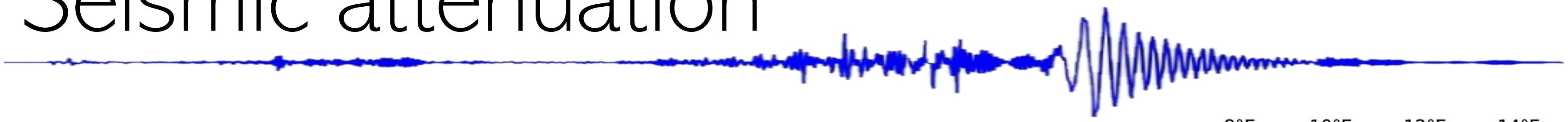
Finite difference forward modelling across the Tyrrhenian basin

Chiara Nardoni[1] (chiara.nardoni@uniroma3.it), Luca De Siena[2], Fabio Cammarano[1], Elisabetta Mattei[1], Fabrizio Magrini[2]

[1]Università degli Studi Roma Tre, Rome, Italy;
[2]Johannes Gutenberg University, Mainz, Germany

Seismic attenuation



We estimated coda-wave attenuation in the frequency band 0.5-1.5 Hz in a diffusive approximation at regional scale.

The drastic spatial variations in the deterministic (interfaces) and scattering properties across the Southern Tyrrhenian basin strongly trade-off with coda-wave attenuation measurements in this area.

In order to investigate the effects of crustal thinning on the energy leaked into the mantle and wave reverberations, we approach a *full-waveform forward modelling*.

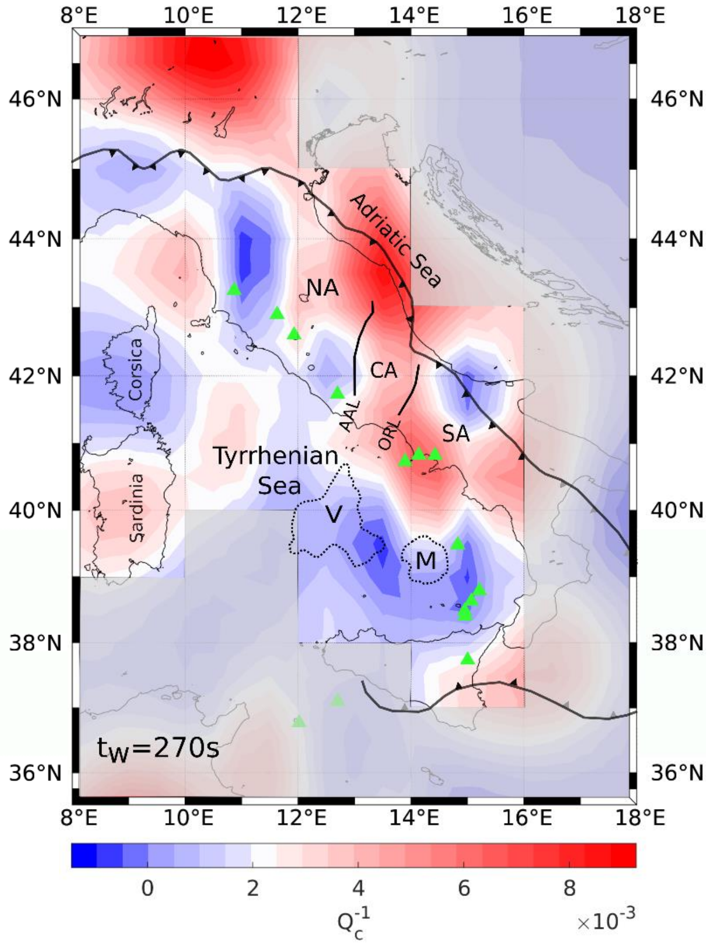


Figure 1: Lateral variations in seismic attenuation in the frequency band 0.5-1.5Hz, estimated in the coda window 270-360 s through the inversion devised by De Siena et al. (2017). The dotted lines highlight the two main sub-basins, Vavilov (V) and Marsili (M), in the Tyrrhenian Sea. The green triangles represent the volcanic centers. The thrust front is represented by the black line .

Open Seismic Wave Propagation Code (*Maeda et al., 2017*)

Full-waveform forward modelling: the code solves the equations of motion in three-dimensional Cartesian coordinates using the *finite difference* method

$$\rho \frac{\partial v_i}{\partial t} = \sum_{j=1}^{N_D} \frac{\partial \sigma_{ij}}{\partial x_j} + f_i$$

- Isotropic and viscoelastic media: Generalized Zener Body
- Velocity fluctuations implementation
- Perfectly Matched Layer (PML)
- Single point source: moment tensor, source time function (STF)

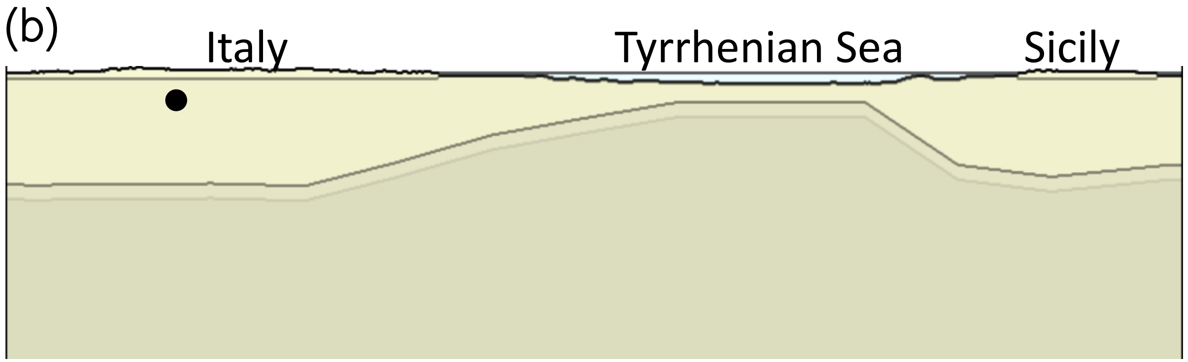
Simulation Grid

dx = dy = dz = 0.5 km

dt = 0.03 s

Source: (13.23°; 42.70°)

Receivers: (13.30°; 37.89°), (13.75°; 37.75°),
(13.53°; 38.09°), (15.51°; 38.26°)



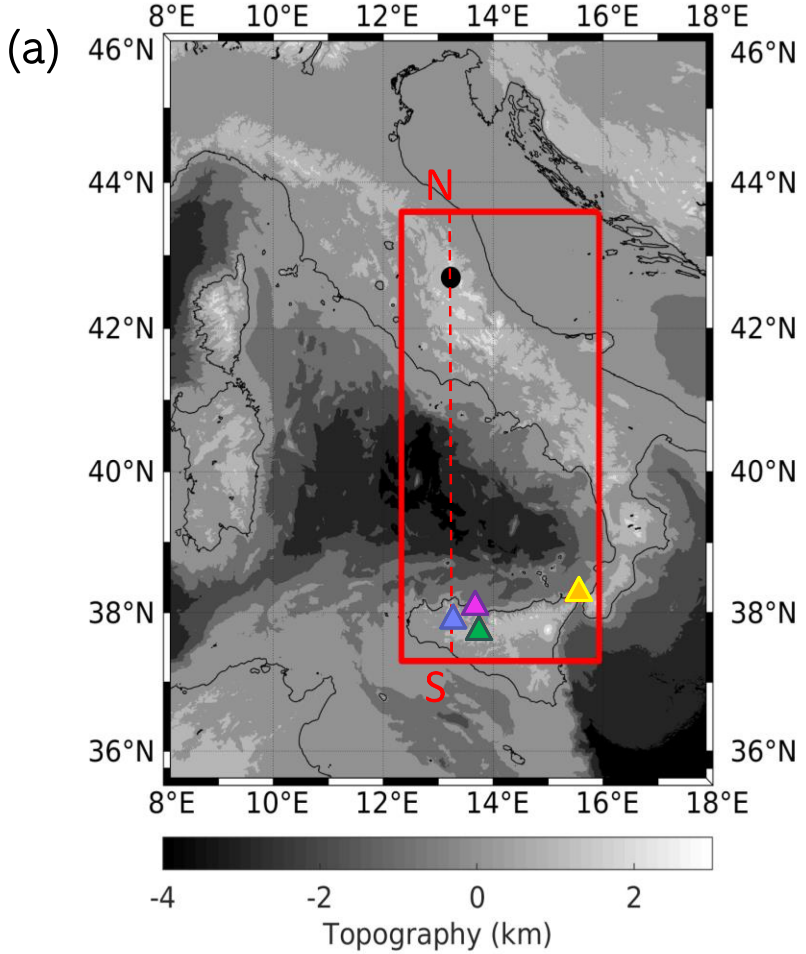


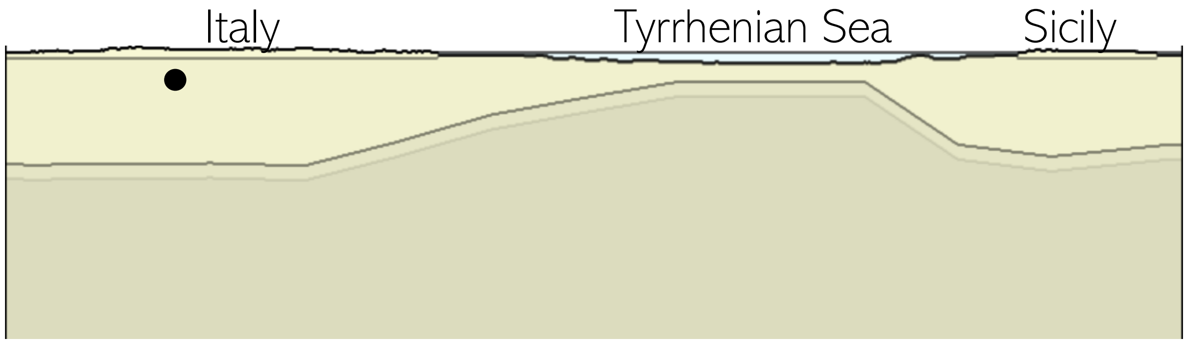
Figure 2: (a) Topography from Amante & Eakins, 2009. The simulation area is marked by the red line. The simulated source is located in Central Italy (black dot) and the synthetic receivers are located in Sicily (triangles). (b) Profile NS: from free surface down to the mantle.

Velocity and heterogeneity model

Free surface : ETOPO1 Global Relief Model (Amante & Eakins, 2009)

Sediments : 2 km below continental region

Moho : Manu-Marfo et al., 2019



Heterogeneity: at each grid node, the velocity fluctuation ξ(I, J, K) is defined

Input values :

	$V_P[km/s]$	$V_S[km/s]$	$\rho[g/cm^3]$	Q_P	Q_S	ε	k	a
Air	0.0	0.0	0.001	10^{10}	10^{10}			
Seawater	1.5	0.0	1.0	10^6	10^6			
Sediments	5.22	2.9	2.2	1000	500	0.07	0.2	0.2
Crust	6.0	3.9	2.8	2000	1500	0.07	0.3	0.2
Moho Transition	7.0	4.0	3.4	1000	500	0.01	0.4	0.2
Mantle	7.7	4.5	3.5	1000	500	0.01	0.5	0.2

Seismic source - depth

We first aim at characterizing the source by exploring the effects of the source time function and focal depth variations. We initially set the velocity and heterogeneity values to the average values obtained for this area from previous Radiative Transfer simulations of the energy envelopes.

Point Source: (13.23°; 42.70°)

MRF: Boxcar (*Tinti et al. 2016*)

Source depths: 6.45, 7.3, 8 km (*Tinti et al. 2016*, INGV)

Receiver: (13.30°; 37.89°)

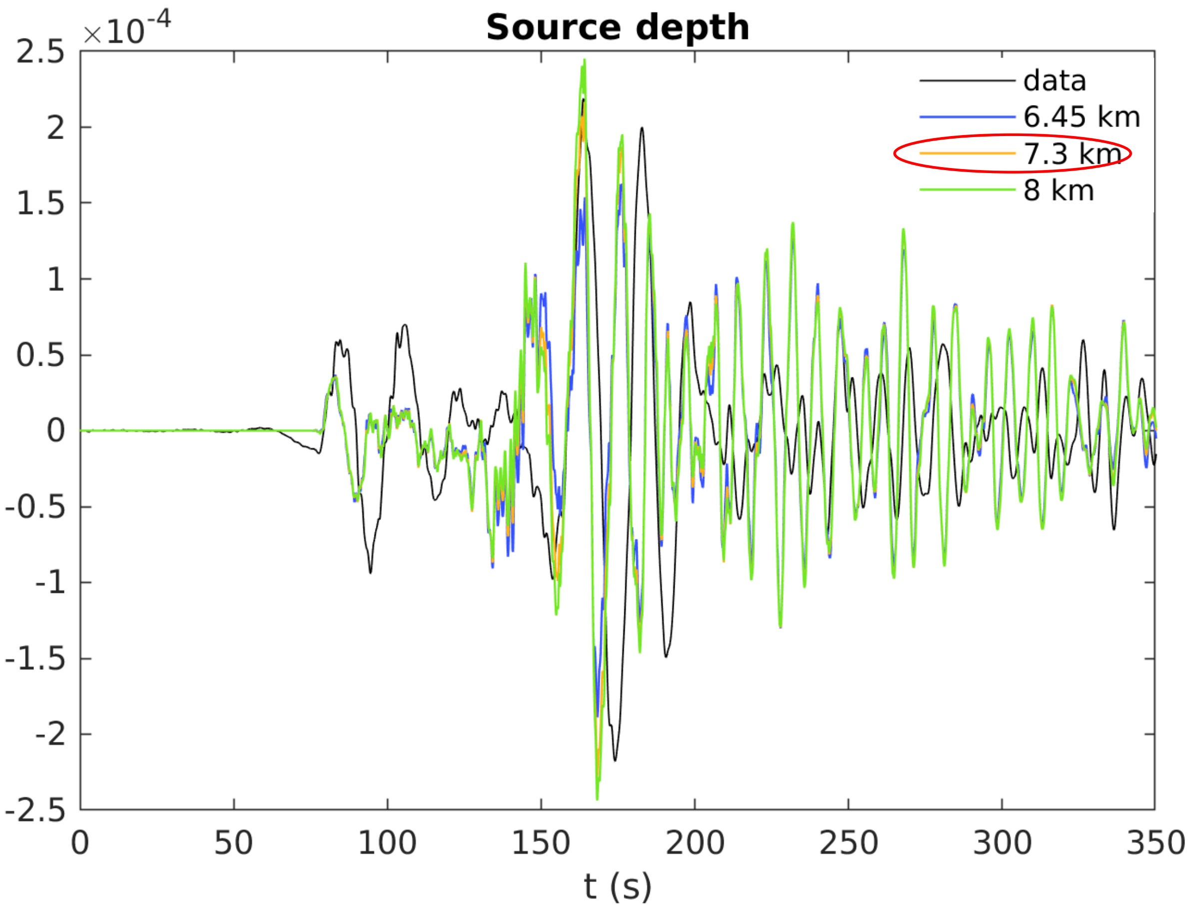
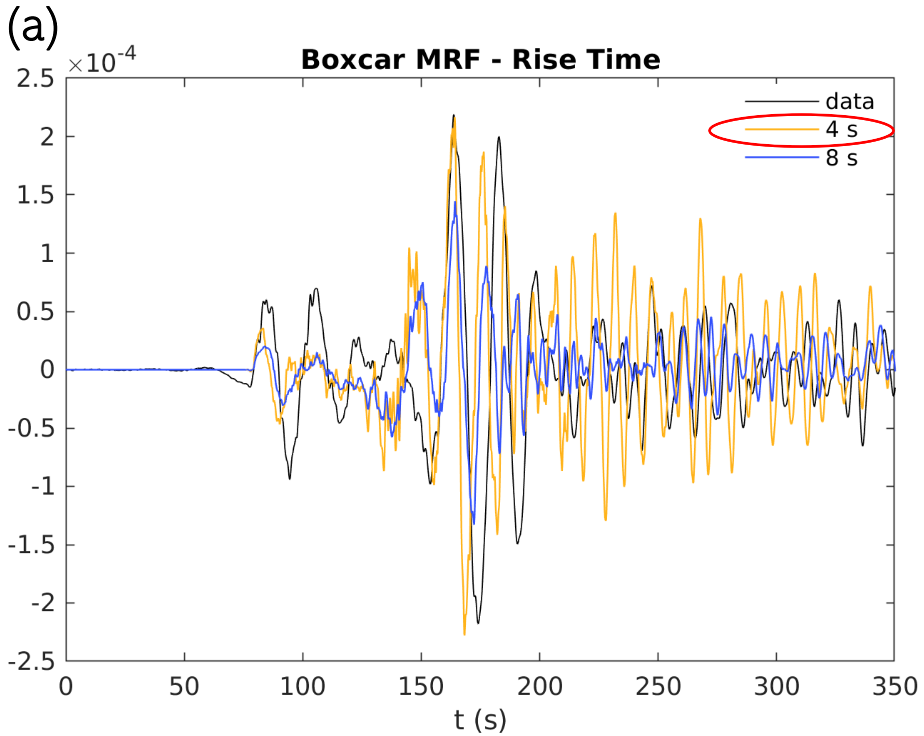
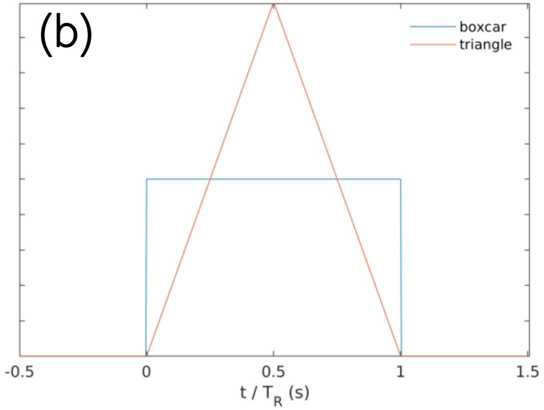


Figure 3: We set the boxcar MRF and we explore different focal depths based on a few of studies (Istituto Nazionale di Geofisica e Vulcanologia - INGV; *Tinti et al., 2016*).

Moment rate function (MRF) $\dot{M}$





Rise time $T_R = 4$
(*Tinti et al. 2016*)

MRF amplitude

Far-field dispacement ~ $\dot{M}$

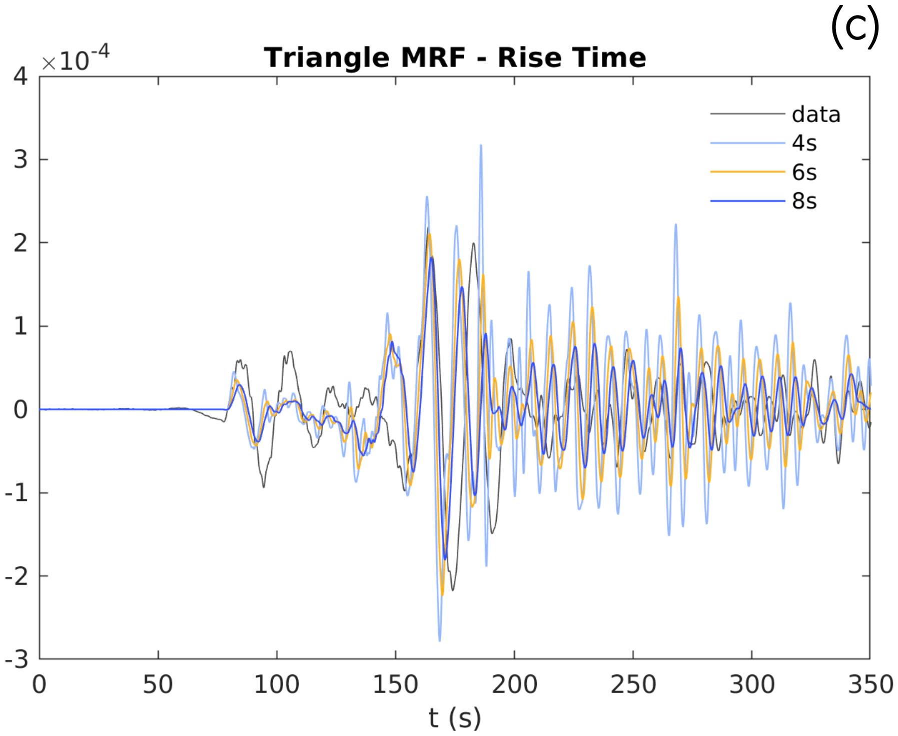


Figure 4: We keep the depth of the single point source fixed at 7.3 km. We explore the effects of varying the rise time and the MRF shape: panel (a) and (b) show the results for the boxcar and triangle MRFs, respectively. In panel (b), we compare the two implemented MRFs.

Velocity models

	Model 1		Model 1.1		Model 1.2		Model 1.3	
	V_P	V_S	V_P	V_S	V_P	V_S	V_P	V_S
Sediments	5.22	2.9	4.9	2.9	5.0	2.8	5.0	2.8
Crust	6.0	3.9	6.0	3.8	6.4	3.9	6.4	3.5
Moho Transition	7.0	4.0	7.0	4.0	7.5	4.3	7.5	4.3
Mantle	7.7	4.5	7.0	4.0	7.7	4.5	7.7	4.5

Table 1: P and S waves velocity of each layer in the four different models implemented in the simulations.

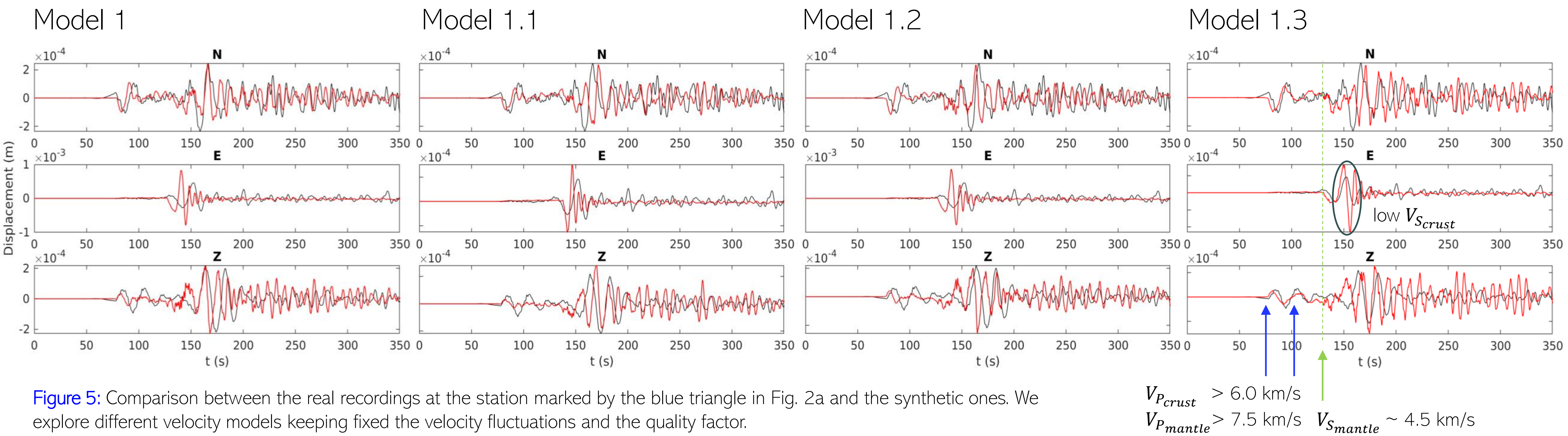
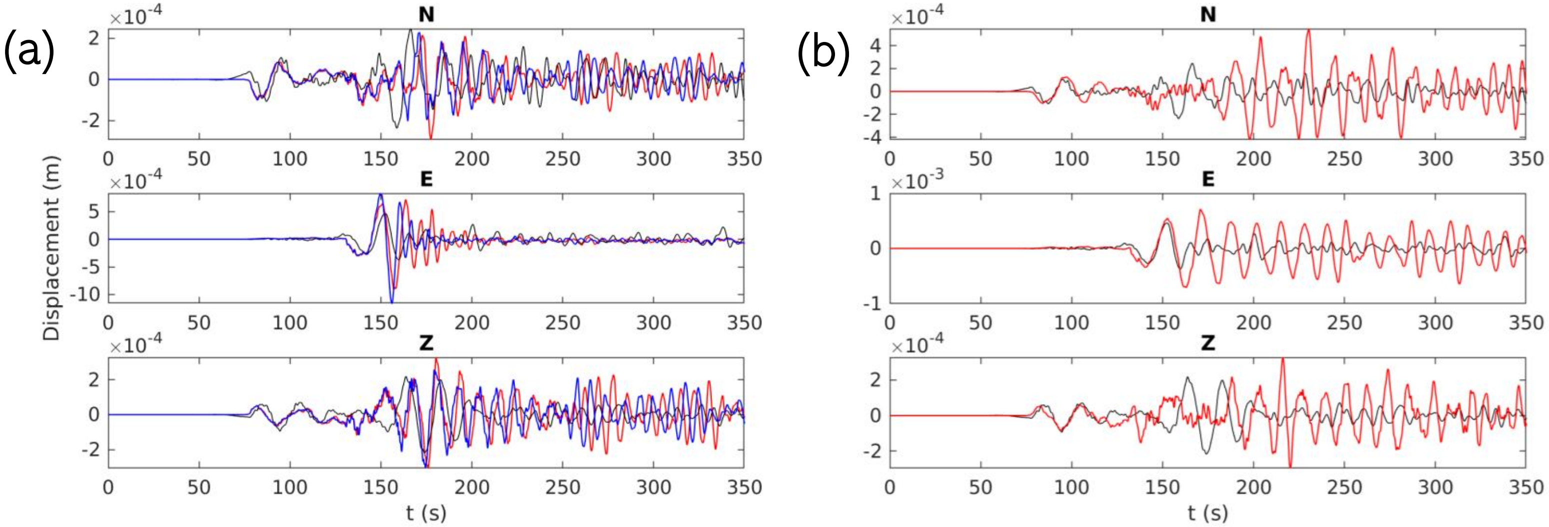


Figure 5: Comparison between the real recordings at the station marked by the blue triangle in Fig. 2a and the synthetic ones. We explore different velocity models keeping fixed the velocity fluctuations and the quality factor.

Thicker sediments

Figure 7: Results obtained by varying the sedimentary layer thickness according to *Molinari & Morelli* (2011). (b) shows synthetic traces obtained by using thicker sediments characterized by lower velocity with respect to (a).



Blu: thinner sediments, velocity model 1.3
Red: thicker sediments (EPcrust), velocity model 1.3

Red: thicker sediments (EPcrust), lower sediments velocity

Thicker sediments produce reverberations

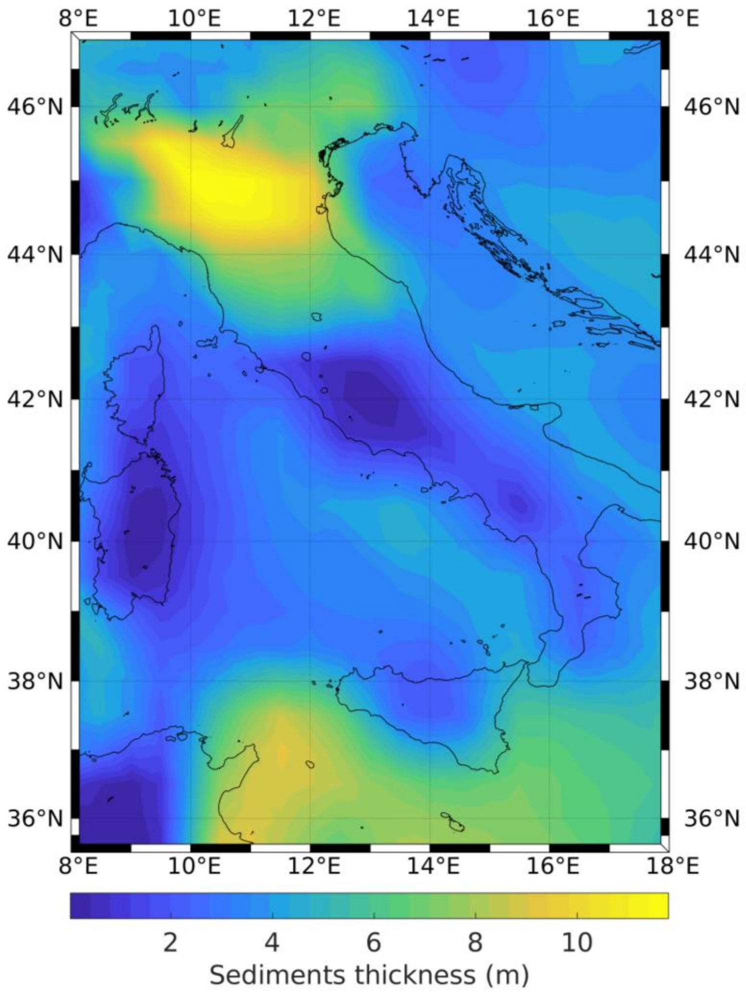


Figure 6: EPcrust sediments thickness (*Molinari & Morelli, 2011*)

Synthetic stations

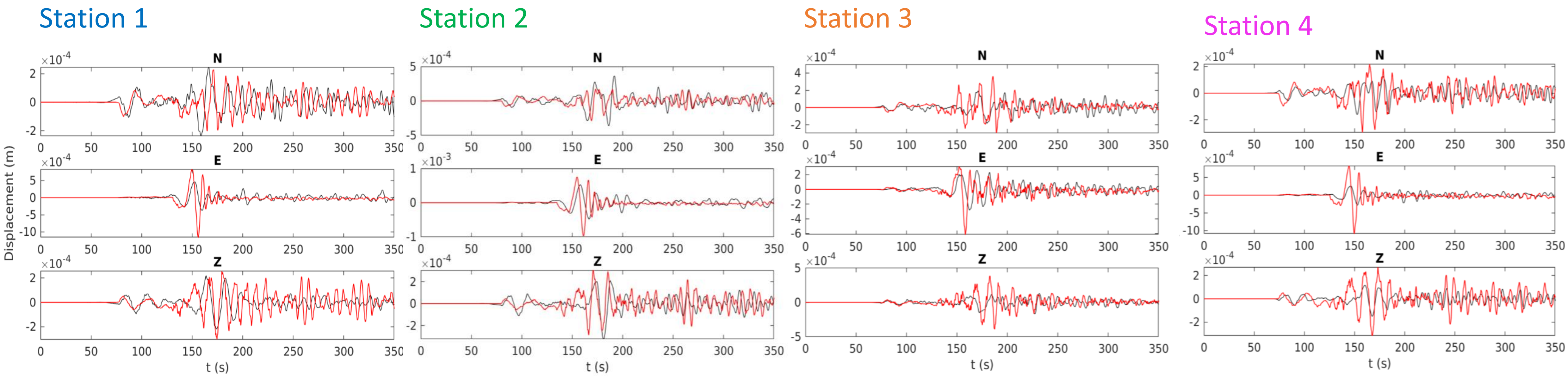


Figure 7: Synthetic traces obtained using velocity model 1.3 (see Tab. 1) at the different station locations (see Fig. 2a).

Conclusions

- The results of the coda wave analysis led the full-waveform forward modelling in a region characterized by a thinner crust causing wave reverberations and energy leakage into the mantle.

- We explored different focal depths and source time function to characterize the Central Italy earthquake.

- The effects of the velocity variation in each layer have been investigated to test the sensitivity of different time windows.

- Next step:
  - Varying the heterogeneity parameters to focus on the coda waves sensitivity
  - Building an automatic procedure to evaluate, from the real signal, the crust parameters which yield the best agreement between simulated and real data.