A feasibility study on the near real-time calculation of the complete seismic moment tensor of the Etna seismicity: application to the earthquakes occurred during the December 2018 eruption

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INTRODUCTION

The complete seismic moment tensor (FULL TDMT, hereafter) computation allows to a complete definition of the seismic source through the inversion of the seismic waveforms. It permits to calculate the seismic source Double Couple component (DC), which allows identifying the nodal planes of the focal mechanism and the non - DC components, i.e. the Compensated Linear Vector Dipole (CLVD) and the volumetric component (ISO). The CLVD can be indicative of the generation of lenticular cracks and fluids dynamics, while the ISO component is an indicator of the volume variations due to explosions or implosions. Therefore, in a volcanic environment, retrieving the non-DC component is important, since it can provide useful insights into the understanding of the source origin and to evaluate the role of magma in the generation of earthquakes.
However, the non-DC components are very sensitive to the uncertainties of the inversion model and a critical analysis of results is needed before a proper interpretation of the moment tensor solutions.

INGV-ONT routinely computes near real-time automatic seismic moment tensor solutions (TDMT, hereafter) in Italy for $M_L \geq 3.5$ earthquakes constraining the ISO component to zero to obtain stable results for the orientation of the best double couple.

In this study, we investigate the possibility to compute, in near real time, the full TDMT (DC, CLVD and ISO components) for the Etnean seismicity. The objective is to tune the already implemented MT software for tectonic earthquakes in a volcanic environment and to test the procedure of obtaining near real time full moment tensor solutions also at INGV-OE. This will give a significant contribution to the monitoring activities of the Sicilian volcano.

To achieve our goal a feasibility study is required to tune the procedure, and to properly validate the results. As case study we considered 10 earthquakes related to December 2018 eruptive episode.

THE 2018 ERUPTION AS STUDY CASE

On 2018 December 24, after 10 years since the last lateral eruption, an episode of intrusion, fracturing and lava emission from the summit area of Mt Etna, was heralded by an increase in ground deformation and seismicity; it culminated on December 26 in a magnitude M_W=4.9 earthquake on the Fiandaca Fault (n. 8 in Table 1 and Figure 5).

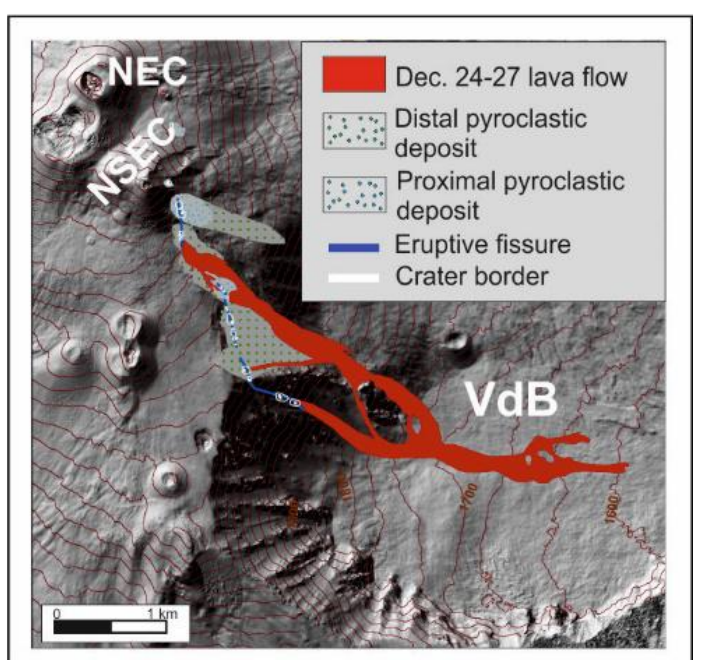

Figure 1 – Eruptive scenario of the 2018 Etna eruption: lava flows, pyroclastic deposits and the eruptive fractures are reported on the DEM of Etna summit area (De Beni et al., in preparation).

More than 3000 earthquakes were recorded by the INGV-OE seismic network and most of them were in the first 24 hours from the start of the eruption. Firstly, seismicity was located in the summit craters' area and along the eruptive fracture. In the weeks following the start of the eruption, the seismic activity continued with hypocentral locations in the summit area and affected also different sectors of the eastern and southwestern flanks (INGV, 2019. Bollettino settimanale sul monitoraggio vulcanico, geochimico e sismico del vulcano Etna. 24/12/2018 - 30/12/2018, Rep. N° 01/2019).

http://www2.ct.ingv.it/it/rapporti/multidisciplinari.html?view=docman&start=150

We selected the most energetic events ($M_L \geq 3.5$) occurred since 2018, October 10 to 2019 January 08, possibly related to the dynamic of the eruption.

N	DateTime	lat N	lon E	depth (km)	Ml	epicentral area
1	06/10/2018 00:34	37,617	14,855	7,37	4,7	S.Maria di Licodia
2	24/12/2018 10:27	37,82	15,111	0,31	3,5	3.4 km SW from Linguaglossa (CT)
3	24/12/2018 11:01	37,743	14,969	0,94	4	1.2 km E from Monte Palestra (CT)
4	24/12/2018 12:08	37,713	15,046	0,56	4	1.1 km W from Monte Zoccolaro (CT)
5	24/12/2018 16:50	37,71	15,045	0,86	4,3	1.3 km W from Monte Zoccolaro (CT)
6	24/12/2018 19:26	37,687	14,957	1,52	4	1.2 km NW from M. Parmentelli (CT)
7	25/12/2018 12:45	37,661	14,887	-1,59	3,5	2.6 km NE from Biancavilla (CT)
8	26/12/2018 02:19	37,644	15,116	-0,29	4,8	1.5 km NE from Lavinaio (CT)
9	04/01/2019 04:10	37,695	14,936	-0,99	3,5	2.2 km E from Contrada Feliciosa (CT)
10	08/01/2019 23:50	37,798	15,051	0,19	4,1	1.5 km NW from I Due Monti (CT)

Table 1 – Hypocenters and M_L value of the data used in this study as reported by the on-line INGV-CT catalogue (Gruppo Analisi Dati Sismici, 2019).

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METHODS & DATA

To compute the moment tensor and the full moment tensor solutions of Etna earthquakes, we adopted the algorithm developed by Dreger (2003) and Minson & Dreger (2008). We used waveforms from broadband 3-component stations provided by the Italian National Seismic Network (IV). Data are checked for signal to noise ratio larger than 5, corrected for the instrument response and the horizontal components are rotated to great circle path.

The Green's functions are computed by using the frequency-wavenumber integration code (FKPROG) of Saikia (1994) for three laterally homogeneous layered velocity structures: SICILY (Barberi et al.,2018), ETNA (Alparone et al.,2012) and NNCIA (Herrmann et al., 2011). Finally, data and Green's functions are filtered in the frequency band 0.01-0.05 Hz or 0.01-0.10 Hz depending on the M_L magnitude value.

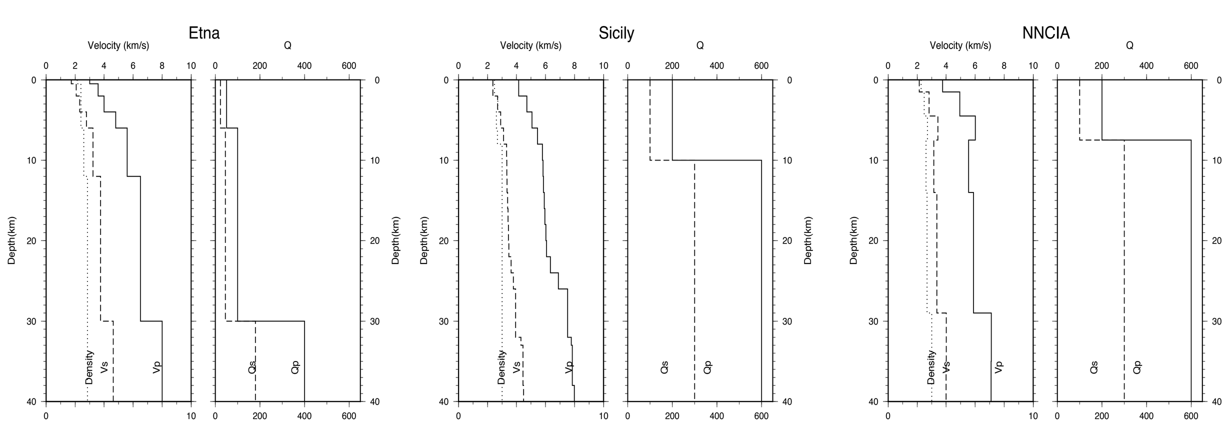
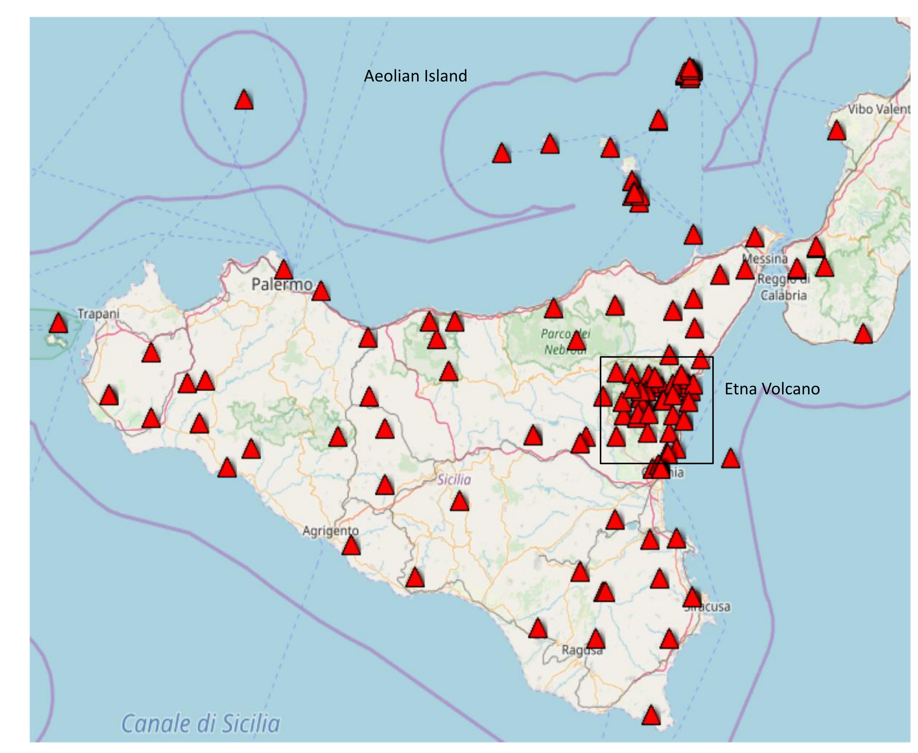


Figure 3 - Velocity models used in this study: ETNA (Alparone et al., 2012; Martinez-Arevalo et al., 2005), SICILY (Barberi et al., 2018; Martinez-Arevalo et al., 2005) and NNCIA (Herrmann et al., 2011).

Figure 2 - Map of the seismic station managed by INGV (red triangle).



RESULTS

Non-double couple mechanisms in volcanic environments are indicators of local modifications of the stress field induced by dike injection, high fluid pressure or by thermal cooling. Nevertheless, the possible biasing effects of wave propagation in structurally complicated regions, the presence of noise or the inappropriate station coverage can make the identification of non-double couple as true source phenomena uncertain (Saraò et al. 2010 and references therein). Therefore, a careful analysis is needed before to interpret the results.

TESTING VELOCITY MODELS

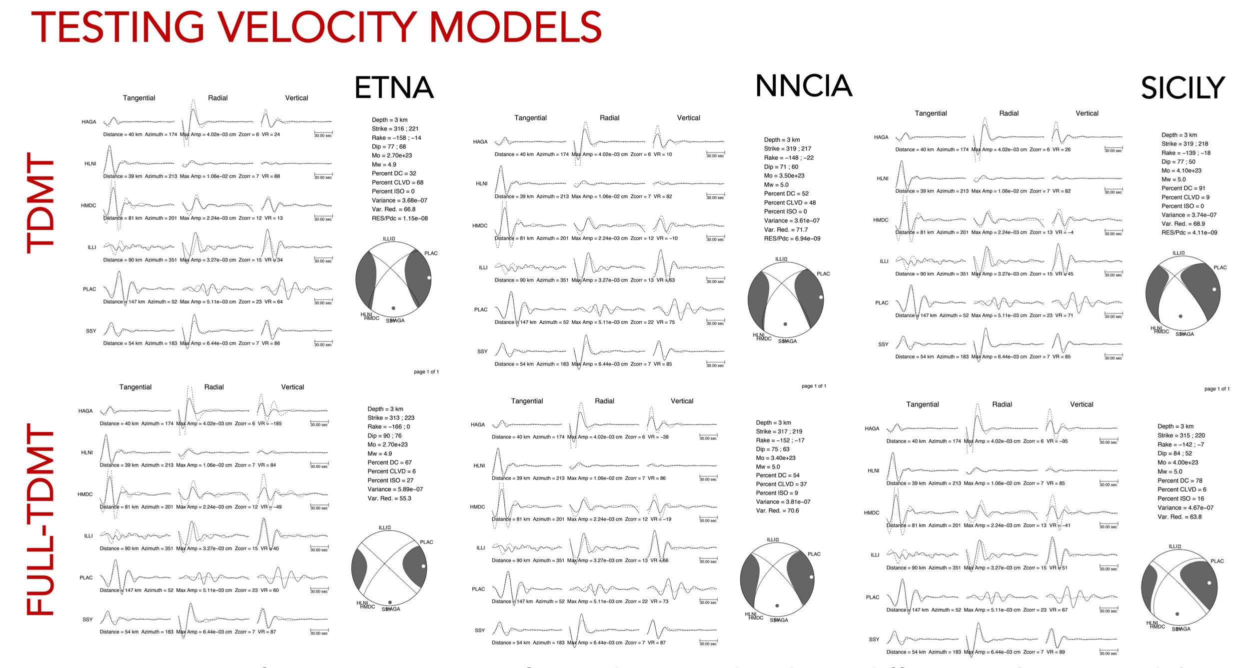
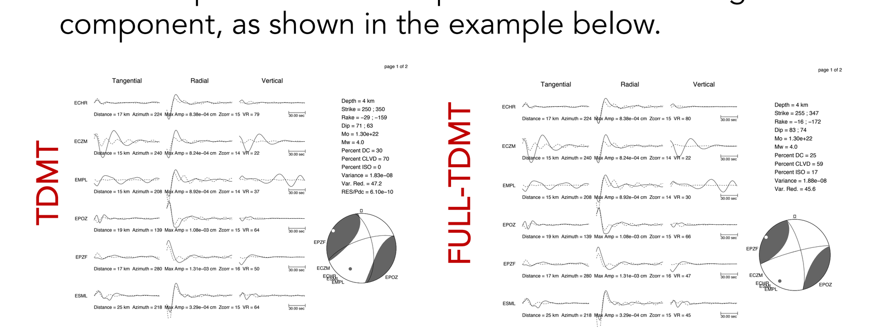


Figure 4 - Waveform inversions performed using the three different velocity model for the same event. For this event, the Etna model provides high ISO component, with respect to the others.

By inverting the records using the same station geometry, outside the volcano area, and the same frequency range we have seen that the three velocity models:

- have no influence on the resolution of the orientation of the best double couple for both applied code.
- affect the non-DC components.

When the the TDMT provides a low DC component, the Full-TDMT helps to confirm the presence of a meaningful non DC component, as shown in the example below.



COMPARING THE SOLUTIONS FOR THE ETNA SEQUENCE

The focal mechanisms retrieved by the TDMT and the full TDMT have been obtained using two different velocity models (NNCIA and Etna) and station geometry, as a first test to verify the robustness of the solutions. The computed moment tensor solutions are then compared with independent estimates of fault plane solutions calculated by the first polarities analysis.

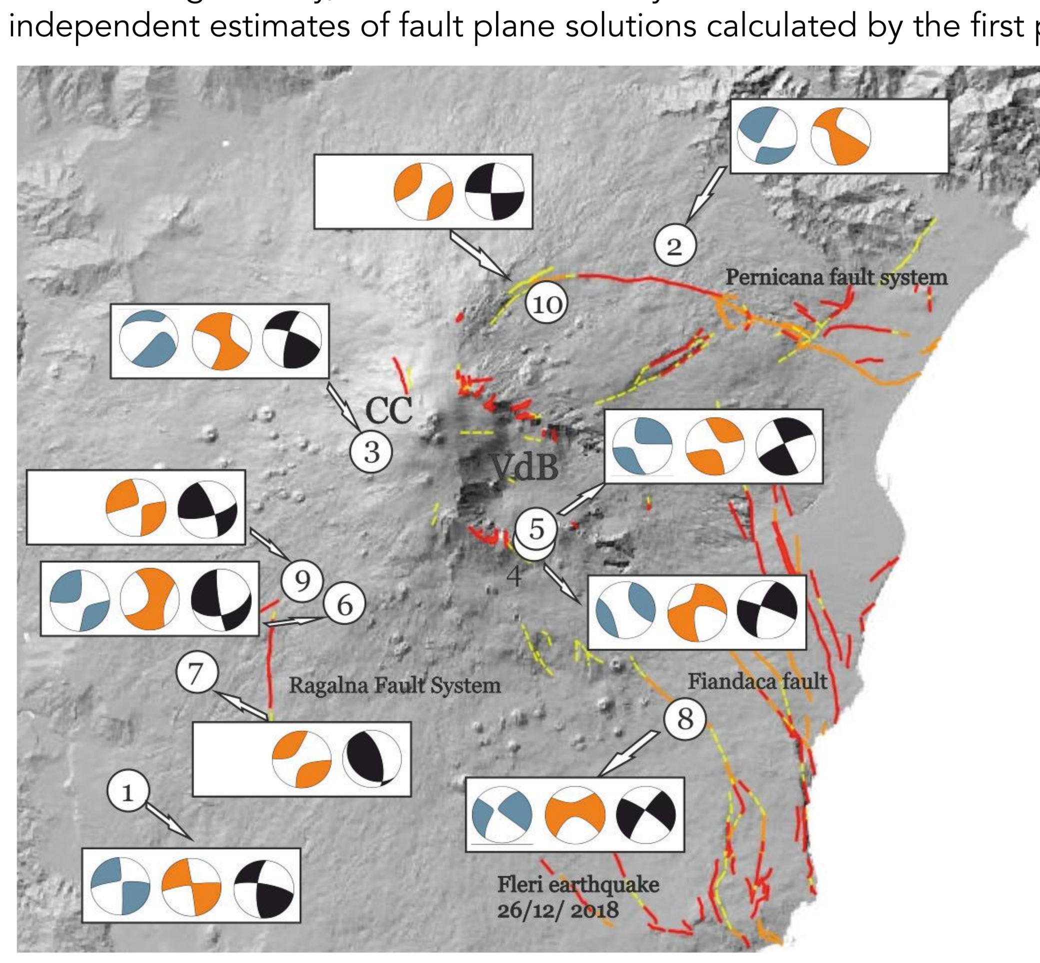


Figure 5 – Digital Elevation Map reporting the epicenters (white circles) numbered as Table1 and the main structural trend in the Etna area (Azzaro et al., 2012). The solutions for TDMT (blu), the FULL TDMT (orange) and the fault plane solutions (black) computed with the first polarities method are plotted (Scarfì et al., 2013).

	TDMT			FULL TDMT			
	DC	CLVD	M_w	DC	CLVD	ISO	M_w
1	98	2	4.6	97	3	0	4.6
2	97	3	3.3	75	16	9	3.5
3	86	14	3.9	57	29	14	3.9
4	35	65	3.6	71	17	11	3.9
5	90	10	4.1	77	23	0	4.3
6	85	15	3.7	32	60	9	3.8
7	TOO NOISE ?			52	47	1	3.8
8	98	2	4.9	48	43	8	4.9
9	HARD TO SOLVE			79	7	13	3.6
10				25	59	17	4.0

Table 2 – DC, CLVD ISO and M_w values obtained by the TDMT and the FULL TDMT inversions.

DISCUSSION

We observe a good agreement among the different solutions when the DC component calculated by the TDMT is dominant (events 1, 2, 5, and 8). When the non-DC component is high, the fault plane solutions may differ (events 3 and 4). In this case the dynamic of the fluids can be relevant and a pure double couple is not suitable to describe the seismic source. This is particularly true for the events 10 where no-TDMT solution could be find probably due to the presence of fluids, as highlighted by the corresponding significative ISO component.
Events 7 and 9 , for which no solutions are given by the TDMT, shows the worst focal mechanism agreement. In this case the reason could be find in the high noise level in the recorded waveforms used for the inversion, highlighting the needs for very good signals to solve for moment tensor components.

Our work is still in progress but the obtained results already highlight the complexity of the earthquake rupture generation in the Etna volcano area mainly interested by the fluid dynamics.

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