The 6 January 2008 (Mw6.2) Leonidio (southern Greece) intermediate depth earthquake: teleseismic body wave modelling

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Introduction

This short report presents the results of the teleseismic body wave modelling for the source parameters of the 6 January 2008 GMT 05:14 earthquake (Mw6.2) which occurred at an intermediate depth (h=79 Km) beneath Peloponnese (southern Greece). The earthquake produced minor damage to the nearby city of Leonidio. and as is the case with intermediate depth events in Greece, it was felt all over Greece and the neighbouring countries.

Teleseismic waveform modelling of the 2008 Leonidio event

Method

The earthquake was widely recorded by stations of the Global Digital Seismic Network and we retrieved the waveforms from IRIS depository. To avoid upper mantle triplications and interference from outer core, *P* waveforms are used in the distance range 30°–90° and *SH* waves in the range 30°–75°.

We used the MT5 program (Zwick et al., 1994) to invert 27 *P* and 23 *SH* waveforms by a weighted least-squares method (McCaffrey & Abers 1988) in order to obtain the strike, dip, rake, centroid depth, seismic moment and source time function. We followed the procedure as described in Benetatos et al. (2004). The source was constrained to be a double couple. The method assumes that the source can be represented as a point (the centroid) in space, although not in time. The time history of the displacement on the fault is represented by a source time function, described by a series of overlapping isosceles triangles, whose number and duration we defined. The amplitudes for each triangular shape are returned by the inversion routine. The seismograms are the combination of direct *P* or *SH* waves with the surface reflections *pP*, *sP* and *sS* and near-source multiples. Amplitudes were corrected for geometrical spreading and anelastic attenuation using Futterman operator with t*=1 sec for *P*- and t*=4 sec for *SH*-waves. Uncertainties in t* may lead to uncertainties in source duration and seismic moment, but have a small effect on centroid depth and source. The inversion adjusts the relative amplitudes of the source time function elements, the centroid depth, the seismic moment and the source orientation, described by the strike, dip and rake, in order to minimize the misfit between the observed and the synthetic seismograms. The best solution is usually referred to as the "minimum misfit solution». The covariance matrix associated with the "minimum misfit solution" usually underestimates the true uncertainties associated with the source parameters. To find more realistic uncertainties, we followed the approach described in Molnar and Lyon-

Caen (1989), by fixing some of the source parameters at values close to, but different from those of the "minimum misfit solution" and allowing all the other parameters to vary during the inversion. The uncertainties shown in Table 1 are determined by visually examining when the match of the observed to synthetic seismograms significantly deteriorates. The width of the first pulse and the presence or absence of later pulses is sensitive to changes in the depth and/or the source time function, whereas the polarity and the relative amplitudes of the pulses are sensitive to changes in the source orientation. In the case of the Leonidio event there were stations that plotted on the focal sphere close to the nodal planes, both on the P and SH focal sphere, to help us better constrain the solution. Uncertainties in the seismic moment and centroid depth arise from errors in the source velocity model. We used a 30 km crust of average P-wave velocity 6.5 km s^{-1}, S-wave 3.7 km s^{-1}, density 2.8 gr/cm^3, and a half-space mantle below the source of P- wave velocity 8 km s^{-1} ; S-wave 4.5 km s^{-1}, and density 3.3 gr/cm^3 . We also tried crust thicknesses from 25 to 35 Km with no obvious effect on the solution and the synthetics.

Application results

Our best-fitting body wave model for the Leonidio event is displayed in Figure 1 (parameters in Table 1). As usually in our teleseismic modelling of Aegean earthquakes the available stations do not sufficiently cover the western and southwestern hemispheres of the focal sphere. However, the available stations are well distributed to constrain the nodal planes, at least the steep dipping one. The minimum-misfit solution shows a reverse faulting mechanism, with considerable strike-slip component. The time function has a simple shape and it is 6 s duration and a depth of 79 km.

The shallower dip (35°) plane was pointed to be the fault plane from the analysis of Zahradnik et al., 2008 (EMSC on-line report). The focal mechanism of the Leonidio event is typical for the western part of the Hellenic subduction zone (Benetatos et al., 2004) with the P-axis parallel to the trench in this part.

Table 1. Source parameters of the 6 January 2008, GMT 05:14:20.0 Leonidion event as determined by us and reported by others at EMSC

Lat °N	Lon °E	Depth (km)	Mw	Nodal Plane 1			Nodal Plane 2			P axis		T axis		Reference
				Strike	Dip	Rake	Strike	Dip	Rake	Az	Pl	Az	Pl	
37.139	22.726	79 (+3/-3)	6.2	112 (+7/-5)	79 (+5/-5)	123 (+9/-8)	218	35	19	176	26	55	46	This study
37.146	22.950	65	6.2	119	87	124	213	34	5	181	33	59	38	Zahradnik et al., 2008 (EMSC-report)
37.02	22.76	73	6.2	113	76	131	219	43	21	173	20	63	44	INGV
36.98	22.85	87	6.1	117	76	130	223	42	21	178	21	66	44	HARVARD
37.28	22.98	73	6.2	106	79	127	210	38	18	168	25	52	44	USGS
37.1	22.82	70	6.0	108	74	116	228	30	34	178	25	49	54	NOA
37.09	22.79	75	6.3	116	75	104	252	20	48	195	29	44	58	UPSL
37.26	22.58	42	6.2	60	55	80	257	36	104	157	10	296	77	KOERI
37.11	22.67	75	6.2	116	57	123	246	45	50	183	7	81	62	ETHZ

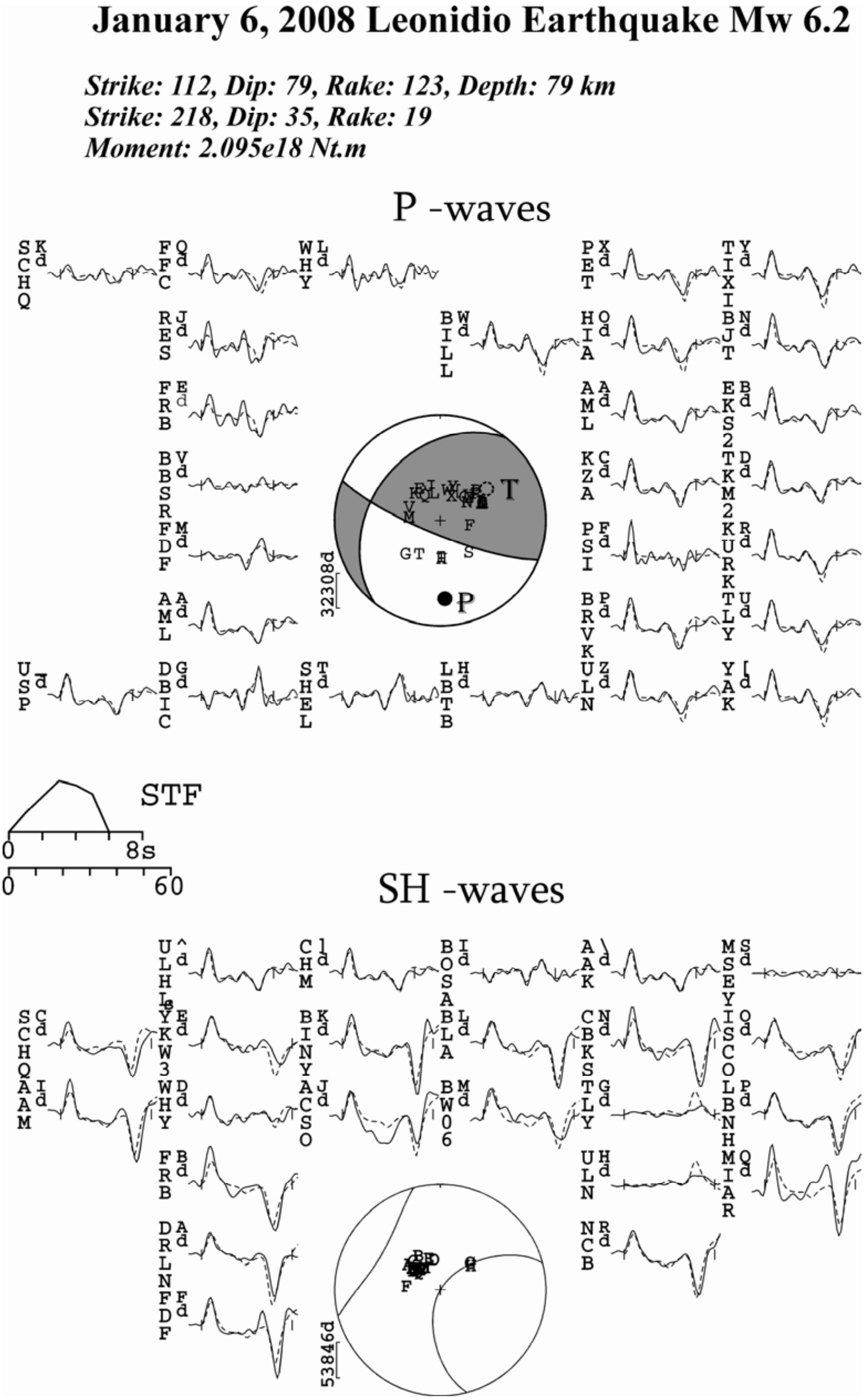

Figure 1. Minimum misfit solution for the 6 January 2008 (05:14:20.0 GMT) Leonidio earthquake, calculated by inverting P and SH body waves for a point source a 30 km crust of Vp = 6.5 km/s, Vs = 3.7 km/s and ρ = 2.8 g/cm3, over a half-space. The focal spheres show P (top) and SH (bottom) nodal planes in lower hemisphere projections; Observed (solid) and synthetic (dashed) waveforms are plotted around the focal spheres; the inversion window is indicated by vertical ticks, station codes are written vertically and station positions denoted by capital letters. The STF is the source–time function, and the scale bar below it (in s) is that of the waveforms.

Constrain of the solution with first motion polarities

We also obtained all the IRIS waveforms for distances less than 30^o and we visually inspected the displacement waveforms (original records were converted to displacement, if necessary), to examine the agreement of the first motion polarities of these stations, in respect to our best fitting inversion solution (Fig.2).

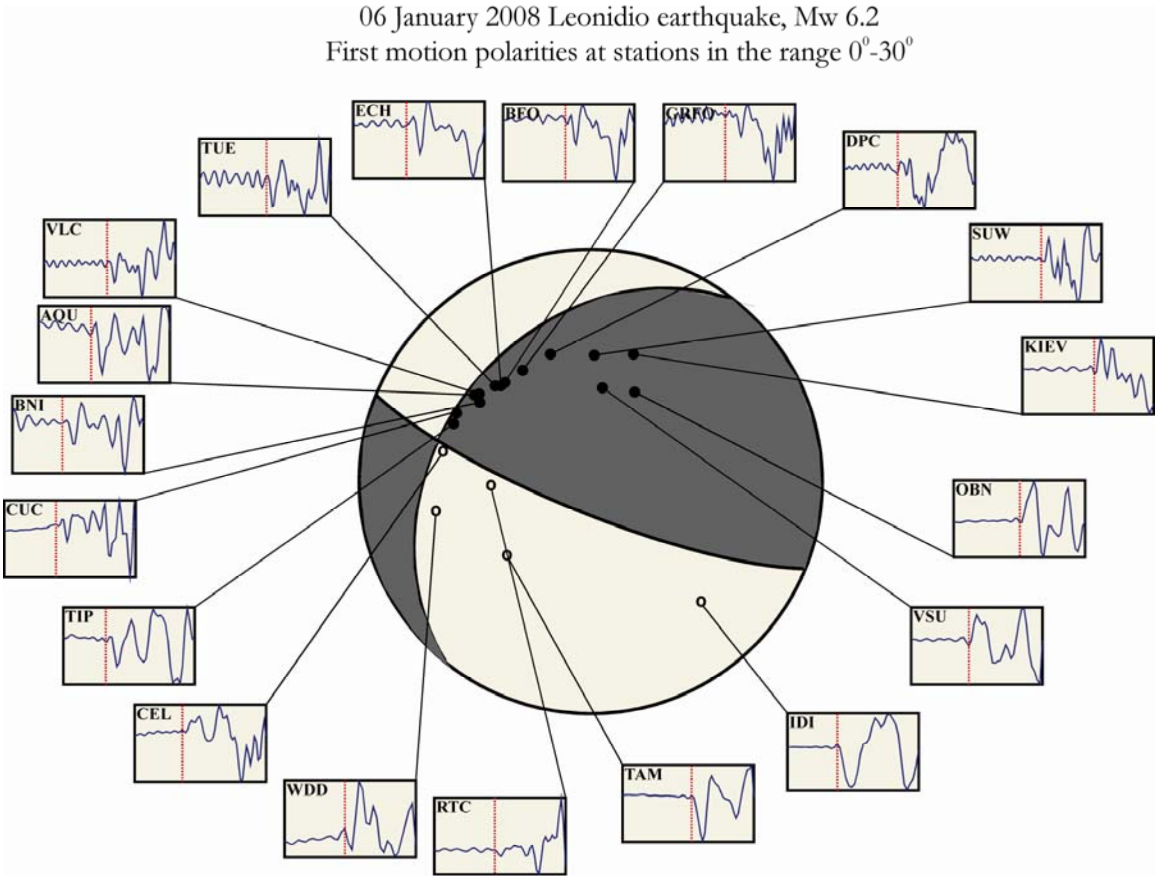

Figure 2. Lower hemisphere projection, of first motion polarities as retrieved from IRIS for stations in the distances less than 30^o. Waveforms were converted to displacement if necessary and bandpassed filtered between 0.008-0.01-0.2-0.3 Hz. The focal mechanism is the one determined from the inversion, first motions are only used here to examine the nodal planes constrain.

The distribution of the stations in azimuth is very good for this specific earthquake and it is observed that both planes are well constrained, with the stations that are clearly nodal (e.g. ECH, BFO, GRFO, DPC from the northern azimuths and CEL, WDD for the southern azimuths).

Intermediate depth events in the Hellenic arc

Figure 3 shows the focal mechanisms of earthquakes with focal depth h>=60 Km, as retrieved from published databases (Kiratzi and Louvari, 2003; Kiratzi et al., 2007 and references therein). The focal mechanisms from microearthquakes are also included. The most recent strongest events are those of 2002 near Milos Island (Mw =6.1; h=93 Km), of 2006 near Kithira Island (Mw=6.7; h=67 Km) and the Leonidion 2008 event. It is clearly seen that most of the events are reverse to pure strike slip with the P –axes parallel to the strike of the Hellenic arc (e.g P axes trend NW-SE in the western part of the arc, nearly E-w in the central part of the arc and NE-SW in the eastern part of the arc). The green beach – balls in this figure indicate the occurrence of sparse normal faulting.

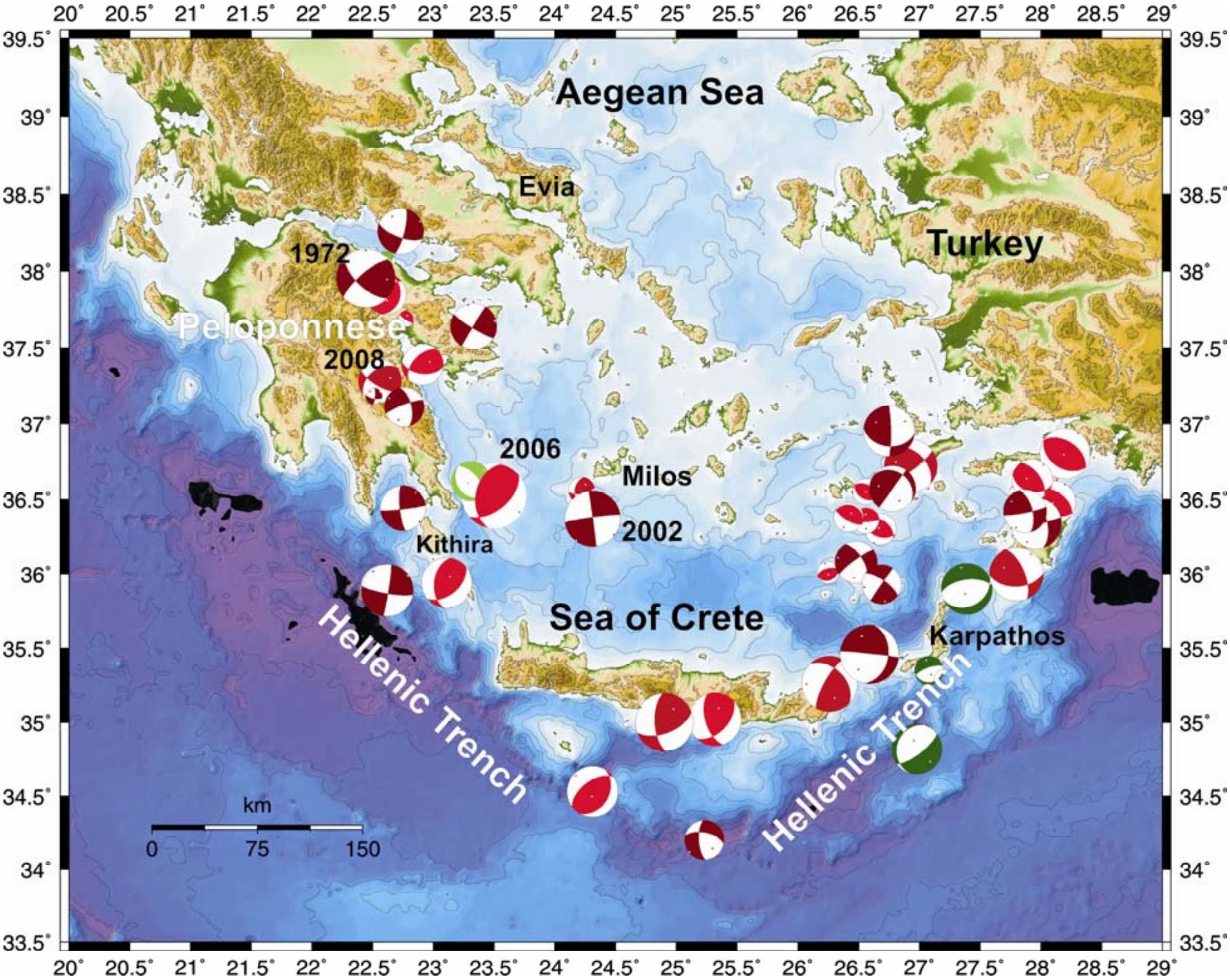

Figure 3. Focal mechanisms of all earthquakes (irrespective of magnitude) with focal depth h>=60 Km, included in our database (Kiratzi et al., 2007 and references therein). Beach – balls are scaled relative to earthquake magnitude. It is observed that reverse faulting combined with strike-slip component is the dominant pattern. The deepest events correspond to the concentration of mechanisms in the inner eastern part of the Hellenic trench, where also occurred the deepest event (h=162 Km) for which a focal mechanism is available. The T-axis usually follow the dip of the slab, e.g are aligned along the slab, however there is indication from cross- sections, not shown here that it is the P –axis that is along the slab in its deepest parts.

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