The Mw 6.2 Leonidio, southern Greece earthquake of January 6, 2008: Preliminary identification of the fault plane.

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Abstract An attempt to quickly identify the rupture plane of the Leonidio (2008/01/06) intermediate depth earthquake is presented. The earthquake produced minor damage to the city of Leonidio and surroundings, but was felt all over Greece, and in several places in southern Italy. The new methodology is based on combining the moment tensor analysis of near-regional waveforms at frequencies up to 0.07 Hz (where the spatial resolution of the centroid position is of the order of a few kilometers), and the location based on manual P- and S-wave picks at 14 stations. Combining the centroid, hypocentral position and the two possible fault planes, the earthquake appears to have ruptured the low-dip fault plane (strike 213°, dip 34°).

Introduction

The objective of this report, submitted within one week after the event, is to test a quick preliminary assessment of the fault plane in a stage preceding analysis of aftershocks. It is based on relative position of hypocenter H, centroid C and nodal planes. Hypocenter (nucleation point) is determined by kinematic location. Centroid (the point approximating the dominant slip region) is determined as a part of the moment tensor (MT) retrieval. The MT is calculated by waveform inversion, repeated for a 3D set of trial source positions, and C is the position of the best match between observed and synthetic seismograms. Nodal planes I and II, passing through the centroid C, are determined by the strike, dip and rake of the optimum deviatoric MT. Then the fault plane can be identified as the nodal plane encompassing the hypocenter.

As a rule, a single location combined with a single MT solution usually provides the hypocenter off the nodal plane. This is the so-called inconsistent H-C case. However, when the single solutions are substituted by families of the acceptable solutions (reflecting the uncertainties), then the H-C consistency can be reached. Here this new method is applied to the M~6 earthquake, January 6, 2008, Southern Greece, the so-called Leonidio earthquake. The MT calculations were made with ISOLA software (Sokos and Zahradnik, 2008), available from http://seismo.geology.upatras.gr/isola.

Data and results

Broadband records from the University of Patras, Seismological Laboratory (UPSL), permanent seismological network were studied (PSLNET, http://seismo.geology.upatras.gr), complemented with waveforms provided by other near-regional stations available through ORFEUS and GEOFON. Finally, 3-component un-clipped records form 11 stations were used in the MT inversion, providing a fair azimuthal coverage of the event; Fig.1. The epicentral distances ranged from 117 to 490 km.

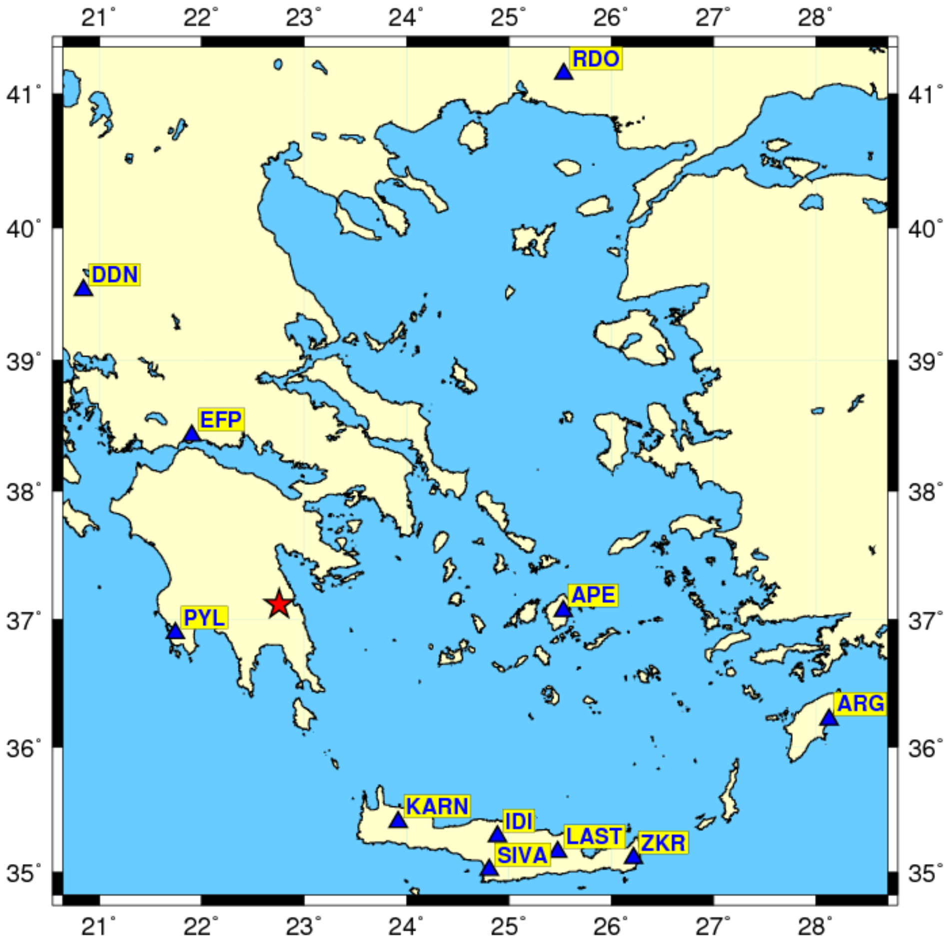

Figure 1. Stations [and networks] used in the MT inversion: PYL, EFP, DDN [PSLNET, HP], ARG and RDO [GI-NOA, HL network], APE, LAST, ZKR, KARN, SIVA [GEOFON, GE] and IDI [MEDNET, MN].

Various preliminary tests were carried out to find the appropriate crustal model and frequency band for the acceptable waveform match. In particular, the crustal models proposed by Novotny et al. (2001) and Endrun et al. (2004) were tested at frequencies below 0.1 Hz. Finally, all the runs were performed in the model of Novotny et al. (2001), using displacement waveforms from 0.02 to 0.07 Hz (tapered 0.02-0.03 and 0.06-0.07). Furthermore, IDI was excluded (always poor match), as well as the two horizontal components of PYL (almost clipped). Stability of the MT solution (the C position and the corresponding strike, dip, rake) was proved by repeatedly removing one station.

Location by HYPOINVERSE code was performed with the use of manual P and S picks from a larger dataset (14 stations), constructed by addition of PSLNET short period stations and a few stations belonging to Aristotle University of Thessaloniki.. The uncertainty was evaluated by repeating calculations with: a) various starting depths, b) two V_p/V_s ratios, and c) two crustal models (Tselentis et al., 1996 and Novotny et al., 2001. The latter provided the least RMS residuals. Four representative solutions selected from these tests are presented in Table 1 and are plotted later in Fig.4; hereafter called the UPSL hypocenter solutions.

Table 1. Representative hypocenter locations.

Origin (GMT)	Lat (N) (deg.)	Lon (E) (deg.)	Depth (km)
05:14:20.24	37.0662	22.8052	70
05:14:20.55	37.0870	22.7912	69
05:14:19.98	37.1133	22.7500	71
05:14:20.16	37.1132	22.7453	70

The nodal planes of the earthquake differ considerably in their dip: plane I of almost vertical dip (strike of about 120°), and plane II of low dip ~35° (strike of about 210°). Fig. 2 compares the position of the nodal planes and the UPSL hypocenter solutions, separately for both the high- and low-dip plane. Only three of the acceptable MT solutions have been chosen for the plot to keep it readable.

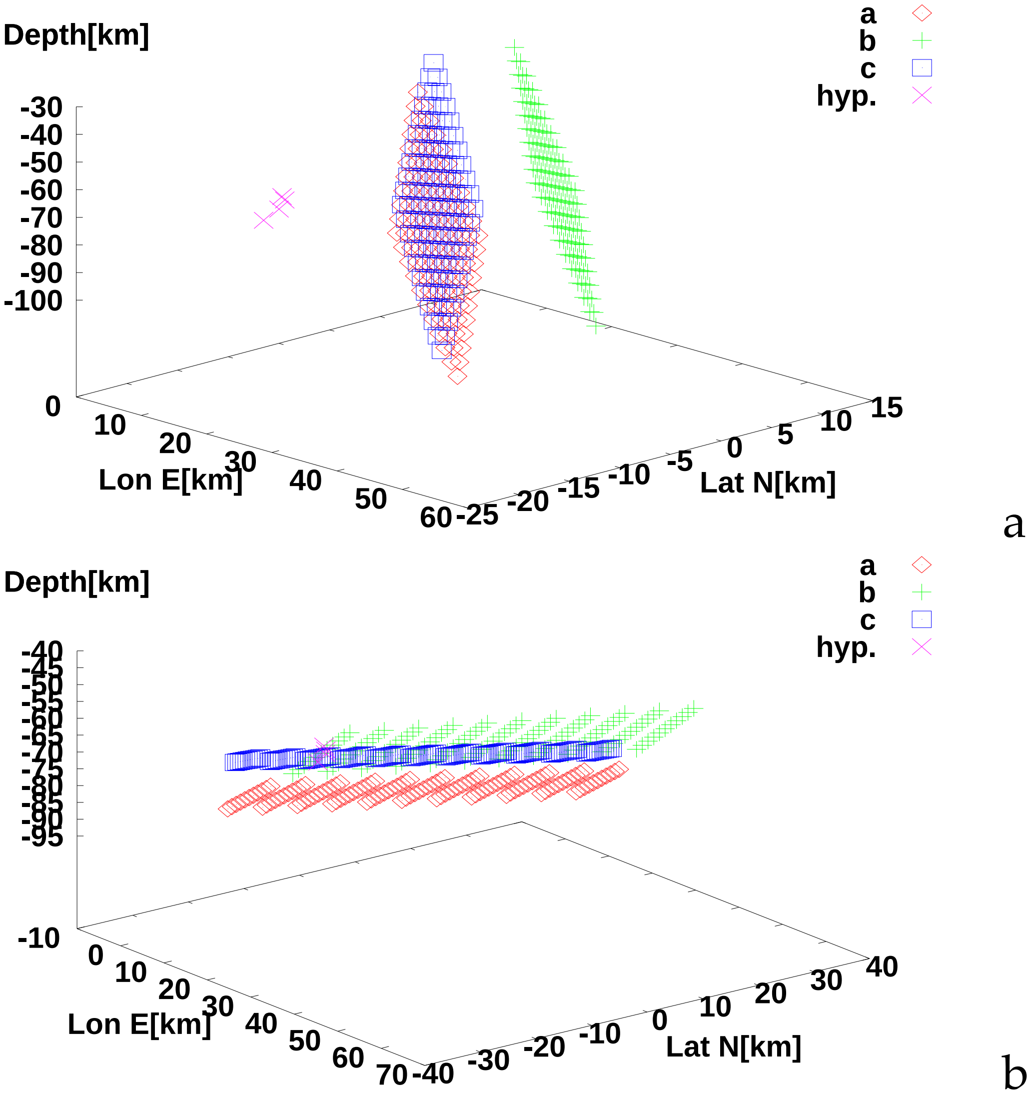

Figure 2. a) Three high-dip nodal planes (**a, b, c,** see below) selected from the acceptable MT solutions of this report. Centroid is in the middle of each plane. Crosses mark the hypocenter solutions of UPSL. With such a distance between the hypocenters and the planes it is unlikely that the high-dip nodal plane was the fault plane. b) As in panel a, but for the low-dip nodal planes. Proximity of the hypocenters (crosses) to the planes indicates that the earthquake ruptured along such a low-dip fault.

The solutions differ in their C positions by a maximum of 10km in NS and/or EW direction, and span the C depths from 60 to 75 km. In some of these calculations the PYL station was omitted at all, while in the others PYL-Z was kept. As seen from the two panels of Fig.2, with no doubt, the hypocenter matches much better with the low-dip nodal plane (panel b).

The three MT solutions presented in Fig.2 correspond to the following data subsets used in the inversion:

a Inversion for a set of trial sources at 75km depth, not including station PYL.
b Inversion for a set of trial sources at 60km depth, not including station PYL.
c Inversion for a set of trial sources at 65km depth (see later in Fig. 4), including the vertical component of station PYL (free of clipping).

All three MT inversions provided very similar results: (i) the focal mechanism differences of the order of a few degrees, (ii) the centroid position differences up to 10km for case **b**, while the **a, c** cases indicated the same centroid position, and (iii) amazing stability of the centroid position within each inversion a, b, c when repeatedly removing one of the stations ('jacknifing)'.

Finally the preferred MT solution was chosen based on the highest overall variance reduction (0.46 for test case **c**) and the H-C consistency (Fig.2). The MT solution for test case **c** is presented in Table 2 while the H-C plot for this case is shown in Fig. 3. Then Fig.4 gives the map view of the solution, and the spatial distribution of the correlation between the observed and synthetic waveforms. Finally in Fig.5 the waveform fit between synthetic and observed waveforms is presented, for the preferred solution.

Table 2. Preferred centroid moment-tensor solution.

Origin (GMT)	**Lat (N) (deg.)**	**Lon (E) (deg.)**	**Depth (km)**	**Scalar moment (Nm)**	**Mw**
05:14:24	37.1456	22.9502	65	1.5e+18	6.2
Strike I	**Dip I**	**Rake I**	**Strike II**	**Dip II**	**Rake II**
119°	87°	124°	**213°**	**34°**	**5°**

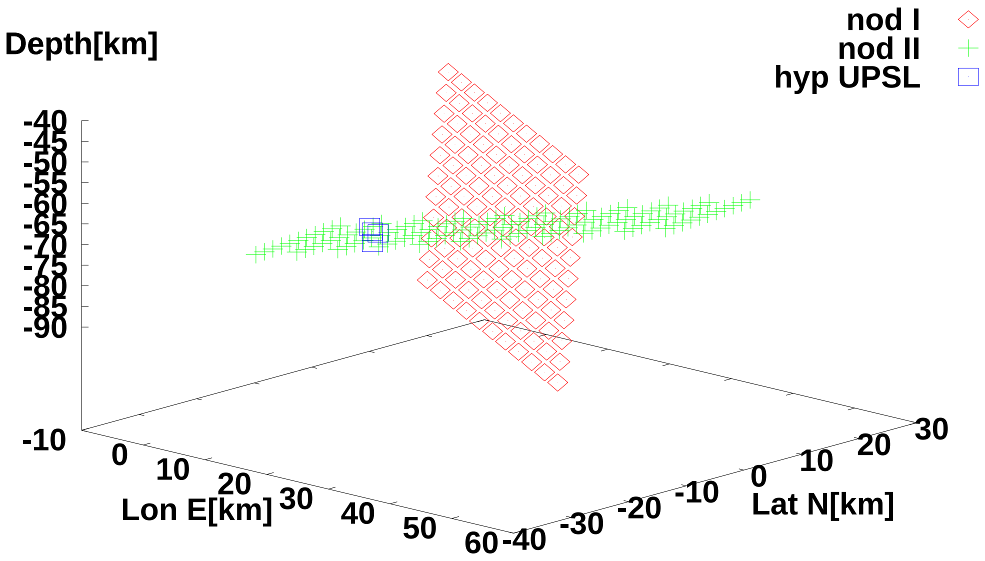

Figure 3. The preferred H-C plot of this report (see table above). Nodal planes I and II are shown in red and green, respectively. Centroid is in the middle of the intersection of the nodal planes. The hypocenter solutions of UPSL are shown in blue. It is the green plane which encompasses the hypocenter, thus this low-dip nodal plane (strike 213, dip 34) is identified as the likely fault plane.

Remarks:

1. All tests indicated an almost double-couple event, with a surprisingly stable DC% (around 90%).

2. When hypocenters of EMSC and USGS are added to those of UPSL, the preferred centroid MT solution of this report still identifies the low-dip nodal plane as the fault plane, although a bit less clearly. (The H-C consistency for the UPSL hypocenter is higher.)

3. As regards the MT solutions of the other agencies, the solution of this report is most close to the USGS CMT solution, including the preference of the low-dip nodal plane for the fault plane.

4. The significant difference between the centroid and origin time (of about 4 seconds), reported also by USGS, Harvard, INGV, is another very stable feature of this event. It reasonably well agrees with the 16-km spatial separation between H and C found here.

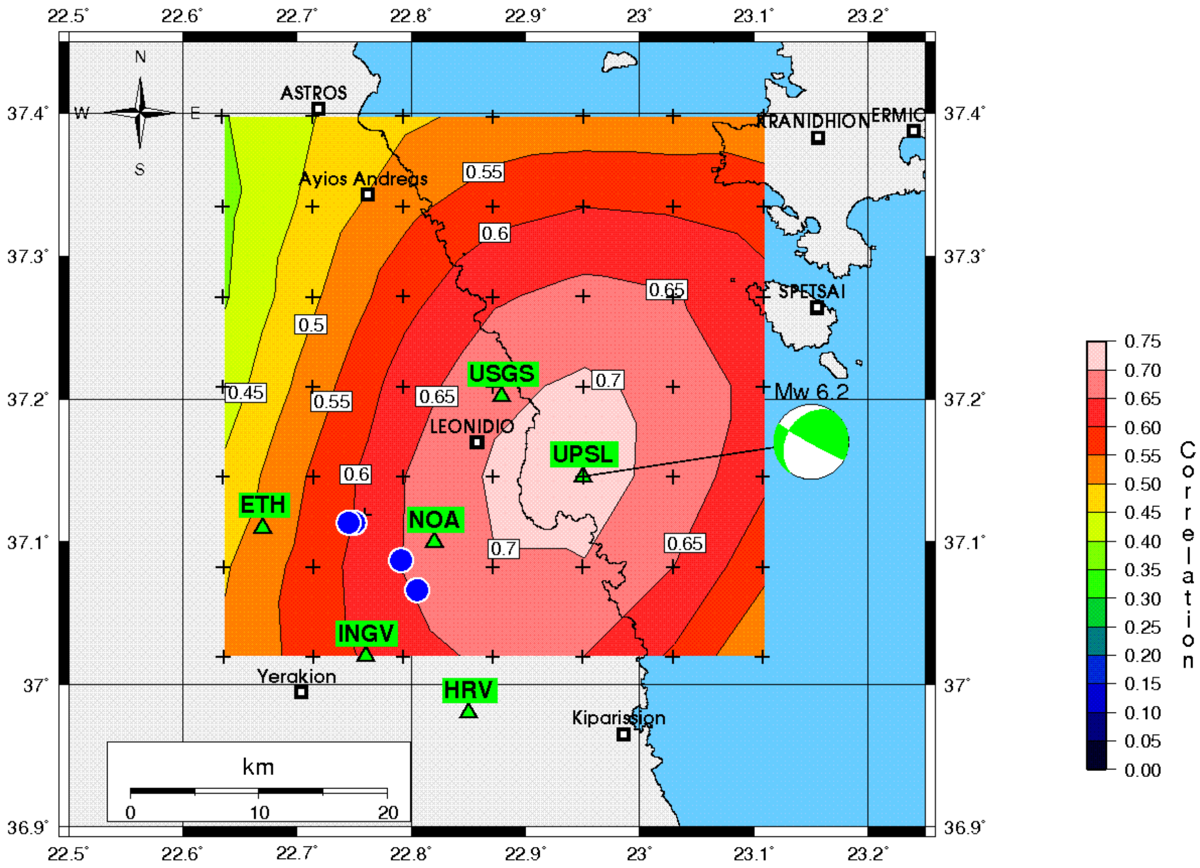

Figure 4. The hypocenter solutions of this report are shown by blue circles. Small black crosses mark the trial source positions at which the MT solution was performed, at the depths 60 to 75 km. The preferred centroid position (UPSL) is connected with the corresponding 'beach ball'. The isolines demonstrate the correlation between the observed and synthetic waveforms at the depth of 65 km. The maximum correlation value 0.71 corresponds to the overall variance reduction of 0.46, at 11 stations. The centroid positions of several agencies are shown by green triangles. As suggested by the position of the hypocenter and centroid of this report, the rupture propagated along the low-dip plane in the north-east direction.

Conclusion

Taking into account uncertainties of the location and MT inversion, the near-regional data (epicentral distances from 117 to 490 km) at frequencies 0.02 to 0.07 Hz suggest that the Leonidio Mw 6.2 earthquake of January 6, 2008, eastern coast of the Peloponnese, occurred on the ***low-dip fault plane*** (strike 213, dip 34). The rupture propagated from the hypocenter in the north-east direction. This preliminary result will be further checked. If new data will significantly alter the conclusion, the new interpretation will appear again on this EMSC web page. The result is in agreement with the shortening of the subducting plate in a direction parallel to the trend of the Hellenic arc, proposed by Kiratzi and Papazachos (1995).

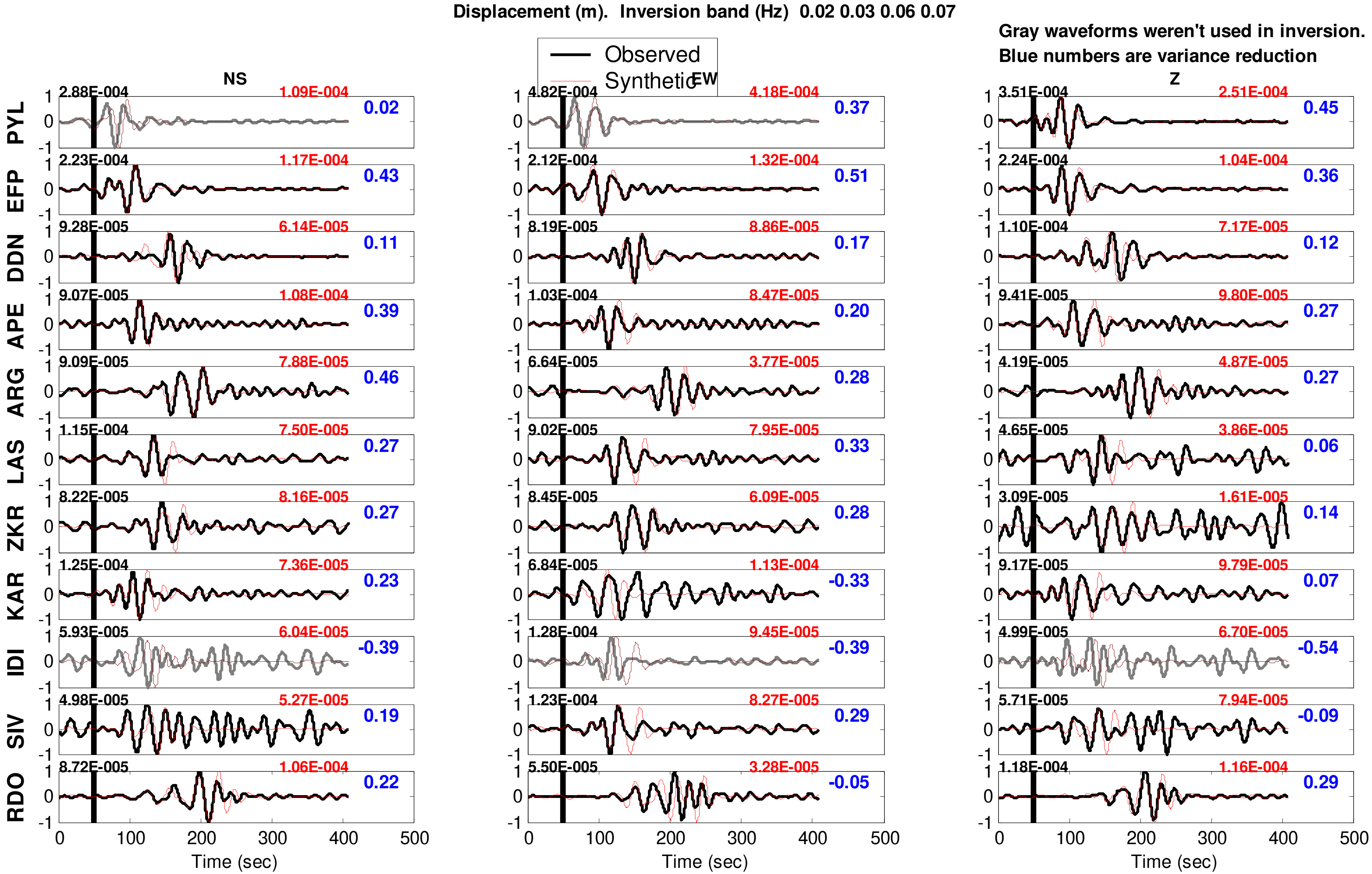

Figure 5. Waveform fit between observed (black) and synthetic (red) waveforms for the preferred MT solution. Maximum amplitudes for observed, synthetic records and variance reduction per component are given with black, red and blue numbers respectively. Components that are plotted in gray color weren't used in inversion. The overall variance reduction from all these 11 stations is 0.46, including the components not used in the inversion.

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