NEAR REAL TIME REGIONAL MOMENT TENSOR ESTIMATION USING ITALIAN BROADBAND STATIONS

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1] Abstract

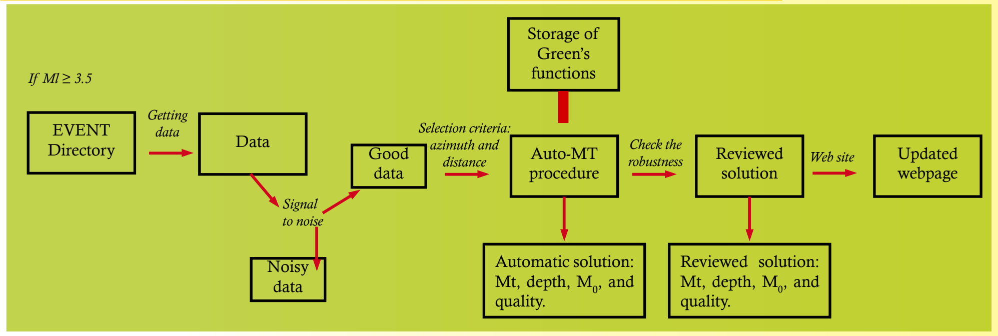
Since 2002, the National Institute of Geophysics and Vulcanology (INGV) in Rome has started the installation of a high quality regional broadband network throughout the Italian territory. Up today, the network consists of 125 stations equipped with 40 s natural period instruments. The dense station coverage allows for the implementation of real-time regional moment tensor (MT) estimation procedures such as that proposed by Dreger and Helmberger (1993).

The automatic MT algorithm uses real-time broadband waveforms continuously telemetered to INGV, and it is triggered for events with magnitude greater than Ml 3.5. This is the lowermost value for which we have found it possible to obtain reliable MT determination in the frequency band used in the inversion. The automatic solution is available within about 3-5 minutes after the earthquake location. Each solution has an assigned quality factor dependent on the number of the station used in the inversion, and the godness of fit between synthetic and observed data. MT is published on the web after revision by a seismologist.

Efforts are also made to evaluate MT solutions for earthquakes occurring in Italy and neighboring regions in the last years. The results are compared to those obtained from application of other moment tensor methods. It is always found a good agreement between the newly determined solutions and those from other methods.

Overall, fast and accurate moment tensor solutions are an important ingredient when attempting to estimate the recorded ground shaking. Overall, in Italy, earthquakes in the magnitude range 3.5 – 5 are very common; the availability of their focal mechanisms allows the mapping of the principal stress field axes leading to a better understanding of the ongoing tectonics.

2] Automatic MT Procedure



The auto-MT procedure uses the 1D Time-Domain INVerse Code (TDMT_INC) software package (Dreger, 2003). It is activated by the Linux cron command, which severy 2 minutes for the existence of a new event. If the event exists, and if Ml ≥ 3.5, the auto-MT starts.

Getting Data

Data collected for the MT inversion are recorded by the INGV Seismic Network, and telemetered back to the seismic center through various communication modalities (e.g., internet, dedicated phone lines, and satellite). The network consists in 125 three components, broadband, high-dynamic range stations, all equipped with sensors Trillium 40s, and Trident digitizer (Fig.1). Waveforms have sampling rate of 100 samples/sec. When an Ml ≥3.5 event occurs, the automatic procedure downloads 800 s data window. Traces start 3 minutes before the event origin time to minimize the distortions induced by the bandpass filtering process at the edge of the signal. Data are corrected for the instrument response, resampled at an interval of 1 Hz, integrated to obtain displacement, and bandpass filtered in the 0.02-0.05 Hz frequency range for events larger than 3.8, and in the 0.02-0.1 Hz range for events smaller than 3.8. The horizontal components are

Figure 1. Italian network map, updated to october 2006.

Station Selection Criteria

The auto MT-procedure selects the best stations to use in the moment tensor inversion, looking for records with signal to noise greater than 5, with good azimutal coverage. Starting from North, the region is divided into 8 sectors of 45° around the event epicenter.

If a sector is populated by more than one station, the procedure chooses the one with the optimal epicentral distance relative to the event magnitude, following an empirically tested, weight-based criteria (Fig.2).

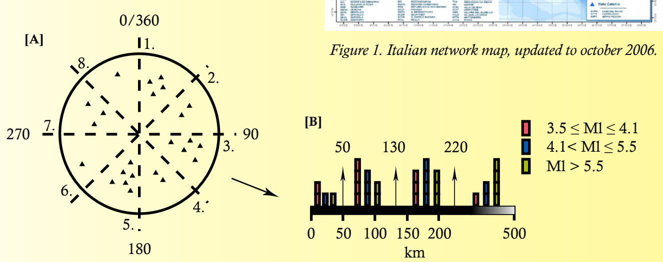


Figure 2. Example of the station selection criteria. Panel A: stations location around epicenter. Panel B: assigned weights to the stations, following an empirically tested mag.-dist. criteria.

Green's Functions

The Green's functions used in this procedure were computed with a frequency-wave number integration code (Saikia 1994). The model used to compute Green's functions is shown in Table 1. To reduce the time of the automatic procedure, the Green's functions for three fundamental faults (vertical strike-slip, vertical dip-slip and 45° dip-slip) are stored in a library. They form the basis functions for all the double-couple mechanisms. Green's functions have been computed for two different frequency bandpass (0.02-0.05 Hz and 0.02-0.1 Hz) at distances up to 500 km and depths up to 600 km.

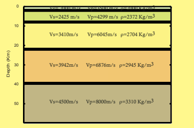


Figure 3: 1D Velocity structure used to evaluate the Green's functions.

MT Inversion: the Mw=4.2 2006/04/16 Forlì earthquake

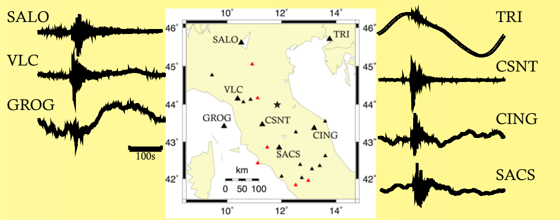


Figure 4. Forlì event-stations map. Triangles are the triggered stations; red color is for stations excluded for noisy data. Seismograms are the tangential displacement components for the inverted stations.

Forlì event was recorded by a large number of INGV Seimic Network. 24 stations were found within 250 km distance range. (Fig. 4). 6 stations were discharged by the signal to noise procedure. The resulting 18 stations were divided by azimuth (Fig. 2a and Fig. 5), and selected again following the distance-magnitude criteria (Fig.2b). Finally the inversion started with 7 stations, at the first depth of 3 km.

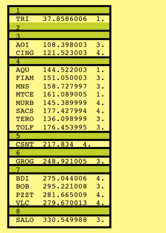
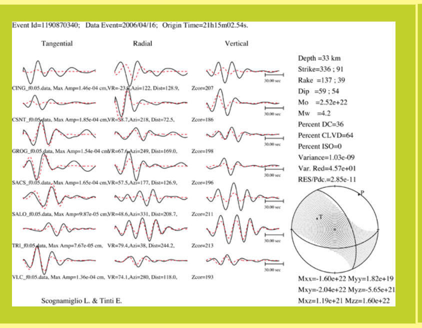


Figure 5. Available stations ordered by azimuth. Green stripes highlight the sector's number (see Fig. 2a).

The inversion is run at several point-source depths: 30 different depths between 3-80 km, for events that have been localized by the seismologist at depth shallower than 65 km, and almost 60 different depths between 40-600 km for deeper events. Source depth is found iteratively by finding the solution with the largest variance reduction. For the Forlì event, the algorithm best solution is a reverse focal mechanism, with Mw 4.2 and depth 33 km (Fig. 6).

AUTOMATIC SOLUTION

Figure 6: On the right side: automatic moment tensor solution and focal mechanism parameters; on the left: comparison between synthetics (red) and data (black), filtered in the 0.02-0.05 Hz frequency range. This example has a good azimuthal coverage (7 filled sectors). However, the best solution inferred by the procedure does not find a good fit for the CING station, which tends to deteriorate the overall fit, due to the unknown velocity structure.



DEPTH STABILITY

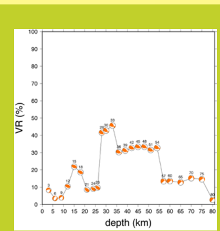


Figure 7: Focal mechanisms and variance reduction versus source depth. This plot shows the stability of the inferred solution. In particular, for this event the moment tesor is stable between 12 and 54 km.

For each MT solution, the automatic algorithm evaluates a quality value. This value can be A, B, C or D and it is dependent on the variance reduction value, and on the number of stations used in the inversion (Fig.8). For the automatic Forlì MT solution we got quality B.

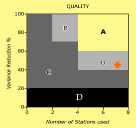
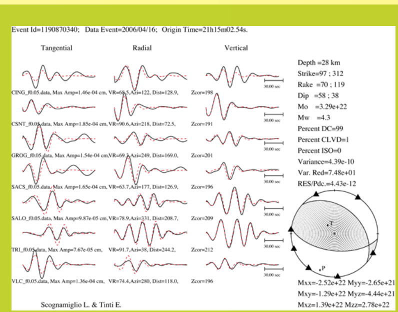


Figure 8: Sketch of the quality parameter criteria. Orange cross indicates the quality for the automatic Forlì solution.

From the time we have the event location reviewed by the seismologist on duty in the INGV seismic center, that is between 5 and 30 minutes after the earthquake origin time, we have an automatic MT solution, with its quality value, and the focal mechanism–depth plot, within 3 to 5 minutes.

Revised Solution

Not all the automatic solutions are good. Data, for example, may suffer of spikes or steps which, once the processing is applied, become hidden, and the solution will be uncorrect. In addition, the solution may fail because the adopted Green's functions are too simple to model the true velocity structure. In this case, the fit needs to be improved manually. The automatic procedure creates a review directory containing all the programs needed to check and manually improve the moment tensor solution. At this moment, all the automatic solutions are checked by a seismologist, before being posted on the web site.



REVIEWED SOLUTION

Figure 9: On the right, reviewed moment tensor solution and focal mechanism parameters; on the left, the comparison of synthetics (red) and data (black) within the 0.02-0.05 Hz frequency range. The reviewed solution has been mainly obtained by fixing the fit for the CING station. Zcor (that is the Green's function alignment parameter) was reduced by 9 samples, to account for the gap of knowledge in the velocity structure.

For the other stations zcor was changed in the typically testing values by +/- 3 samples. We didn't need to change any station, because those selected by the automatic procedure had a good signal.

Once the fit is improved manually varing the zcor parameter at any station, the seismologist on duty checks for some additional depths around the automatic depth solution. In this example the best solution has been found at 28km depth with total variance reduction of 75 %, resulting in a quality A solution.

3] Results and Comparisons

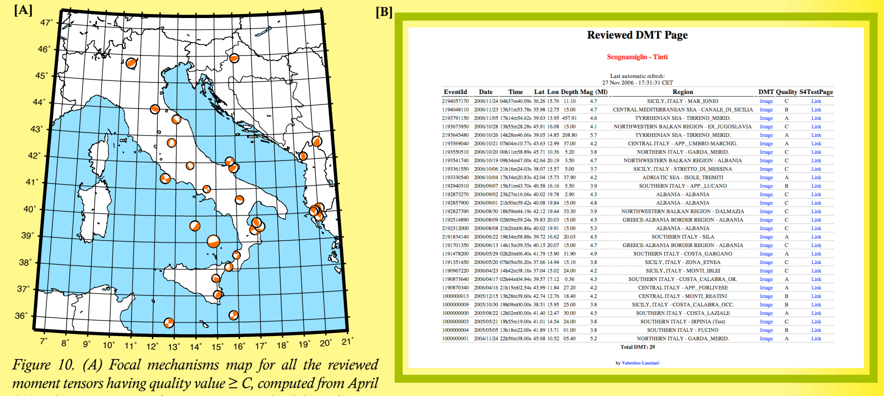


Figure 10. (A) Focal mechanisms map for all the reviewed moment tensors having quality value ≥ C, computed from April 2006 (automatic procedure starting time). (B) Web page prototype including the same solutions.

We compared some of our focal mechanism solutions, to those obtained from Centroid Moment Tensor method (CMT, Pondrelli et al., 2006). CMT are computed only for events with Mw ≥ 4.0.

The two solutions are generally consistent among each other.

Data	Region	CMT	DMT
06/11/24	Sicily, Italy	Mw=4.4; Depth=22 km	Mw=4.2; Depth=30 km
06/11/23	Central Mediterranean Sea	Mw=4.8; Depth=12 km	Mw=4.6; Depth=12 km
06/11/05	Tyrrhenian Sea	Mw=4.7; Depth=444 km	Mw=4.7; Depth=460 km
06/10/26	Tyrrhenian Sea	Mw=5.8; Depth=211 km	Mw=5.7; Depth=200 km
06/10/21	Central Italy	Mw=4.2; Depth=42 km	Mw=4.1; Depth=42 km
06/10/19	Northwestern Balkan Region	Mw=4.7; Depth=47 km	Mw=4.7; Depth=36 km
06/10/04	Adriatic Sea	Mw=4.3; Depth=12 km	Mw=4.1; Depth=36 km
06/06/22	Southern Italy	Mw=4.8; Depth=35 km	Mw=4.6; Depth=36 km
06/05/29	Southern Italy	Mw=4.6; Depth=33 km	Mw=4.5; Depth=24 km
06/04/17	Southern Italy	Mw=4.8; Depth=31 km	Mw=4.7; Depth=18 km
06/04/16	Central Italy	Mw=4.5; Depth=29 km	Mw=4.3; Depth=28 km
04/11/24	Northern Italy	Mw=5.0; Depth=18 km	Mw=4.9; Depth=12 km

Figure 11. Comparison between some of our moment tensor solutions (orange beach balls) and CMT focal

4] Summary

Work done

1. We have designed an automatic tool to evaluate MT in near real time for Italy, using the recently installed broadband INGV seismic network data and the TDMC_INV code. The automated procedure demonstrated that reliable moment tensor solutions can be obtained within 3 to 5 minutes after the revised earthquake location has been provided.

2. We have stored more than 7000 Green's functions filtered in the 0.02-0.05 Hz frequency range, as well as in the 0.02 0.1 Hz frequency range. Those Green's functions, computed with a representative velocity structure, go from 5 to 500 km in distance, and from 3 to 600 km in depth.

3. Automatic and reviewed MT solutions, with their quality value, are posted on the INGV web page (http://earthquake.rm.ingv.it/tdmt.php).

Work in progress

1. We are working on a regionalization of the Green's functions. We want to account, as much as possible, for the complexity of the Italian peninsula by means of 1-D velocity structures.

2. We are extending the italian MT data-base to earthquakes with Ml ≥ 3.5, by computing focal mechanism for "past" earthquakes.

3. We want to find a better indicator of solution quality by including a selection criteria based also on the percent of double-couple.

4. We are working to extend the auto-MT procedure to the whole Mediterranean Region.

References:

Dreger, D. S., and D. V. Helmberger (1993). Determination of source parameters at regional distances with single station or sparse network data, *J. of Geophys. Res.* **98**, 8107-8125.

Saikia, C. K. (1994). Modified frequency-wavenumber algorithm for regional seismograms using Filon's quadrature; modeling of Lg waves in eastern North America, *Geophys. J. Int.* **118**, 142-158.

Dreger. D. S. (2003). Time-Domain Moment Tensor INVerse Codel (TDMT-INVC) Release 1.1. *International Handbook of Earthquake and Engineering Seismology*, W. H.. K. Lee, H. Kanamori, P. C. Jennings, and C. Kisslinger (Editors), Vol B, 1627 pp.

Chiarabba C., L. Jovane, R. Di Stefano (2005). A new view of Italian seismicity using 20 years of instrumental recordings, *Tectonophysics* **395**, 251-268.

Pondrelli, S., S. Salimbeni, G. Ekström, A. Morelli, P. Gasperini and G. Vannucci (2006). The Italian CMT dataset from 1977 to the present, *Phys. Earth Planet. Int.*, doi:10.1016/j.pepi.2006.07.008,**159/3-4**, pp. 286-303.

Acknowledgements

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