New Directions in Seismic Hazard Assessment through Focused Earth Observation in the Marmara Supersite

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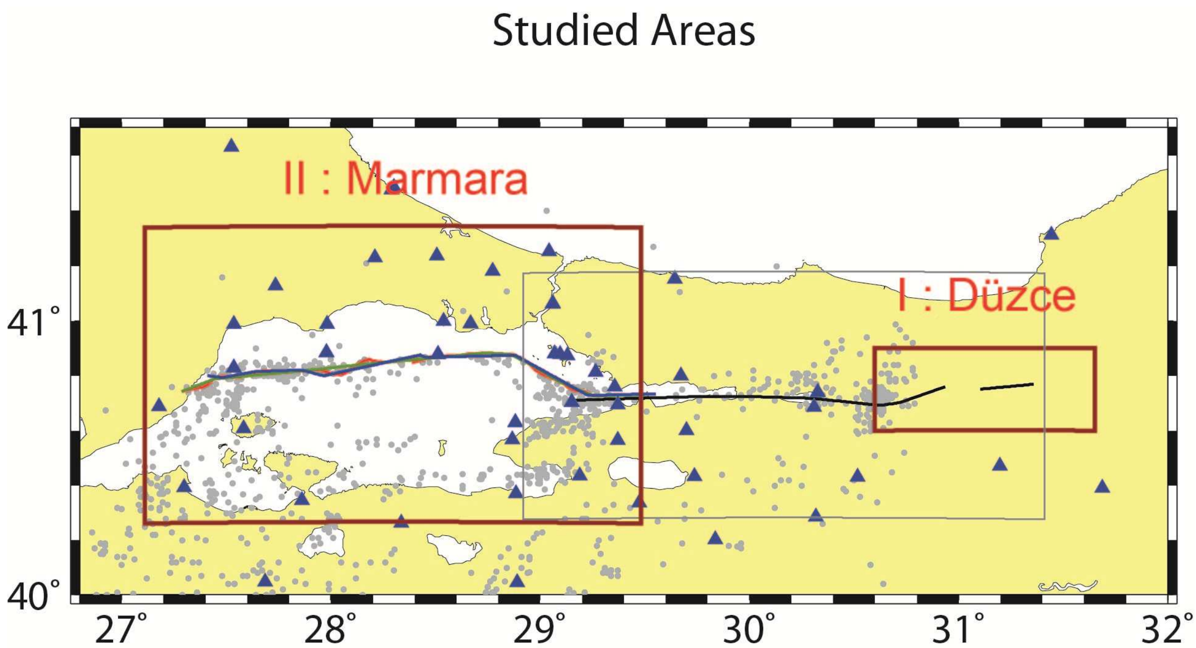
1.SYNTHETIC SCENARIO FOR THE 1999 DUZCE EARTHQUAKE



The 1999 Duzce earthquake (M_w 7.1) occurred on November 12 at 16:57 UTC; the Sapanca-Bolu (SABO) seismograph network, determined its epicenter as 40.82°N, 31.20°E and its focal depth to be 12.5 km (*Milkereit et al., 2000*).

In this work we model seismic scenarios by considering the slip distribution retrieved by Umutlu et al, (2004), from the inversion of teleseismic and strong motion data. A discrete wavenumber/finite element technique (*Spudich and Xu, 2003*) is used to compute full-wave displacement and velocity time histories in the low-intermediate frequency band (up to 3 Hz). We investigate the variability of the ground motion by computing PGV, PGD and PSV at 1 sec on a grid of real and virtual sites.

1.1 GEOMETRICAL SETTING AND FAULT PARAMETERS

We model scenarios for a single fault plane with the focal mechanism given by Umutlu et al., 2004 (see previous section). We assume a fault plane 65 km long and 25 km wide (see Figure1), with 67° dip, 267° strike and -172° rake.

We assume a simplified 1D crustal model valid for the area (Umutlu et al., 2004) to compute the Green's functions (see Table1) and we do not include any variability in ground motions due to variations in site response.

Synthetic seismograms are computed on bedrock in the frequency band 0-3.0 Hz, for a grid of 66 sites; including 56 virtual sites and 10 real stations (see Figure2)

1.2 Results

We consider the slip model retrieved from the inversion of Umutlu et al. (2004); by assuming a rise time of 0.3 sec and a constant rupture velocity of 2.8 km/s (Figure1).

In order to obtain a slip distribution with a corresponding spectra including a frequency content up to 3 Hz, the initial model has been modified by applying a self-similar k-square slip model (Herrero and Bernard, 1994).

The simulated three-component time series at each sites, both in displacement and velocity, allow us to compute peak velocity (PGV), peak displacement (PGD) and response spectra (PSV at 1 sec) distributions (see Figures 3-4-5, respectively).

TABLE 1:Velocity Structure

H [km]	**V_p [km/s]**	**V_s [km/s]**	**ρ[g/cm^3]**
0.40	1.40	0.70	2.00
1.00	2.20	1.10	2.20
7.00	4.00	2.00	2.40
5.00	6.00	3.40	2.70
6.00	6.60	3.70	2.90
7.00	7.20	4.00	3.05
∞	8.15	4.60	3.35

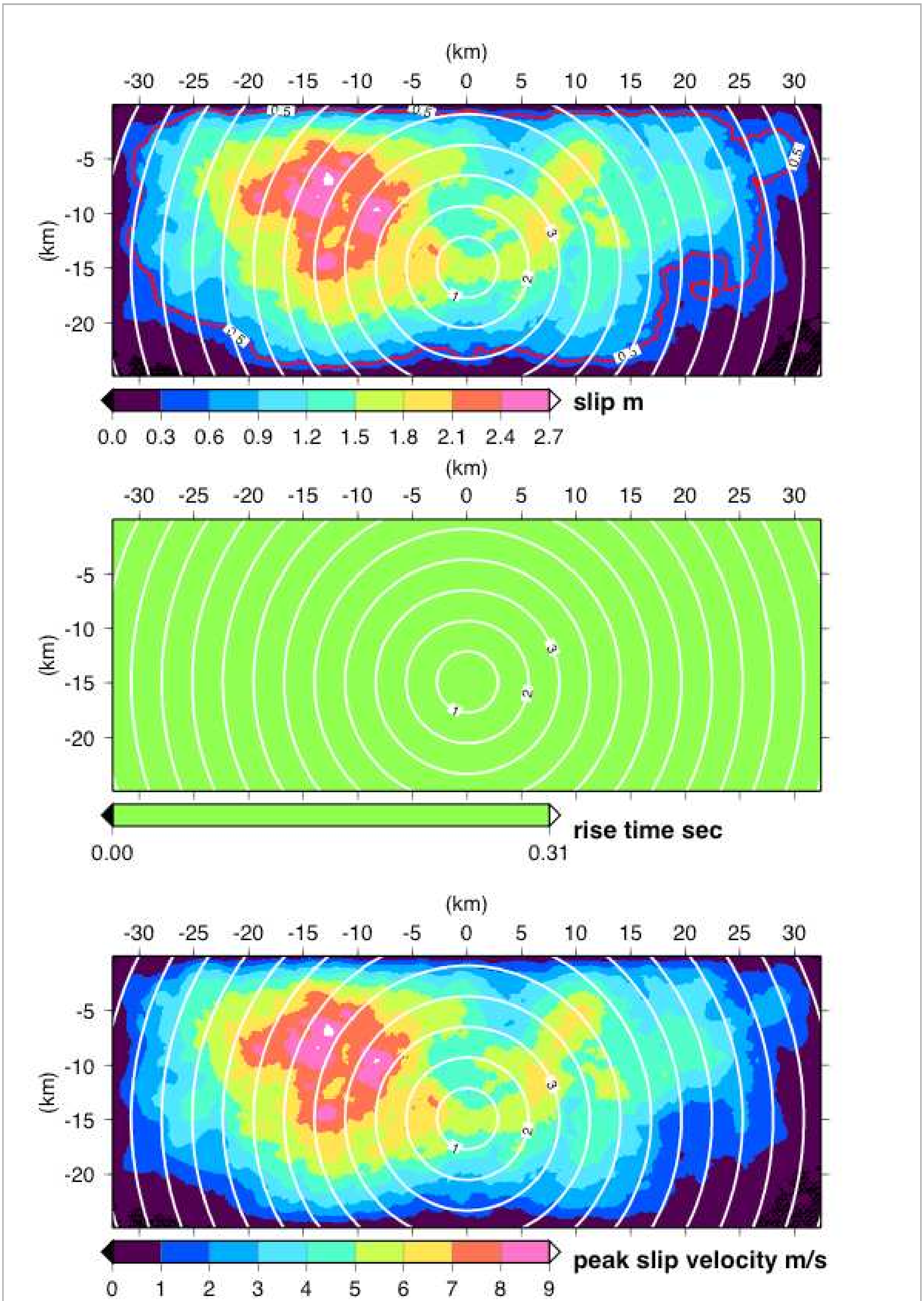


Figure 1. Rupture history adopted in this study to generate synthetic time histories. Slip, rise time and peak slip velocity distributions on the fault plane (upper, middle and bottom panels, respectively). Rupture fronts are displayed in each panel.

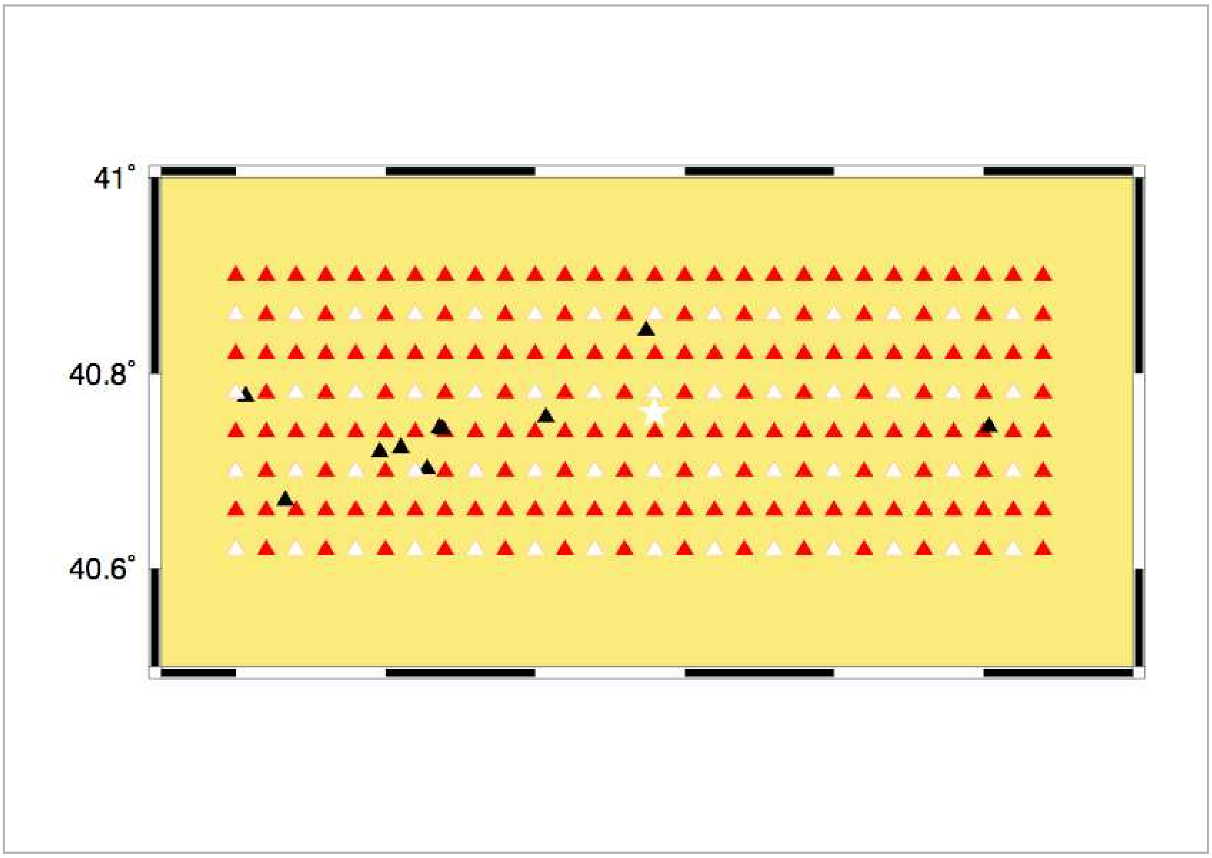


Figure 2. Stations grid: red and white triangles show the virtual sites, black triangles are the real sites adopted in this study.

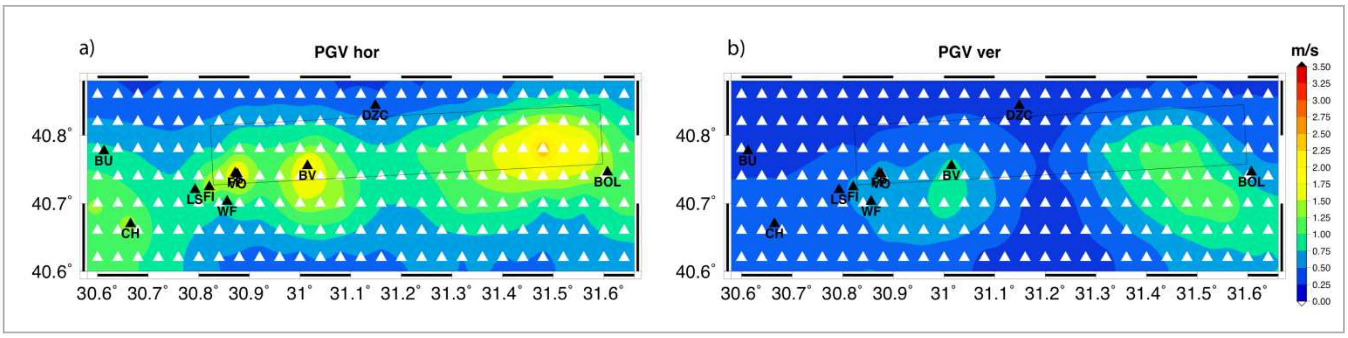


Figure 3. a) Horizontal PGV distribution; b) Vertical PGV distribution. Black triangles and black box, show the real site location and the fault projection, respectively.

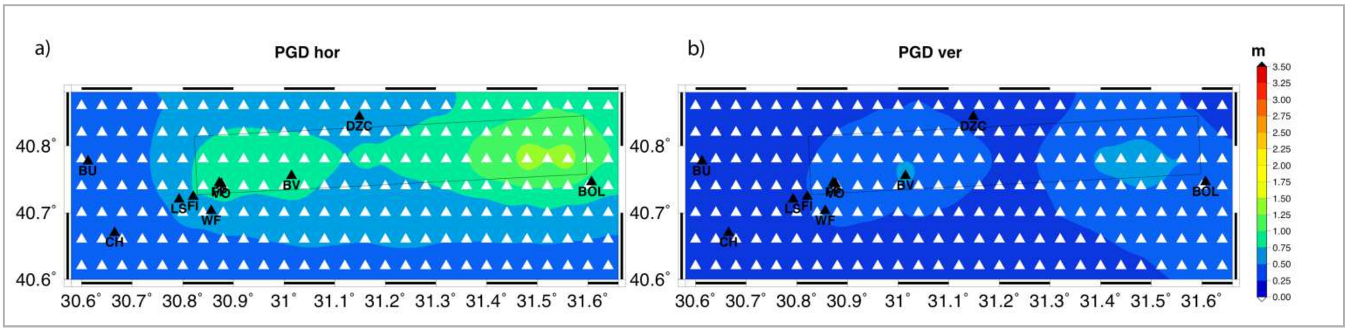


Figure 4. a) Horizontal PGD distribution; b) Vertical PGD distribution. Black triangles and black box, show the real site location and the fault projection, respectively.

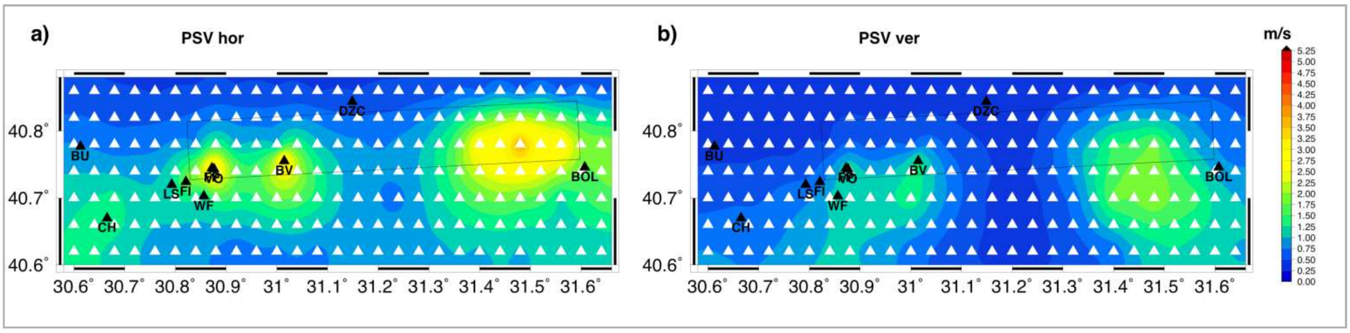


Figure 5. a) Horizontal PSV (computed at 1sec) distribution; b) Vertical PGD (computed at 1sec) distribution. Black triangles and black box, show the real site location and the fault projection, respectively.

2. GROUND MOTION SIMULATIONS IN THE MARMARA REGION

In this report, we present the progress of the work on “the ground motion simulations around the Marmara sea” (Working package 5). For this purpose, we have collected the available structure models of this region. In particular, we adopt a new version of simulation code (finite difference scheme parallelized using GPU). We began to test a moderate earthquake to check the model parameters before providing the reliable ground motion simulations of scenario large earthquakes. The results presented here is intermediate, and it requires some more time to calibrate the model parameters enough to produce a reliable ground motion simulations. Here, we summarize the information available from the partners or other resources to be used for our simulations.

N°	Data Type	Provider	Characteristics	References/Comments
1	Bathymetry	GEBCO - http://www.gebco.net/	Bathymetry extracted from a global 30 arc-second grid	Downloaded.
2	3D structure under Marmara Sea	Louis Gelis, Gaye Bayrakci	3D model every 6 km x 6 km x 2 km under the Marmara sea	Bayrakci et al. (GJI, 2013), numerical file sent by G. Bayrakci.
3	Source parameters of the 2011/07/25 ML5.2	Yasemin Korkusuz, Nurcan Meral Ozel	Source mechanisms	Korkusuz (M. Sc, 2012), sent by Y. Korkusuz.
4	3D structure around Marmara region	Eser Cakti	3D model by 0.5 km mesh	Durukal et al. (EGU, 2007), numerical file sent by E. Cakti, under checking
5	1D model	Karabulut et al. (BSSA, 2001)	5 layered model used for Izmit and Eastern Marmara regions	To be used as first reference model.
6	Source and receiver locations	Aybige Akinci		Ansal et al. (SDEE, 2009)

7	3D structure model	Hideo Aochi	Temporally constructed 6 layered models after the bathymetry	Preliminary model.
8	Station locations	KOERI, http://udim.koeri.boun.edu.tr/	List for BB/SP KOERI stations	Downloaded.
9	Seismograms	KOERI, http://udim.koeri.boun.edu.tr/	Waveform data for the 2011/07/25 ML5.2 event.	Downloaded.
10	1D structure models for East and West Marmara region	Hayrullah Karabulut	15 layers models used for the Marmara region	Sent by H. Karabulut
11	Focal mechanism solutions for 2011/07/25, 2012/06/07	Hayrullah Karabulut	Focal mechanisms determined manually	Sent by H. Karabulut

2.1 MODEL DIMENSION

After several preliminary simulations, we are going to prepare a model dimension of 200 km (EW) x 120 km (NS) x 40 km (depth) to cover the whole Marmara Sea and the surrounding area. For the numerical simulation, we set the model origin at (E28°, N40.8°), being the model (-75 km, 125 km) in the EW direction and (-60 km, 60 km) in the NS direction. We do not take into account of the topography, which is relatively flat at regional scale (without the SE area), as the main purpose of the ground motion simulations are rather on the northern coast of the Marmara Sea. However in some extended model, we take into account of the bathymetry so as to introduce one layer of water, and this should be important to explore the observations at the bottom of the Sea. For the rapidity under the current test study, we carry out the numerical simulation with a grid spacing of 500 m using a finite difference method. We are going to refine the model resolution for producing reliable higher frequencies in the future.

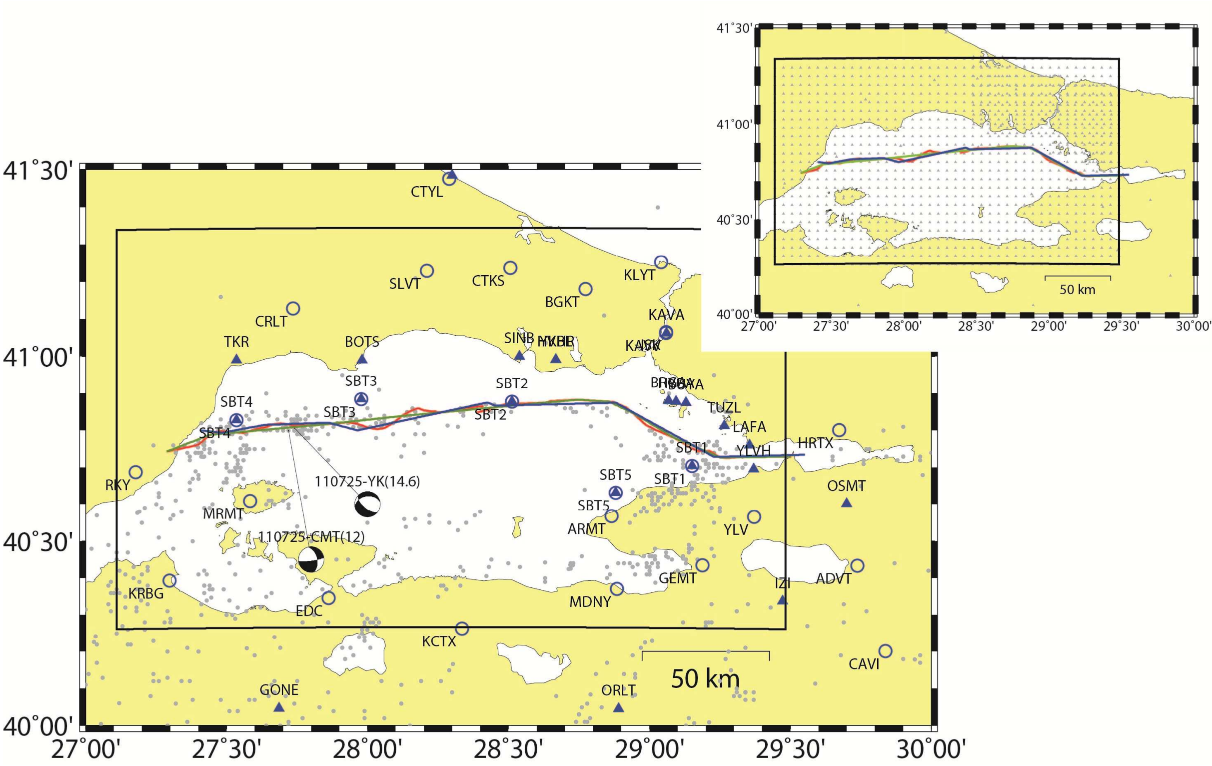


Figure 6 : Configuration map for ground motion simulations around the Sea of Marmara. The framework represents a dimension of 200 km x 120 km, set to our model domain. The grey circles show the seismicity between 2000 and 2013 (M equal or larger than 2.8) from KOERI catalogue. The receivers (right top panel) are distributed over the whole model area, including (6) and (8), so as to provide different mapping of ground motions.

2.2 Structure models

- 1D structure model (5)

We use the 1D model used in Karabulut et al. (2002) as our reference. This model was calibrated for the analyses of the aftershocks of the 1999 Izmit earthquake. As we find that the velocities are quite fast even in the shallower part (5.7 km at 1 km depth), it would be suitable for the stations located on land.

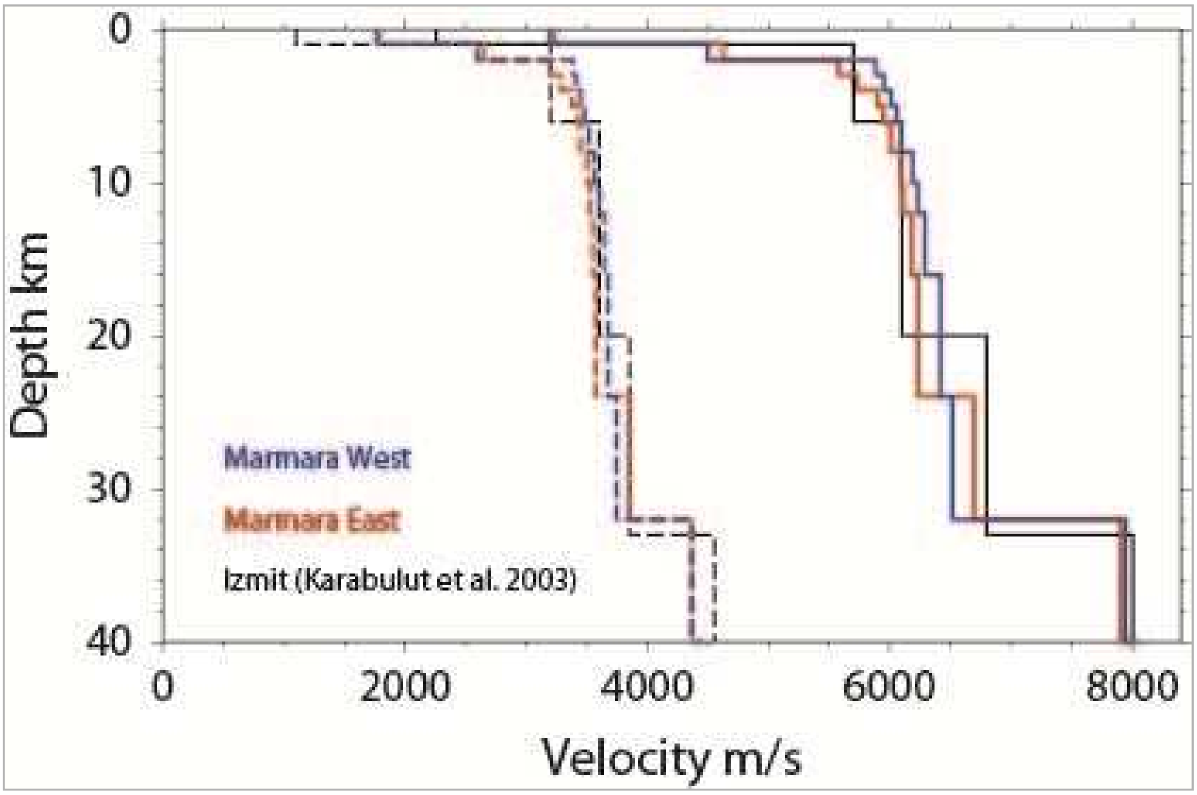


Figure 7: Velocity model used in Karabulut et al. (2002) (5) in comparison with the other two models (Karabulut, pers. Comm) (10) used in the Marmara regions. P-wave and S-wave velocities are shown by solid and broken lines, respectively.

- 3D model (2)

This model is the result of a tomography campaign in the Sea of Marmara region Bayrakci et al. (2013). It is considered that the basin characteristics under the Sea of Marmara are well established. The provided numerical model consists of 7 horizontal layers given at various depths ranging from 0 to 12 km. In each of these planes, the horizontal variation of V_p is given with a resolution of about 6 km. The values of V_s and ρ have are obtained using the following relations:

$$V_S = \frac{V_P}{\sqrt{3}}$$

$$\rho = 1.74\, {V_P}^{0.25}.$$

The Figure 8 gives a representation of the variations of V_p. The region right under the sea globally presents most of the heterogeneities of the model.

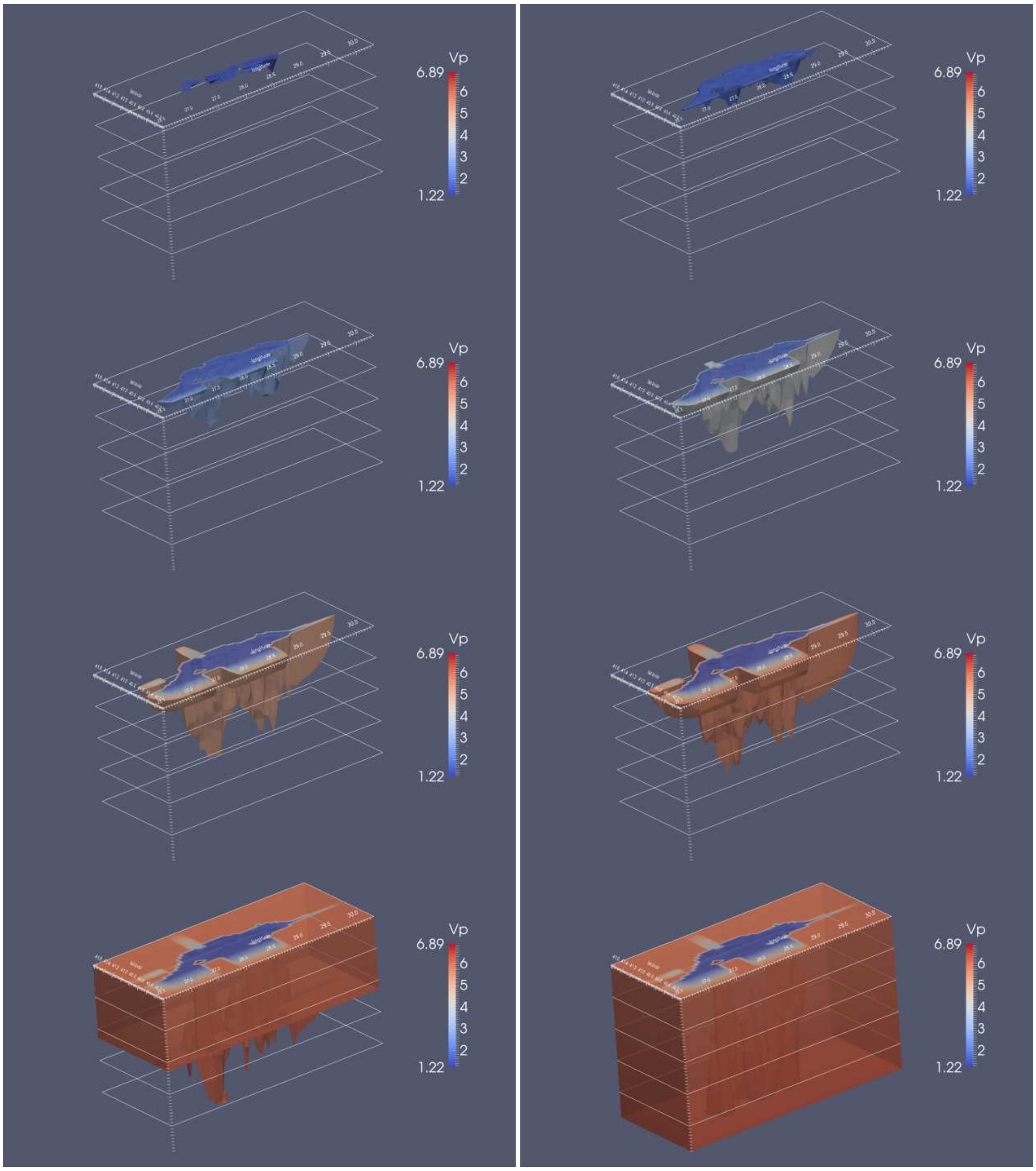


Figure 8: Representations of the 3D structural model of Bayrakci et al (2013)(2). The horizontal planes in the each panel indicates every 2.5km along depth. The first panel represents the volume with V_p in the range 0 – 1.5 km/s. Similarly the following panels corresponds the volumes for a V_p equal or slower than 2, 3, 4, 5, 5.5, 5.9 and 6.1 km/s, respectively.

Because of the low sampling of the model along the depth direction, the sea volume is not precisely modeled in this initial 3D model. Then, we are going to refine the model from the bathymetric data (1), as shown in Figure 4. When these data are juxtaposed with the 3D model (Figure 5), it appears that the areas of low velocities are roughly corresponding with the sea. Information from the bathymetry are finally taken into account by set V_p at 1.5km/s, V_s at 0 km/s and ρ at 1500kg/m^3 over the sea level.

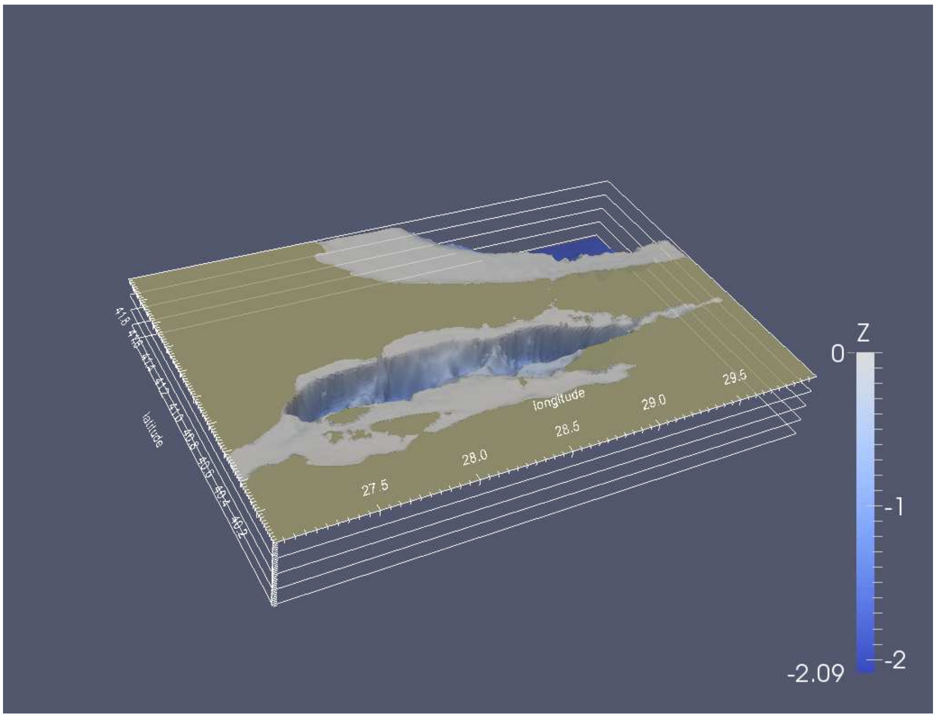


Figure 9: 3D representation of the Marmara Sea bathymetry (1). The northern part of the sea is much deeper than the southern part.

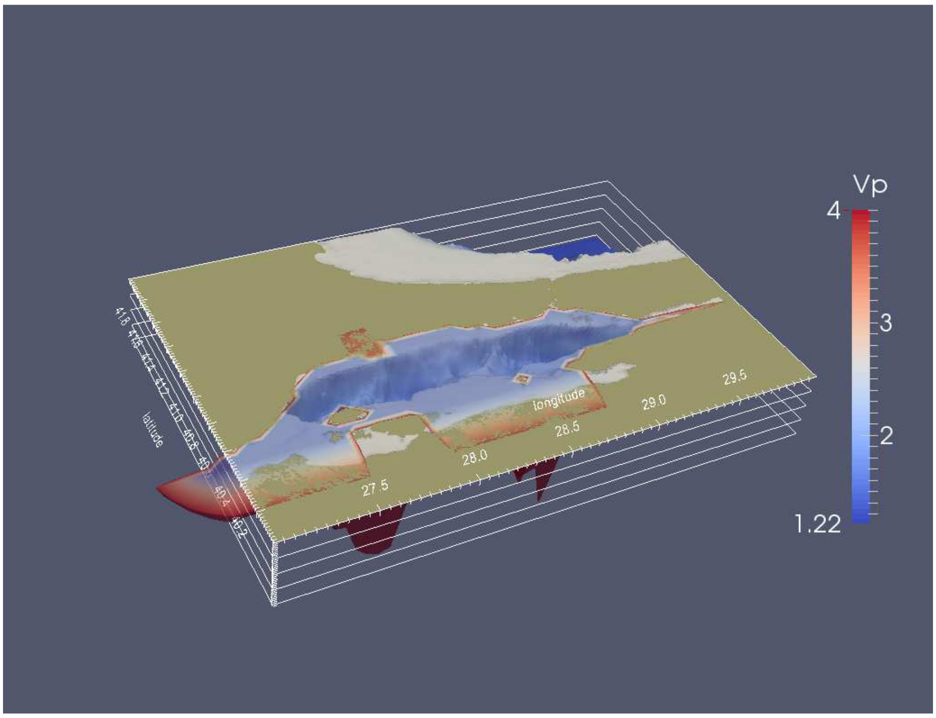


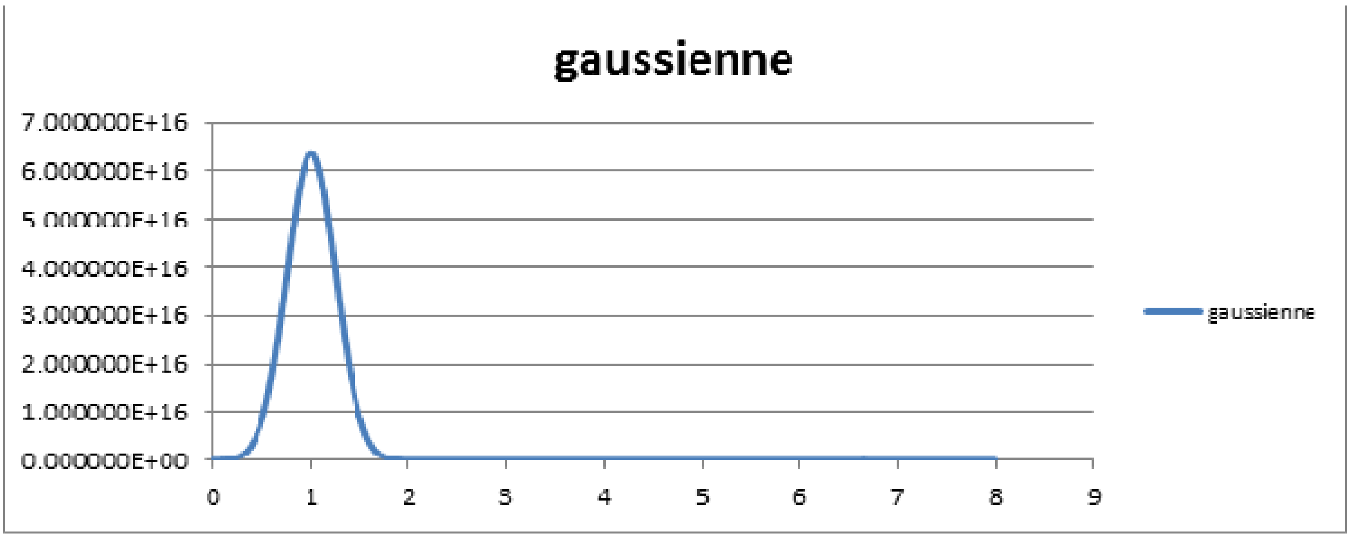
Figure 10: Juxtaposition of the 3d structure (represented here only in the V_p range 0-4 km/s) and the bathymetric surface. This figure clearly shows that the region of low V_p roughly corresponds with the Marmara sea. This comparison also highlights the limited sampling of the 3D structural model.

2.3 The ML5.2 2011/07/25 Earthquake

This is a good example to calibrate the models, as this recent event is well documented. The source parameter is in the following.

Date	Time	Magnitude	Latitude	Longitude	Depth	Strike	Dip	Rake	Ref
2011/07/25	17:57:20.85	ML 5.2	40.8108°	27.7388°	15.3 km	-	-	-	(9)
	17:57:21.1	ML 5.2	40.807°	27.740°	14.6 km	130°	63°	63°	(3)
	17:57:21.1	ML 5.2	40.823°	27.743°	10.8 km	137°	72°	-59°	(11)
	17:57:22.4	Mw5.1	40.80°	27.72°	12.0 km	346 83	50 82	-11 -140	CMT

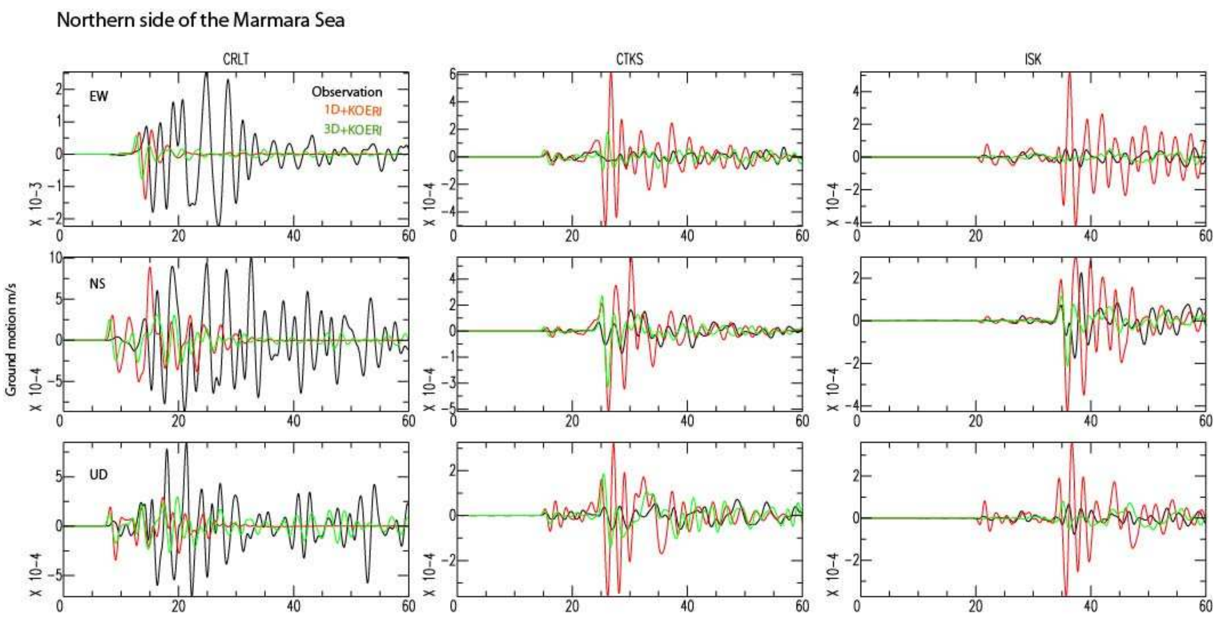
For our first attempt, a source time function of Mw5.0 is given by a Gaussian function;

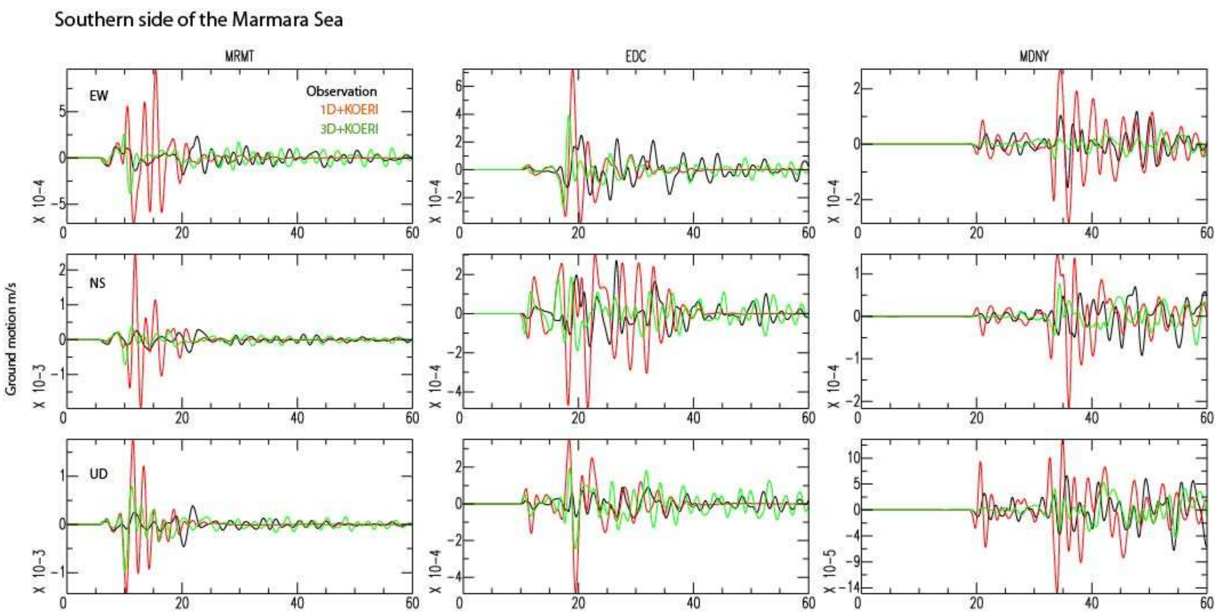


2.3.1 Test 1: 1D and 3D Structures

We compare the ground motions at several selected stations for the 1D and 3D models. The same source mechanism (3) is given. The synthetic and observed seismograms are aligned at 17:57:20.85, which is considered as the origin time (9). A bandpass filter between 0.05 and 0.5 Hz is applied on both the observation and synthetics.

Station CRLT may be subjected to the local site effect, as not only the amplitude but also the duration is very large in the observation. For the all the other stations, a significant improvement is recognized when a 3D model is applied. In general, we observe a good agreement of the first pulse (P-wave). We could improve somehow the S-wave velocity in the models.

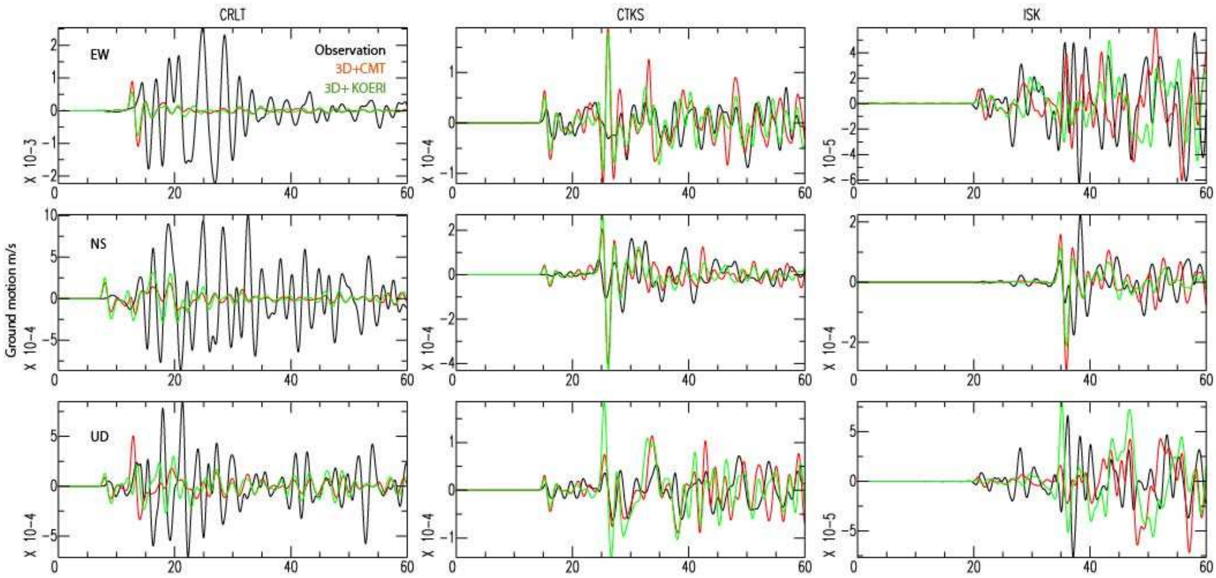




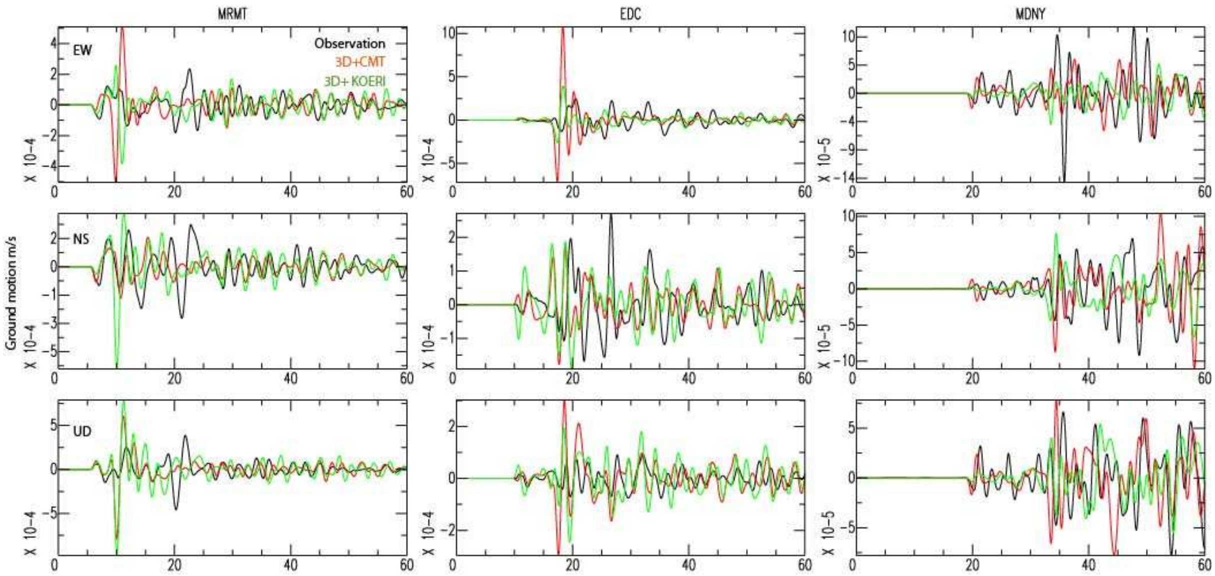
2.3.2 Test 2: Focal Mechanisms

As locally obtained focal mechanism is somehow different from the global CMT solution, we compare the two mechanisms in the 3D model. The hypocenter locations are fixed at the solution obtained locally (3), only focal mechanisms are varied. The influence depends on the component and the station. Although the amplitude of some phases changes according to the different radiation pattern, their timing is unchanged.

Northern side of the Marmara Sea



Southern side of the Marmara Sea



2.4 SUMMARY/PERSPECTIVE

From our first attempt, the 3D model improves significantly the waveforms. We continue to test a few other moderate earthquakes (for example, 20120607 Mw5.0) to check the models. If necessary, we will calibrate some parameters of the structure, as Vs value had not been given in the original model (2). The models (4, 7) are not tested.

For this moment, the receivers (Figure 1) are put on the ground surface level (depth = 0 km) by default of the code. However, it is necessary to extract the ground motion at the bathymetry level so as to use the OBS stations and the ground motion parameter maps. We also plan to provide some rupture scenarios along the fault models (See Figure 1).

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