

# Lesvos June 12, 2017, Mw 6.3 event, a quick study of the source

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On June 12<sup>th</sup> 2017, at 12:28 (UTC time), a strong earthquake occurred between the Greek islands Lesvos and Chios and the Turkish coast:

[http://bbnet.gein.noa.gr/alerts\\_manual/2017/06/evman170612122838\\_info.html](http://bbnet.gein.noa.gr/alerts_manual/2017/06/evman170612122838_info.html)

<https://www.emsc-csem.org/Earthquake/alert/?id=EWJP8;INFO&date=2017-06-12>.

The event resulted in one death and severe damage to village Vrisa in southern Lesvos. Slight damage was reported for other villages at the southern coast of Lesvos, too. A normal fault mechanism was reported for this event by various agencies with Mw values ranging from 6.2 to 6.4: <https://www.emsc-csem.org/Earthquake/tensors.php?id=0&year=2017&id3=GGBXL>.

The objective of this short report is to summarize the first results indicating source rupture propagation. The analysis is based on regional seismic data. Full waveforms are inverted into a point- and multiple-point source models. Moment tensor (MT) is calculated by least-squares fitting of band-pass displacement waveforms, while the source position and time are grid-searched. Multiple sources are computed using iterative deconvolution (Sokos and Zahradník, 2013; Zahradník and Sokos, 2017). We used waveform data from the following regional networks a) National Observatory of Athens Seismic Network, doi:10.7914/SN/HL, b) National Seismic Network of Turkey (DDA) and c) Bogazici University Kandilli Observatory and Earthquake Research Institute (KOERI), doi: doi:10.7914/SN/KO. Stations at distances ~180 to 350 km, providing a good azimuthal coverage and being free of instrumental disturbances, were selected

(Fig.1); all the stations are broad-band. Green's functions were calculated in a 1D velocity model of Karagianni et al., 2002. The ISOLA code was used for this multi-test investigation; the latest version of the code is available here: <http://seismo.geology.upatras.gr/isola/> and [http://geo.mff.cuni.cz/~jz/isola\\_2015/](http://geo.mff.cuni.cz/~jz/isola_2015/).

We started from simple low-frequency source models and moved to more complicated ones. The reference point is the epicenter reported by the Geodynamic Institute of the National Observatory of Athens (GINOA) at 38.8388N, 26.3623E; the origin time is 2017/06/12 at 12:28:38.26 UTC. The reported hypocenter depth is 12 km.

### **Test 1. Centroid depth**

The centroid position is initially grid-searched below the reference point at trial depths from 3 to 21 km (step 2 km) in frequency range 0.01-0.05 Hz; deviatoric MT is assumed. The optimum solution is at depth 7 km, with similar correlation values at ~5-9 km, providing variance reduction  $VR=0.58$  and a high double-couple percentage  $DC=91\%$ . The solution has a large stability in depth and time, with MT varying just slightly around the optimum strike/dip/rake values, hereafter denoted as  $s/d/r = 107^\circ/38^\circ/-95^\circ$ .

### **Test2. Centroid moment-tensor 3D search**

We perform horizontal grid search of the centroid position using deviatoric MT inversion at frequencies 0.01-0.05 Hz. Four horizontal grids (with 5 km horizontal step) are used, situated at depths 5, 7, 9 and 11km, and centered at the reference point (Fig.2). The form of the highest-correlation isoline clearly indicates that the centroid is shifted with respect to the GINOA; the formally optimal position of centroid is situated 5 km northward and 5 km westward of the epicenter (Fig. 2). The largest variance-reduction values were obtained for depths 7 and 9 km, i.e.  $VR=0.63$ , while  $s/d/r$  solutions for these depths are very similar. We prefer the solution at the depth of 9 km since it provides low condition number,  $CN=1.9$ , thus indicating a good MT resolution. The solution for this depth is: *Nodal Plane 1:  $s1/d1/r1 = 118^\circ/44^\circ/-75^\circ$ , Nodal Plane 2:  $s2/d2/r2 = 278^\circ/48^\circ/-104^\circ$ ,  $DC=96\%$ ,  $VR= 0.63$ . Scalar moment is  $3.046e18 Nm$ , hence moment*

magnitude is  $M_w=6.3$  (Fig.3). The waveform fit is shown in Fig. 4. The non-inverted components where either clipped or with instrumental disturbances and are shown in gray.

Furthermore, we applied the H-C method to check consistency of hypocenter (H) and centroid (C); for the method description, see Zahradnik et al., 2008. Using hypocenter coordinates as given by GINOA and centroid position as derived above we found that the distance of hypocenter from Plane 1 is only 0.6km (and 5km for Plane2), thus the SW dipping Plane1 seems to be the fault plane. The H-C method for normal faults may be problematic, thus any additional support is useful. An important support comes from the aftershock distribution (Fig. 5), and more specifically from the seismicity cross section. Although the hypocenter distribution is dispersed there seems to be a seismicity dip towards the SW (Fig. 5b). Finally, the SW dipping fault is also supported by the bathymetry deepening at the southern coast of Lesvos. Another important result that the seismicity plot revealed, is the absence of aftershocks close to the centroid position; indeed, the aftershock sequence is more intense towards the east.

### **Test 3. Multiple point-source model**

Having found the centroid position and the orientation of the ruptured plane we searched for a multiple-point source model. As in Sokos et al., 2016, we designed a line of trial sources, passing through the centroid at azimuth of  $120^\circ$ , i.e., close to strike of Plane1 (25 trial positions, step 2.5 km), using frequencies 0.05-0.08 Hz (Fig.6). The line is situated at the depth of 9 km. To stabilize the inversion, we kept the focal mechanism constant (same  $s/d/r$  as in the centroid solution). The inversion indicated that even at this increased frequency the wave field is still well explained in terms of a *single* dominant subevent (=centroid). Thus, we conclude that the major moment release occurred in a relatively compact slip patch situated NW of epicenter, at the depth of  $\sim 9$  km, thus indicating that the rupture propagated basically towards NW (Fig. 6). Next investigation will make use of local strong-motion stations.

## **Conclusions**

In this short report, we present a quick investigation of the source properties of the Lesvos June 12, 2017, Mw 6.3 event. Our findings are the following:

- Lesvos event centroid was found at 38.88 N, 26.30 E, depth 9km,  $M_0=3.04e18Nm$ , Mw6.3
- Centroid position is located NW of the epicenter in an area which is sparsely covered by aftershocks
- Relative position of centroid and epicenter suggests rupture propagation towards the NW
- Dominance of a single subevent in the inversion up to 0.08 Hz indicates a relatively compact moment release, without much space-time complexity
- Since the likely rupture propagation is towards the village of Vrisa, where most damage was concentrated, it is possible that we could add the source directivity to factors that determined the damage pattern of this event.

## **Acknowledgements**

We acknowledge waveform data from the following regional networks a) National Observatory of Athens Seismic Network, doi:10.7914/SN/HL, b) National Seismic Network of Turkey (DDA) and c) Bogazici University Kandilli Observatory and Earthquake Research Institute (KOERI), doi:10.7914/SN/KO. Aftershock locations were taken from <http://bbnet.gein.noa.gr/>. The EIDA service at the National Observatory of Athens was used (<http://eida.gein.noa.gr/>).

## References

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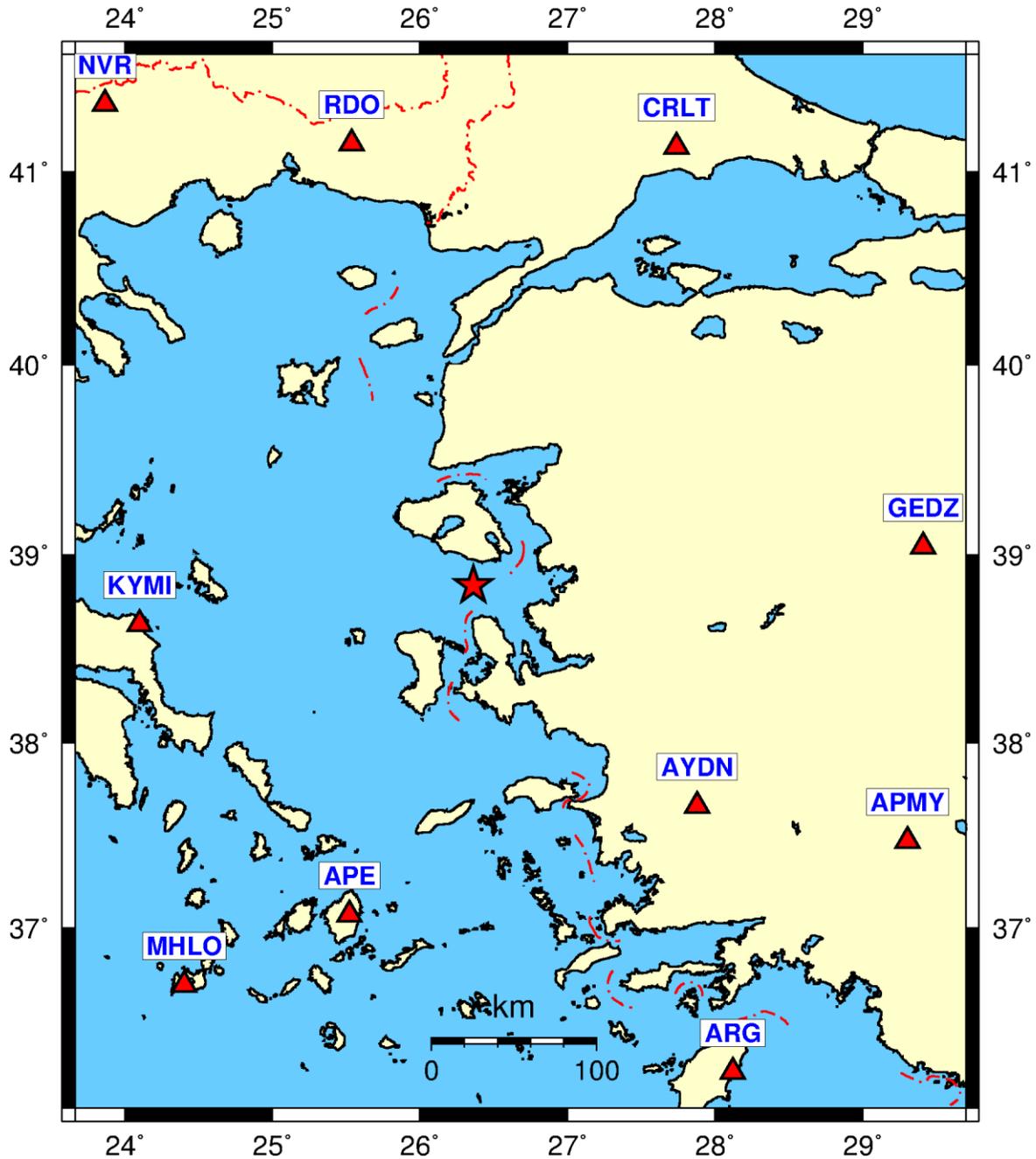
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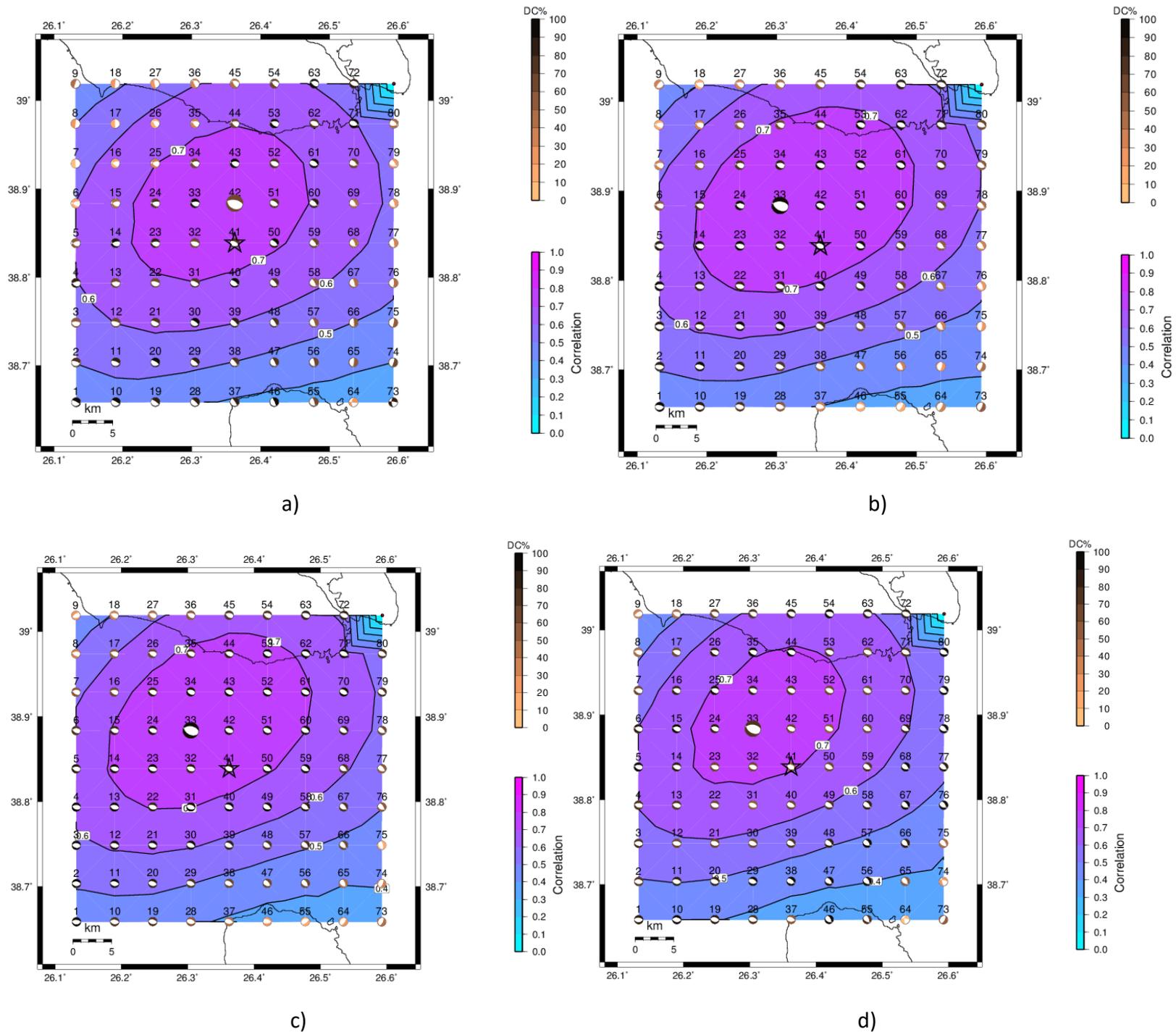
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## Figures

Event ID:170612\_12\_28\_38.26



**Figure 1.** Map of seismic stations used in the inversion, red star denotes the epicenter. Stations belong to networks with codes HL, KO, TU (see the text for details).



**Figure 2.** Correlation plots for the four horizontal grids, depths a) 5km b) 7km, c) 9km d) 11km.

# MOMENT TENSOR SOLUTION

## HYPOCENTER LOCATION (NOA)

Origin time 20170612 12:28:38.26  
 Lat 38.8388 Lon 26.3623 Depth 11

## CENTROID

Trial source number : 33 ( Multiple Source line or plane inversion)  
 Centroid Lat (N)38.8838 Lon (E)26.3047  
 Centroid Depth (km) : 9  
 Centroid time : +1.45 (sec) relative to origin time

Moment (Nm) : 3.046e+18

Mw : 6.3

VOL% : 0

DC% : 96.2

CLVD% : 3.8

Var.red.: (for stations used in inversion): 0.63

Var.red. (for all stations) :

SNR CN FMVAR STVAR  
 NaN 1.9 6±3 0.06

Strike Dip Rake  
 278 48 -104

Strike Dip Rake  
 118 44 -75

P-axis Azimuth Plunge  
 121 79

T-axis Azimuth Plunge  
 18 2

Mrr Mtt Mpp  
 -2.913 2.745 0.168

Mrt Mrp Mtp  
 0.400 0.414 -0.961

Exponent (Nm) : 18

Frequency band used in inversion (Hz)  
 0.01 - 0.05

Stations-Components Used-Distance  
 NS EW Z D(km)

Station	NS	EW	Z	D(km)
AYDN	+	+	-	186
KYMI	+	+	+	198
APE	+	+	+	209
GEDZ	-	-	+	265
RDO	+	+	-	266
CRLT	-	-	+	280
MHLO	+	+	+	294
APMY	+	+	+	299
ARG	+	+	+	330
NVR	+	+	+	351

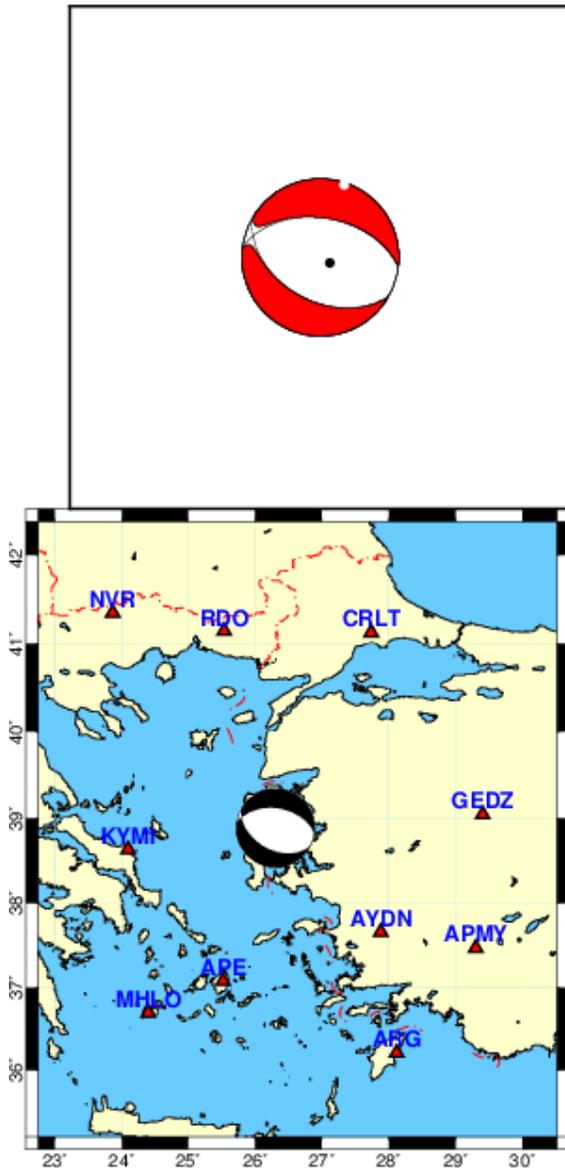
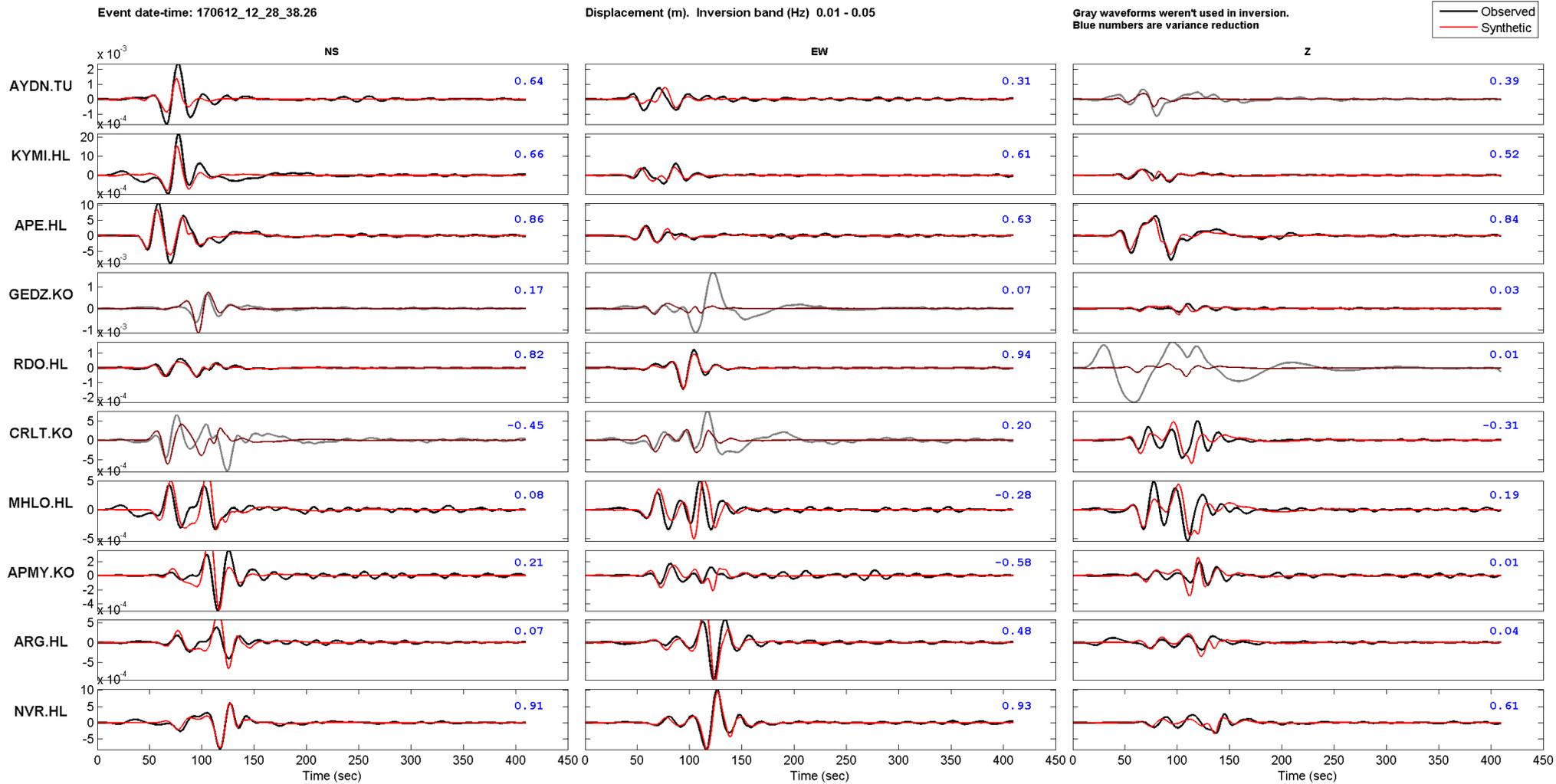
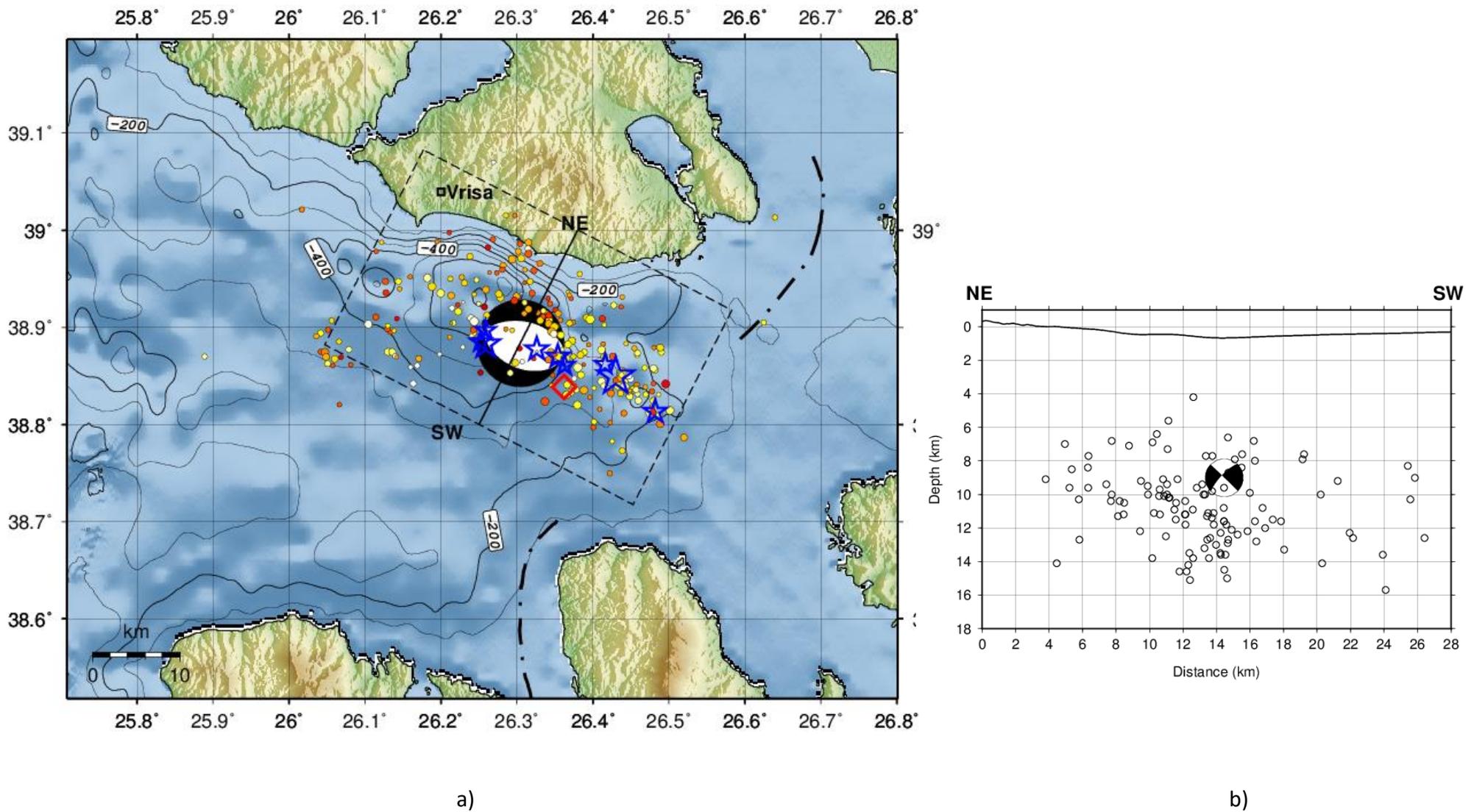


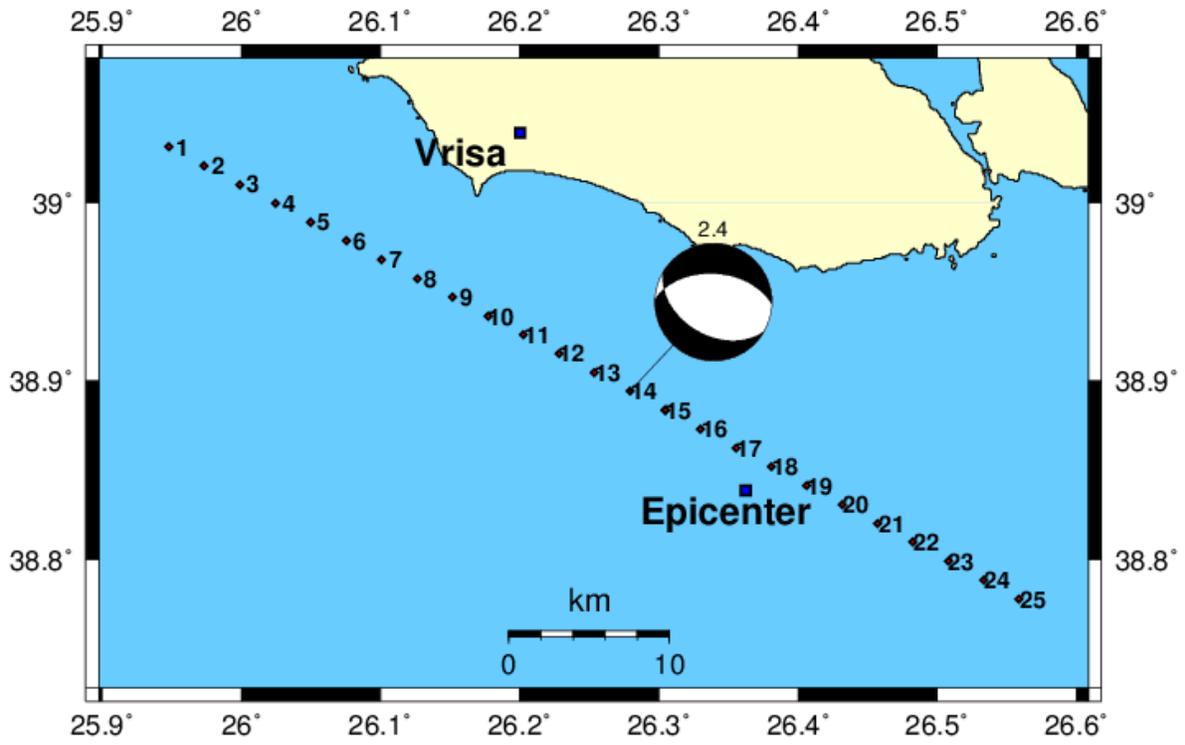
Figure 3. ISOLA code solution summary for the final centroid position.



**Figure 4.** Waveform fit for the centroid solution shown in Fig.3 (gray waveforms were not used in the inversion).



**Figure 5.** a) Map of aftershocks (data from <http://bbnet.gein.noa.gr/>), red diamond denotes the epicenter, blue stars denote the major aftershocks of magnitude > 3.9, focal mechanism is the centroid, b) seismicity cross – section.



**Figure 6.** Multiple point source inversion results. Even up to 0.08 Hz the waveform is strongly dominated just by a single subevent.