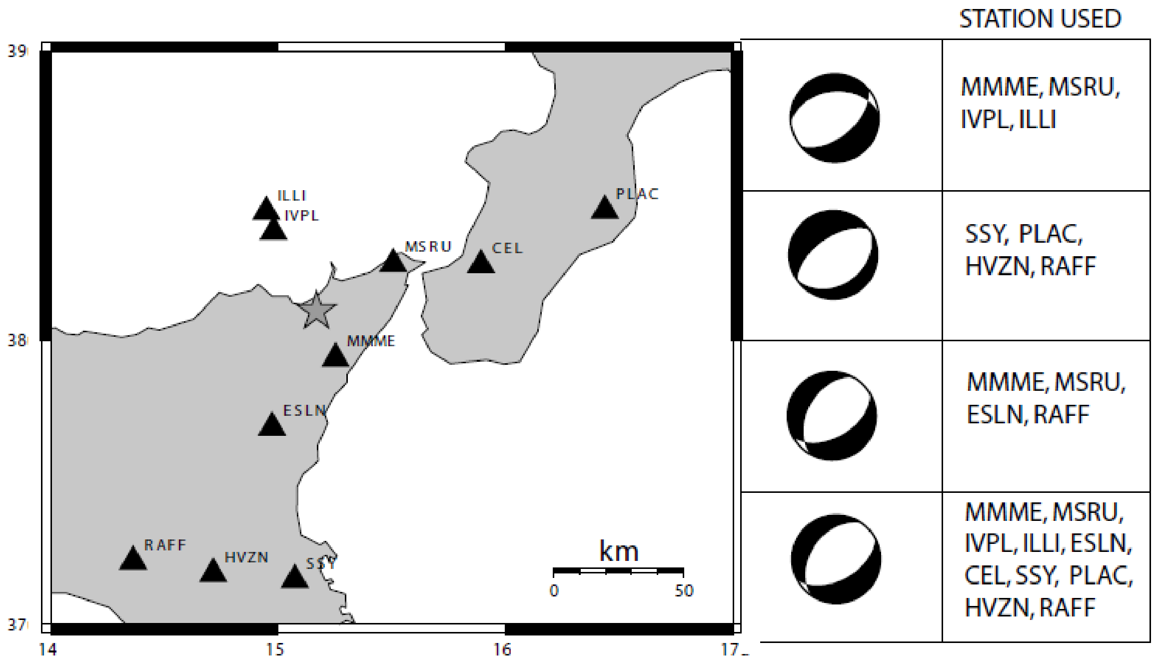


Figure 1 Examples of some tests done to verify the stability for the final focal mechanism using CAP method. The map shows the epicentral location and the station distribution used in these tests. The beach balls represent the solution obtained using some near stations (a), some further stations (b), a combination of them with an azimuthal gap of almost 180 degrees (c), and the focal mechanism obtained forcing the epicenter to be at 5 km South in respect to the true location (d).

The focal mechanisms obtained using these different methodologies agree acceptably well. However, it is possible notice that there are some slight differences in the final focal mechanisms due to the fact the QRCMT and the TDMT technique use a different velocity model, the QRCMT solution is near the acceptable limit of magnitude, and the final TDMT solution is obtained just using three broadband seismic stations within a distance range of 40 km (http://earthquake.rm.ingv.it/tdmt.php). The CAP method, successfully applied to study earthquakes with magnitude lower than 3 in other regions [Zhu et al., 2006], is able to furnish good quality solutions in the Messina Straits area in a magnitude range (3-4) which is not properly represented in the RCMT (Regional Centroid Moment Tensor) catalog [Pondrelli et al., 2006] and where the solutions estimated from P-onset polarities are often poorly constrained. Figure 3 reports the focal mechanisms computed with the CAP method. Most of events display normal faulting and dextral strike-slip.

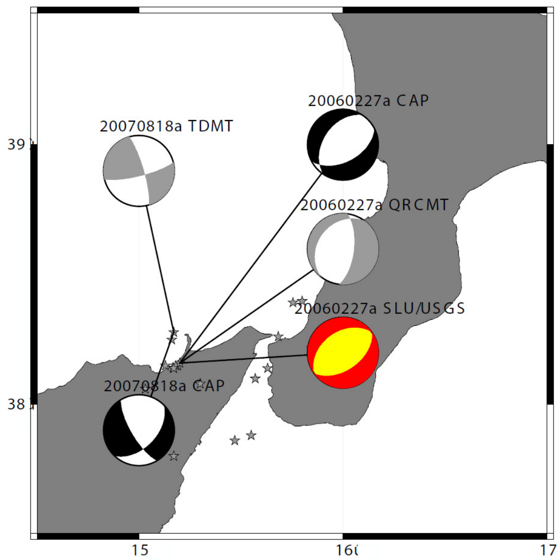


Figure 2 Comparison of the focal mechanism solution using different technique for two different events. The gray solution were computed by INGV (RCMT and TMDT solutions), The black ones were obtained in this study from the waveform inversion.

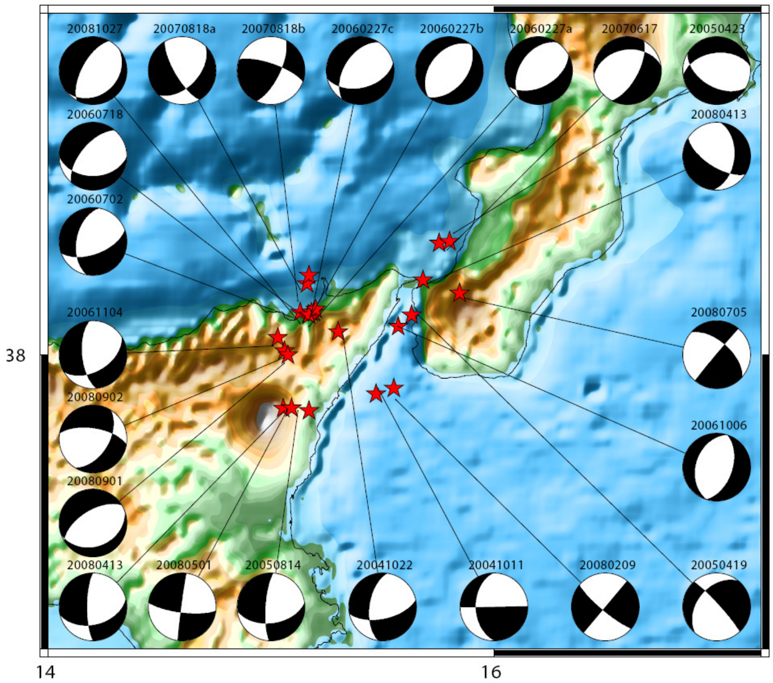


Figure 3 Focal mechanisms computed with the CAP method.

These results bring new data on the seismogenic mechanisms in the study area. The already existing information coming from the application of waveform inversion methods (CMT, RCMT and TDMT) is limited to 6 data only relative to earthquakes of magnitude greater than 4. The solutions estimated by inversion of P-onset polarities (Frepoli and Amato, 2000; Gasparini and Vannucci, 2004; Neri et al., 2004) are affected by uncertainties larger than 15-20° due to poor network geometry caused by offshore location of many events and the lack of OBSs in the study.

The new data obtained in the frame of this Project can lead us to make some progress in the knowledge of tectonic stress accumulation mechanisms and consequent processes of seismogenic faulting in the area of our interest.

2.1 Activity of UR in phase 1

The first year activity of the UR-Messina primarily consisted (a) in the preparation of the earthquake dataset relative to seismicity occurring during 1988-2007 in the Messina Straits area and (b) the focal mechanism computations by application of different techniques. Up to date, the analyses have been performed using the information collected during the last twenty years by the local and national permanent seismic networks. In the third semester, we are going to use also the data coming from the current INGV experiment in the study area (Messina 1908-2008).

We extracted from the INGV seismic catalogue all the earthquakes occurring in the study area until October 2008 characterised by focal depth less than 25 km and magnitude Ml ranging between 3 and 4.1. The dataset was restricted to the earthquakes recorded at a minimum of 4 three-component seismic stations equipped with broad-band sensors such as Trillium 40s, STS-2-120s, and Lennartz-3D-20s, located within a radius of 300km from the epicenter. The final data set used in this study consisted of about 1000 waveforms from 23 earthquakes. We relocated these events using the BAYLOC non-linear probabilistic location method by Presti et al. (2004, 2008) and the 3-D seismic velocity model proposed for the study area by Barberi et al. (2004).

The state of art of knowledge on the earthquake mechanisms is represented by few solutions from waveform inversion (CMT, RCMT, TDMT solutions relative to earthquakes of magnitude 4 and larger; Pondrelli et al. [2006], http://earthquake.rm.ingv.it/tdmt.php), and by tens of solutions estimated with the traditional methods of P-onset polarity inversion (Frepoli and Amato, 2000; Gasperini and Vannucci, 2004; Neri et al., 2004). Nearly all the fault plane solutions estimated by inversion of P-onset polarities are affected by uncertainties larger than 15-20° due to poor network geometry caused by offshore location of many events and the lack of OBSs in the study area.

We computed the moment tensor solutions using the “cut and paste” method based on broadband waveform inversion (Zhu and Helmberger, 1996, and Zhu et al., 2006). These results bring new knowledge on the seismogenic mechanisms in the study area. The results are going to be interpreted also in cooperation with others UR of this Project.

The obtained focal solutions have been integrated with the data available in the official databases and in the literature. The already existing information coming from application of waveform inversion methods (CMT, RCMT and TDMT) is limited to 6 data only relative to earthquakes of magnitude greater than 4. The solutions estimated by inversion of P-onset polarities (Frepoli and Amato, 2000; Gasparini and Vannucci, 2004; Neri et al., 2004) reveal the “gross feature” of prevailing normal faulting but do not indicate any other significant feature. The new focal solutions, which will be obtained using also the data coming from the current INGV experiment in the study area, will hopefully lead us to obtain in the second year of the Project remarkable progress in the knowledge of tectonic stress accumulation mechanisms and consequent processes of seismogenic faulting in the area of our interest.

2.2 Deliverables

D16 (100%) Title: Database of focal mechanisms of earthquakes in the Messina Straits over the time period between 1988 and 2007

2.3 Problems and difficulties

No problems were encountered

2.4 Key publications

D'Amico, S., Orecchio, B., Presti, D., Zhu, L., Herrmann, R. B., Neri, G., 2009. Moment tensor solutions of recent earthquakes in the Messina Straits area, southern Italy. Abstract presented at the Seismological Society of America, Annual Meeting Monterey, CA, (USA), April 8 - 11 2009.

D'Amico, S., Orecchio, B., Presti, D., Zhu, L., Herrmann, R. B., Neri, G., 2008. Moment Tensor Solutions in the Area of the 1908 Messina Earthquake: Preliminary Results. Abstract presented at the 1908 – 2008: Scienza e Società a 100 anni dal grande Terremoto Conference, Reggio Calabria (Italy), December 10-12 2008.

Neri, G., Presti D., 2008. Indagini sismologiche per la caratterizzazione delle strutture sismogenetiche e la valutazione dell’hazard sismico nell’area dello Stretto di Messina e settori limitrofi. Abstract presented at the 1908 – 2008: Scienza e Società a 100 anni dal grande Terremoto Conference, Reggio Calabria (Italy), December 10-12 2008.

Neri, G., Orecchio, B., Presti, D., 2008. Sismicità attuale, campo di sforzo e dinamiche litosferiche nell’area dello Stretto di Messina. In “Il terremoto e il maremoto del 28 dicembre 1908”, INGV-SGA, edited by Bertolaso G., Boschi E., Guidoboni E., Valensise G.

Report of UR05 of the project S5 by Antonio Avallone

Since 2003, INGV deployed a continuous GPS network (RING, http://ring.gm.ingv.it) in order to study the complex pattern of deformation in the Central Mediterranean, at the plate boundary between Africa and Eurasia. Most of the CGPS sites, acquiring at 1Hz and 30s sampling rate, are integrated either with broad band and very broad band seismometers or accelerometers for an improved definition of the seismically active regions. Most of the sites are connected to the acquisition centre (located in Rome and duplicated in Grottaminarda) through a satellite system (VSAT), while the remaining sites transmit data by Internet and classical phone connections. Both the satellite and the Internet data transmission allow the real-time epoch by epoch data acquisition at the acquisition centres. In the figure 1-left we show the location of all the CGPS sites which are acquiring and transmitting data in real-time. This network represents the high-rate GPS reference network outside the investigated area, such as the Irpinia region. In the figure 1-right, we show the locations of all the RING sites present in the Irpinia area. All the sites present in this figure transmit data in real-time: green triangles represent sites transmitting data at 1Hz, while red triangles correspond to sites transmitting data with a rate of 1 epoch every 30s.

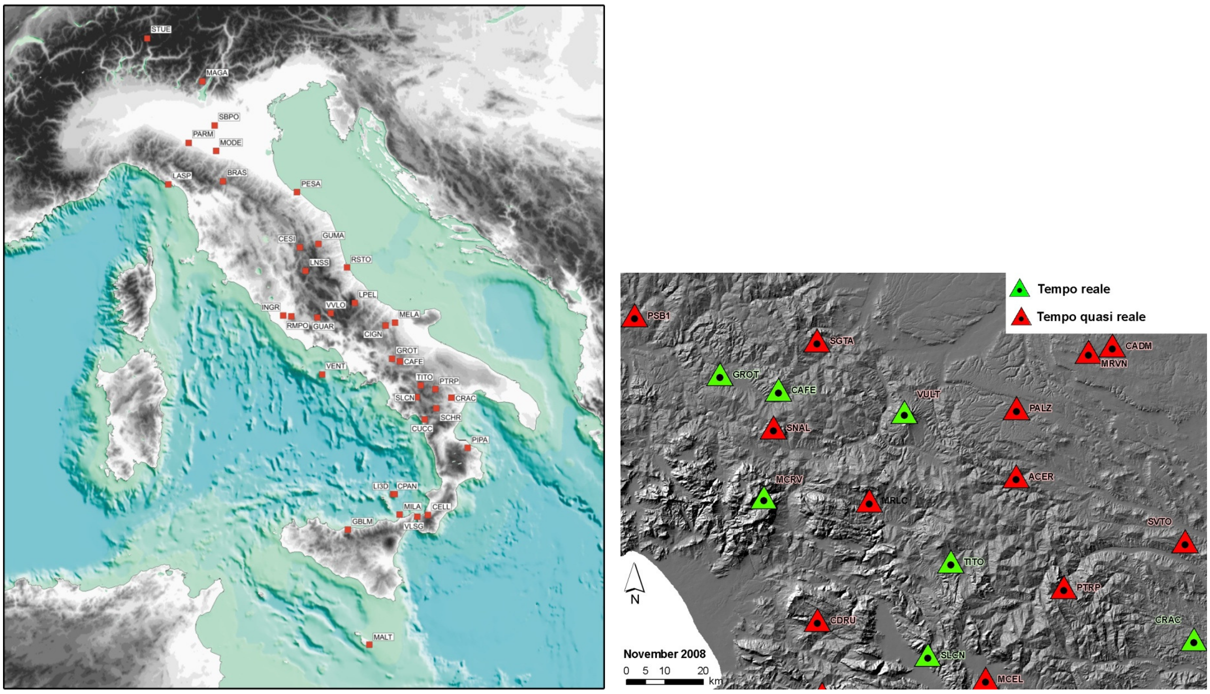


Figure 1: (left) Present-day RING Real-time (1Hz) network; (right) present-day real-time (1Hz) and quasi-real-time (every 30s) network in Irpinia area.

Most of the sites in Irpinia transmit data either by satellite telemetry (every 30s) or by Internet connections (every 1s). The Internet connection is assured by using the GPRS/UMTS technology (Falco, 2008). We choose an alternative and redundant transmission type to assure the acquisition of the data, which represent a fundamental aspect in case of emergency. The High-rate data acquisition at the sites in Irpinia represents one of the topics of the project, because the quick estimation of the potential co-seismic dislocations at RING sites after an earthquake strongly depend on the latency of the acquired data. The 1Hz data are stored in Rome and Grottaminarda with a ringbuffer strategy spanning a period of 1 week, thus assuring a sufficient amount of data to retrieve co-seismic and immediately successive post-seismic signals. In case of event, the ringbuffer is turned off and the data are stored in the hard disk.

The other main aim of the workpackage 3.4 in the 1st year consisted in learning how to analysis the acquired high rate GPS data. Traditionally, the active tectonics studies require a

GPS data processing strategy which allows to obtain a daily solution with data sampling rate at 30s. However, in this project, the need to obtain quick determinations of the co-seismic displacements at the CGPS sites after an earthquake, constrain us to process GPS data with a completely different strategy. The data should be analyzed epoch by epoch. We used the Gipsy/Oasis II software, a non-commercial geodetic-quality software developed at JPL (Zumberge et al., 1997). For the epoch by epoch analysis we used the "gd2p" Gipsy program to obtain a kinematic solution for each site. The kinematic solution allows us to carry out, for each epoch, the position of each site with respect to its nominal a-priori precise position. The analysis uses data for all the satellites located above an elevation angle of 15° with respect to the horizon. For the moment, we used a procedure which works with a post-processing approach by using and constraining precise JPL orbits to estimate the station positions. We applied this analysis to data of the CGPS sites described in the work of Blewitt et al. (2006). In addition, the station coordinate time series were calibrated to mitigate carrier phase multipath error, which approximately repeats every sidereal day [Genrich and Bock, 1992; Choi et al., 2004]. This calibration was computed using a position-based sidereal filter, by stacking the 30-s epoch coordinate time series from the previous 4 days, shifting each series by 4 min per day.

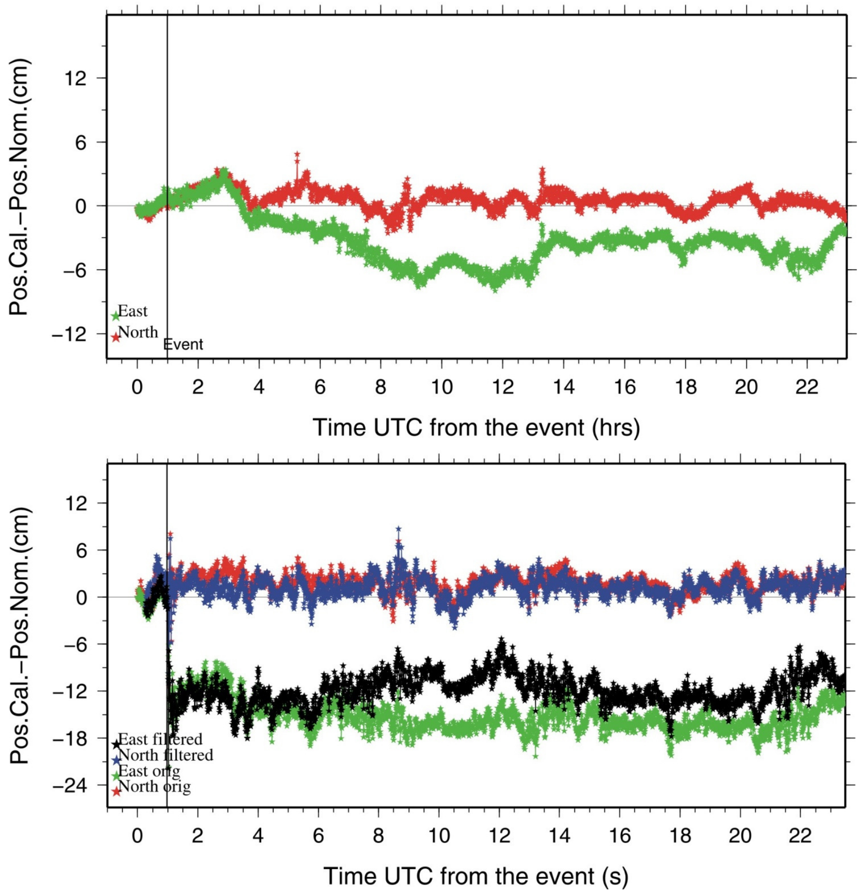


Figure 2: (top) Contribution of the multipath effect in a time period spanning 24h for he two horizontal components; (bottom) comparison between the analysis for the site SAMP before (red and green stars for the North and East components respectively) and after appliying sidereal filtering (blue and black stars for the North and East components respectively). Vertical black line corresponds to the earthquake time.

In Figure 2 we show the contribution of the sidereal filtering computed for the site SAMP, located 300 km far away from the epicenter. The contribution of the sidereal effect at the time of the earthquake is quite low. However, it is important to notice that in case the earthquake had occurred between 10am and 12am, the co-seismic displacement detected on the East component would have been largely overestimated (6 up to 10 cm). After applying the sidereal filtering, the results obtained for the stations SAMP and NTUS are perfectly comparable to the ones obtained by Blewitt et al. (2006) (Figure 3).

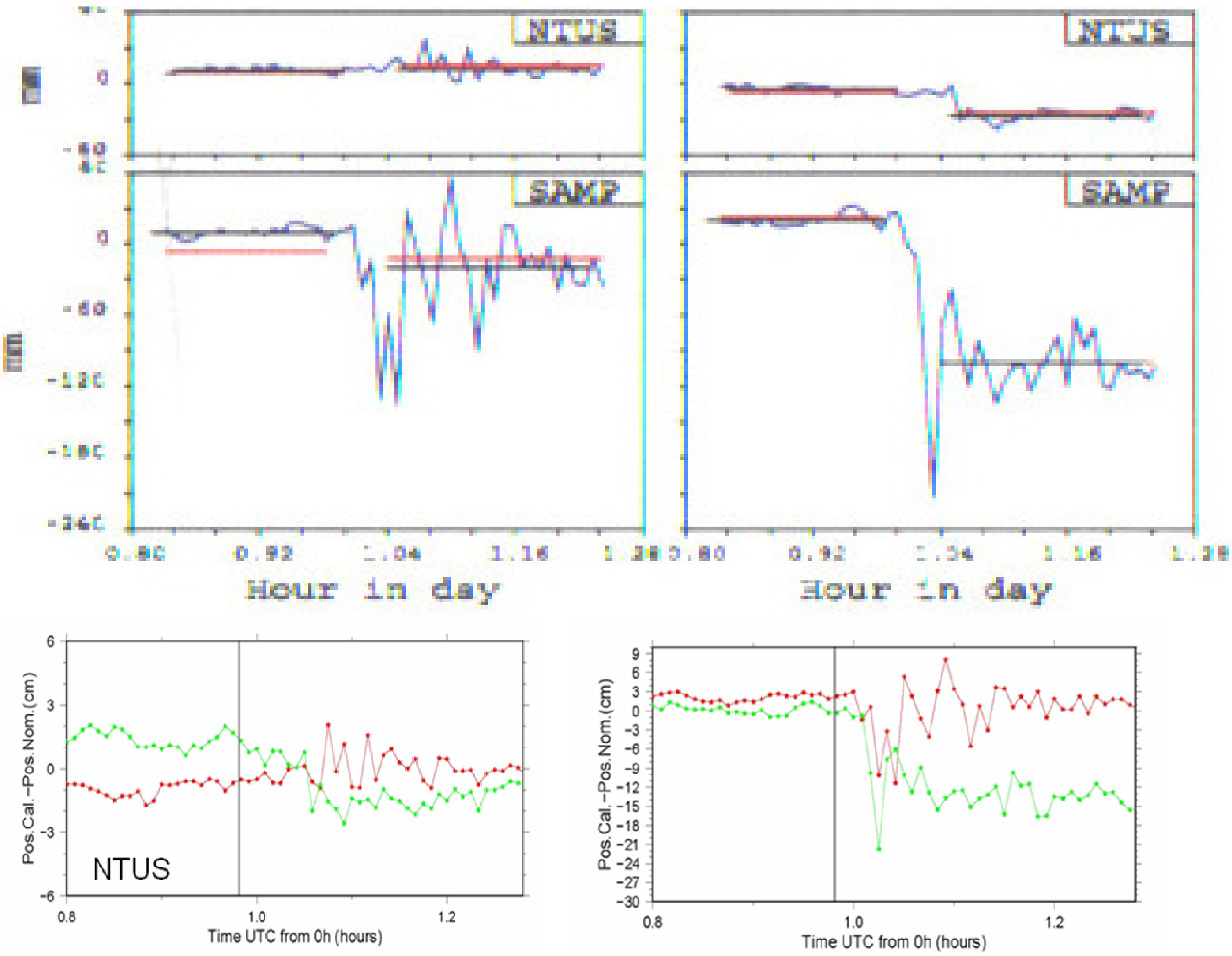


Figure 3: (top) Co-seismic displacements detected at NTUS and SAMP sites in occasion of the Sumatra earthquake by Blewitt et al. (2006). (bottom) Co-seismic displacements detected at NTUS and SAMP sites obtained with this study.

The next steps of the work are devoted to transform this procedure in a quasi real-time procedure to detect quick co-seismic displacements few tens of minutes after the earthquake. Furthermore, the developed procedure will be applied also to the data collected in occasion of the earthquake occurred at l'Aquila the last April, 6th, 2009.

2.1Activity of UR in phase 1

High-rate GPS acquisition: All the RING sites located in Irpinia area now transmitting data in real- or quasi real-time. All of them transmit data 1 epoch every 30s by satellite telemetry and most of them (5 of the 7 sites) transmit data also at 1Hz by GPRS/UMTS technology.

High-rate GPS processing: Advances in the epoch by epoch GPS data analysis have been made by using the Gipsy software, a noncommercial geodetic-quality software developed at JPL (Zumberge et al., 1997). Presently, a kinematic solution in post-processing is performed to obtain the variation of the position of each site with respect to its nominal a-priori precise position. The post-processing procedure has been used applied to the Sumatra earthquake GPS data, as done Blewitt et al. (2006), and the results are perfectly comparable.

2.2 Deliverables

- acquisition, storage and analysis of high-rate GPS data in the Irpinia test area: 100 %
- development of a procedure for detecting the mean ground displacement associated with the arrival seismic waves: 0%
- analysis of earthquake detection thresholds for the investigated area: 0%

2.3 Problems and difficulties

A 3-months delay in the planned work has been represented by the beginning of the fellowship founded by this project. The fellowship started on August, 1st , 2008, while the project started on May, 1st , 2008.

Furthermore, because of the occurrence of L'Aquila earthquake, most of the people involved in this project were devoted to discrete GPS measurements in the epicentral area to obtain a co-seismic displacement and a first model of the activated fault. Moreover, 3 new permanent stations have been created to study the post-seismic effect related to the earthquake.

2.4 Key publications

Falco L., 2008, Implementazione e gestione di una rete di monitoraggio GPS e sismica mediante tecnologie GPRS/EDGE/UMTS/HSDPA, rapporti tecnici INGV, n. 69.

Report on the project by UR6 – Unina Fed II Responsible: Prof. Aldo Zollo

2.1 Activity of UR 6 "UniNA" in phase 1

Workpackage 3.1: **Seismic noise analysis and Green functions**

The main objectives of the Workpackage are (1) the computation of Green functions among the broad-band ISNet stations, from noise cross-correlation; (2) the S wave velocity model for the Irpinia area, to be compared to P wave tomographic models derived from the inversion of first arrivals; (3) the extension of the method up to higher frequencies (0.5 to 1 Hz), with the investigation of the stability and robustness of the solutions.

The appraisal of the Green function from cross-correlation of ambient noise is a well consolidated technique at global and regional scales, where coherent sources are associated with the low frequency motion of the oceans. In such cases, low frequency signals (between 0.01 and 0.1 Hz) are cross-correlated and stacked over a period of several months. In this WP, we started to apply the technique to the local scale of ISNet, the characteristic size of which is about 100 km with an inter-station distance of 10-20 km. There are several problems in downscaling the methodology at smaller wavelengths. First, the arrival time of low frequency contributions (below 0.1 Hz) is so close to the origin, that they cannot be recognized from the cross-correlation. Hence, it is necessary to move to higher frequencies (above 0.1Hz), where the coherency of the noise may be lost between the stations. We also apply the one bit normalization to the data, to cancel out the phases which not clearly appear with the same shape and frequency content at both stations. In such a case, we need to sum up a large amount of signal to allow the Green function to get raised from the noise.

We processed 4 months of data from the broad-band stations COL3, RDM3, RSF3 and TEO3, starting from July 15, 2008 to November 13, 2008. Single station data have been subdivided in windows of 6 hour length, such a time representing a good compromise between the amount of RAM required by the computation and the accuracy of the cross-correlation. Data have been filtered and whitened in the frequency band 0.1-1 Hz; then they have been one-bit normalized in order to suppress any information about the amplitude and preserve only their phase content. For each couple of stations, data have been time-aligned and common windows selected for the computation of the cross-correlation. Final traces have been stacked with the constrain that the signal to noise ratio is larger than 3, where the signal corresponds to the maximum of the amplitude in a time window compatible with the surface wave arrival and the noise is measured as RMS on the coda of the cross-correlation.

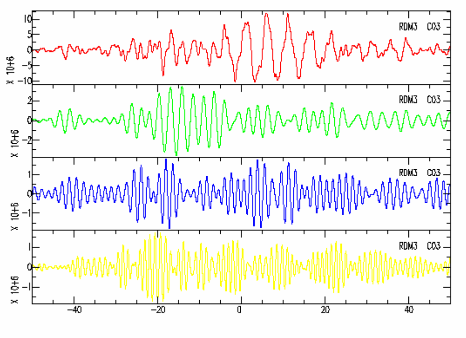


Figure 4 Total cross-correlation for the couple of stations RDM-TEO, stacked over 4 months of records (upper panel) and the same function filtered in the frequency bands 0.3-0.5 Hz, 0.5-0.7 Hz and 0.7-1 Hz respectively. In the filtered traces a dispersive wave is visible at a negative time, indicating an anisotropic source of noise, likely propagating signal from West to East.

As results for the first year, this WP (1) completed the procedure for data recovery and conversion for the computation; (2) realized a software for the preprocessing of the noise recorded at the single stations and the computation of the cross-correlation; (3) provided the cross-correlation for all the possible couples of broad-band stations for ISNet; (4) started the analysis of dispersion for the retrieval of the dispersion curves for surface waves.

The software realized by the WP has been tested against the one of Campillo and Stehly. The comparison is performed through the analysis of data recorded at two stations located in central Europe at

regional distances, for which the cross-correlation clearly show the presence of the Green function. The good agreement between both solutions confirmed the goodness of the procedures used in this work.
In Figure 1 we plot (upper panel) the cross-correlation between the stations of RDM3 and TEO3. The filtered Green function in the bands 0.3-0.5 Hz, 0.5-0.7 Hz and 0.7-1 Hz are plotted in the underneath panels. The surface wave is not symmetric but clearly appears on the negative branch of the cross-correlation indicating a dominant source of noise located westward with respect to ISNet. Very often cross-correlation functions are asymmetric.

Workpackage 3.2: **Refined estimates of micro-earthquake source parameters**

The objective of this work package is to achieve high-resolution images of the Irpinia active fault system through the accurate determination of source parameters of micro-earthquakes in the magnitude range $1<M<3$. During the first year of the project we developed several procedures for automatic event detection and analysis of local earthquakes recorded at the Irpinia Seismic Network (ISNet). While automatic detection guarantees a completeness threshold of about ML 2.0, by setting up a manual procedure, through visual inspection of helicorders, we were able to lower this threshold to about ML 1.0.
We performed a manual re-picking of local earthquakes recorded by the ISNet and the nearby INGV stations in the period 2005/08/22 – 2008/09/28. The number of events is 640 (44703 traces), for a total number of 4705 P picks and 2916 S picks.
A first evaluation of picking consistency has been performed analyzing the modified Wadati diagram (Chatelain, 1978), which also provides an estimate of Vp/Vs of 1.87.
Then, picking quality has been assessed by performing a preliminary location and looking, for each station, at outliers on the histograms of residuals. The 1D velocity model used for location has been constructed as a 3-layer gradient model, visually averaging several models of the area available in literature. For all the analyses we used the NonLinLoc location code (Lomax et al., 2000). A selected data set of 230 well-constrained earthquakes is now being used for determining an optimal, 1D P velocity model of the area, using the Velest code (Kissling et al., 1994).
Furthermore we have developed an automatic procedure for the inversion of the P and S-displacement spectra and the computation of the following source parameters: seismic moment, moment magnitude, corner frequency, source radius, seismic energy, static and apparent stress releases.
For this aim a selected data-set of 339 earthquakes recorded between 2005 and 2008 has been compiled, integrating the ISNet traces with recordings from the nearby INGV stations and manually picking the first-P arrival. The total number of traces analyzed is 15297. The results of S-wave analysis are presented in this report. We made use of the source spectral model by Brune (1970), and of a propagation term which takes into account for the attenuation, through the travel time T and the quality factor Q_S. We studied the $t^*=T/Q_S$ parameter as a function of the hypocentral distance. The results show that t^* does not depend on distance (it is well represented by a Gaussian distribution

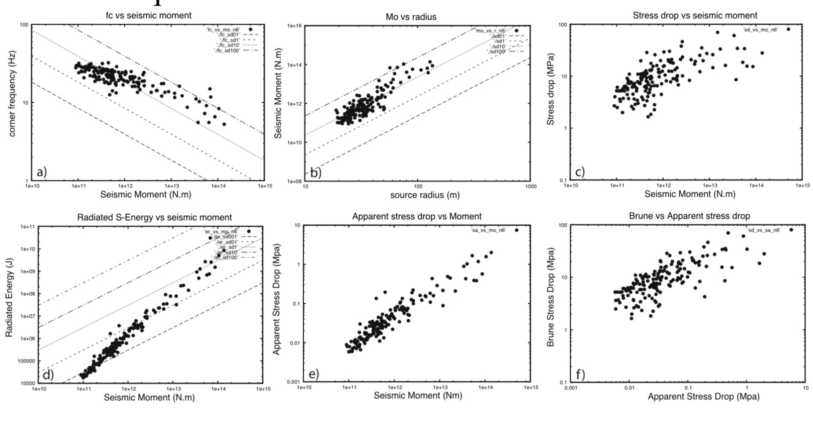


Figure 2 Retrieved scaling relationships for microearthquake source parameters. a) corner frequency vs. seismic moment; b) seismic moment vs. Madariaga source radius c) Brune stress drop vs. seismic moment d) radiated energy vs. seismic moment e) apparent stress vs. seismic moment d) Brune vs. apparent stress

centered on t*=0.027 sec), suggesting that Q_S varies almost linearly with hypocentral distance. We therefore corrected the S wave spectra for a t* value of 0.027 sec and inverted the resulting spectral shape for estimating the seismic moment, radiated energy and corner frequency parameters. The retrieved scaling relationships for the average source parameters are reported in figure 2, where averages and standard deviations are computed using a minimum number of 6 data from acceleration and velocity sensors. The S-wave corner frequencies decreases with seismic moment, according to a constant Brune stress drop law (self-similarity) down to Mo about 1e12 Nm (Mw ~ 1.9) (figure 2a).

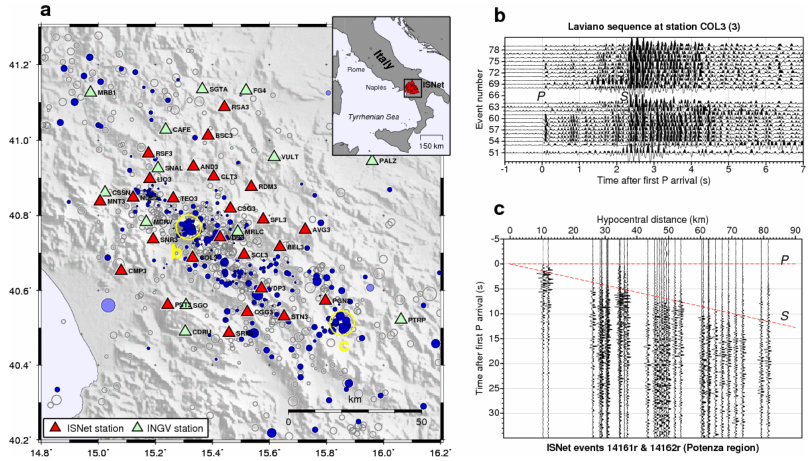


Figure 3 (a) Map of seismic stations and l ocal events currently available for this study. Filled circles represent events from the ISNet bulletin (since December 2007), and gray circles are events recorded between August 2005 and November 2007. The circle size is proportional to the local magnitude. Yellow circles mark the source regions of the seismograms shown on the right. (b) Vertical-component seismograms of events from the Laviano sequence recorded at station COL3, aligned at the first P onset. (c) Horizontal-component seismogram section

At smaller seismic moments, there appears an abrupt slope change which is the evidence for a violation of the self-similar scaling at very small magnitudes (Mw < 1.5). The plot of Brune stress drop vs. seismic moment (figure 3b) confirms the transition at Mo about 1e12 Nm, above which the stress drop is nearly constant with a value of 30 MPa (figure 2c).
The radiated seismic energy (Er - computed from the integral of the spectrum) depends on Mo (figure 2d), but with a slope greater than expected from the relation $asd = \mu\, Er/Mo$ (where μ is the shear modulus - Wyss, 1970). This implies that the apparent stress drop (asd) varies with the seismic moment (figure 2e).
Finally, the apparent stress drop is correlated with the Brune stress drop (figure 4f), but is almost two orders of magnitude lower, in accordance with results from Abercrombie (1995).

Workpackage 3.3 "**Reflection seismology applied to micro-earthquake data**"

In this work package local micro-earthquakes are used to image the crustal structure in the greater Irpinia region (in cooperation with WP3.2). Applicable methods include standard reflection processing, array beamforming and migration for reflected/converted events as well as the earthquake sources themselves, and possibly reflection tomography. The first-year activity comprised of data collection and pre-processing, data gathering and identification of event clusters, related software developments, the definition of a background velocity model, and initial imaging tests. Multi-component waveforms for about 850 local events are currently available for the time period August 2005 to April 2009 (Figure 3a), and 120 of these events have a local magnitude of 2 or larger. A common set of meta data has been defined, which permits a reliable quality control and an easy integration of future events. Typically, waveforms with a manual first-arrival pick, i.e. waveforms with a good signal-to-noise ratio, are used in this study. Previously developed codes for array beamforming or migration of microearthquake data have been modified for acquisition geometries with sources and receivers at arbitrary depths. These codes have been tested successfully on a limited data set of local and near-regional events. Optimization and the systematic application to the entire data set is scheduled for second year of this project. By-products of the software development phase are utilities for reading and manipulating SAC headers, and (experimental) codes for first-arrival picking. The recorded seismograms are organized in trace gathers (e.g. common shot or common receiver) for processing parameter tests, identification and picking of secondary phases, and for imaging/migration applications. Figure 3b shows a common-receiver gather for a cluster of earthquakes with very similar waveforms, which have been selected automatically by a cross-correlation analysis. Several coherent secondary phases are clearly visible before the first S onset at about 2.2 s. Such clusters are either suitable for source array beam imaging, or the traces may be stacked to increase the signal-to-noise ratio, if the individual events are nearly co-located. Figure 3c shows a horizontal-component common-source gather, constructed from two similar events to increase the spatial coverage in the entire offset range. Some coherent arrivals can be seen in the S coda, e.g. near 16 s in the central part of the section. This type of a trace gather also helps to correctly identify and pick the first S onset, which can then be used for a refined event relocation.

2.2 Deliverables
D.20 Refined re-picking arrival time catalogue and earthquake locations (Irpinia test-site) (50% of completion)
D.21 Parametric catalogue of micro-earthquakes including source parameters (Irpinia test-site) (50% of completion)

2.3 Problems and difficulties
N/A

2.4 Key publications

Bobbio A., Vassallo M., Festa G., 2009. A local magnitude scale for southern Italy, Bull Seis. Soc. Am., in press

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Iannaccone G., Zollo A. et. al., 2009. PRESTo: a new stand-alone software tool for earthquake early warning, The 2nd International Workshop on Earthquake Early Warning, Kyoto, Japan.

Iannaccone G., Zollo A., Satriano C. et. al., 2009. The Irpinia Sesimic Network (ISNet): hardware and data management, EGU General Assembly, Vienna, Austria

Stabile T.A., De Matteis R., Zollo A. and Emolo A., 2009.COMRAD: a dynamic ray-tracing algorithm for rapid multi-phase seismogram computation, EGU General Assembly, Vienna, Austria

Satriano et al. 2009. Earthquake Early Warning: System performance and application design, International Workshop on Real Time Seismology: Rapid Characterization of the Earthquake Source and of its Effects, Erice, Italy, May 2-8.

Zollo A., 2009. The earthquake early warning system in Southern Italy: technologies, methods and performance evaluation, The 2nd International Workshop on Earthquake Early Warning, Kyoto, Japan.

Zollo A., 2009. Lectures on "Real time processing and seismic alert with examples of their implementation", IASPEI Summer Training School, General Assembly, Cape Town, South Africa, 10-16 Gennaio

Zollo A., Iannaccone G. et. al., 2008. Performance test of earthquake early warning system in southern Italy, ESC – XXXI General Assembly, Crete, Greece, 7-12 September