Stochastic simulation of the intermediate earthquakes using the 3D attenuation model for the southern Aegean subduction zone

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It is well-known that low body-wave velocities (Papazachos and Nolet, 1997) and quality factor (high attenuation) (Ventouzi et al., 2014) have been observed beneath the Southern Aegean volcanic arc, at the depth of ~60–90 km. This is usually attributed to the subduction process of the Eastern Mediterranean lithosphere under the Aegean microplate, resulting in the partial melting above the subducting slab. As a result, P and S waves from intermediate-depth earthquakes are strongly attenuated along the South Aegean Sea volcanic arc. On the other hand, P and S waves from in-slab events, propagating toward the outer Hellenic arc, exhibit relatively high-frequency amplifications (Fig. 1). More recently, Ventouzi et al. (2018) confirmed the existence of the high attenuation mantle wedge beneath the volcanic arc by calculating a new 3D attenuation (Q_P and Q_S) model. This 3D-model has been determined by the tomographic inversion of the linear decay of acceleration spectra at high frequencies, t_S*, calculated for body waves and assuming an ω^2 earthquake source model

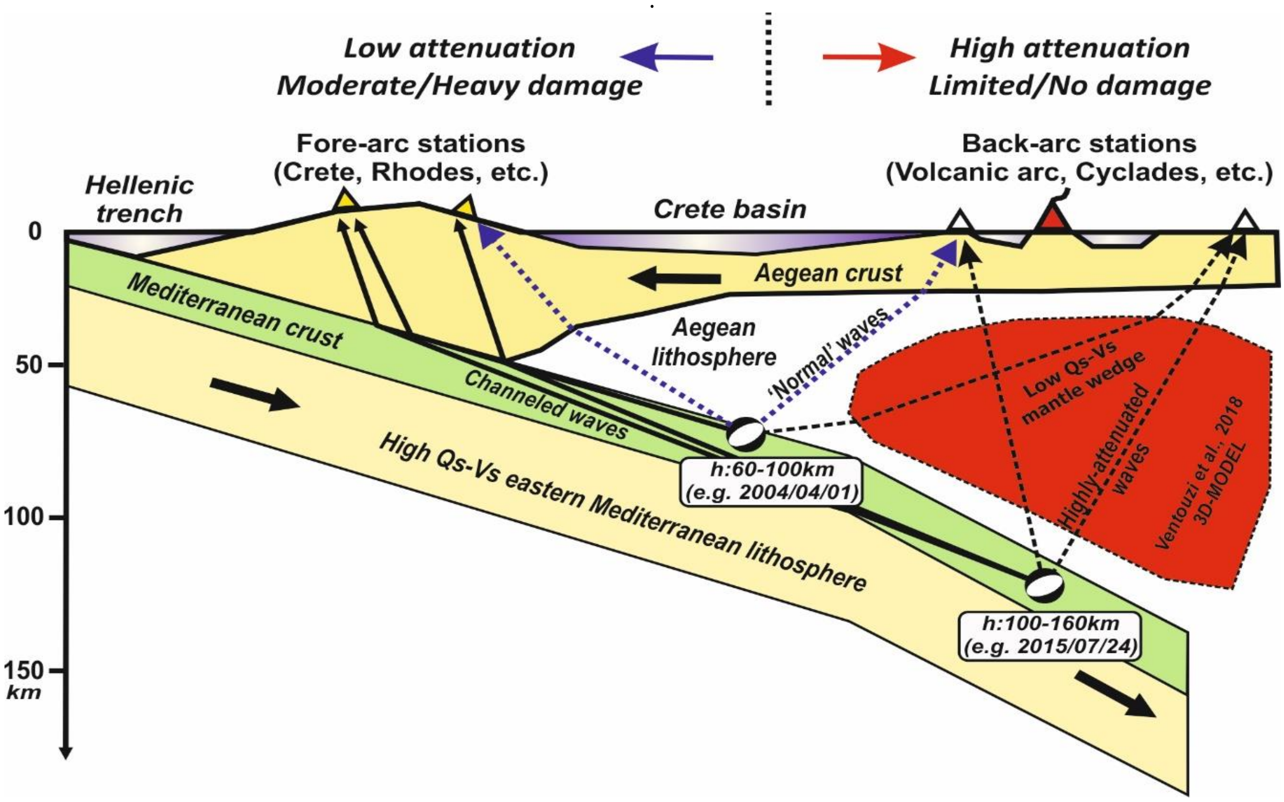

Figure 1. Schematic representation of the seismic wave propagation pattern of intermediate-depth events occurring at the Hellenic arc along a cross section parallel to the subduction direction for earthquakes occurring at the subducted slab of the Eastern Mediterranean lithosphere at different depths. Seismic rays from in-slab events travelling through the low Q_S–V_S back-arc mantle wedge or the high Q_S–V_S subducting eastern Mediterranean slab are depicted by dashed and solid lines, respectively. Seismic energy from deep events (h ≥100 km) is strongly attenuated in the back-arc area and channeled through the slab, resulting in larger damage in the fore-arc region than in the epicentral area (back-arc area) above the slab. For shallower events (h~ 60–100 km) this pattern is prominent only at larger distances, since short-distance propagation is not affected by the mantle wedge presence (blue dotted rays). The vertical projections of typical fault-plane solutions are also shown (modified from Skarlatoudis et al., 2013).

The main target of this study is to compare the new 3D anelastic attenuation model for the upper mantle of the southern Aegean Sea subduction area (Ventouzi et al., 2018) with the Ground Motion Prediction Equations, GMPEs (Skarlatoudis et al., 2013) and to employ this model into the stochastic simulation approach developed by Kkallas et al. (2018a, b), in order to generate realistic seismic waveforms for intermediate depth events occurring in the southern Aegean subduction area. For this purpose, we initially used a synthetic dataset of intermediate-depth events recorded by the same seismological stations later used in the stochastic simulation and calculated the theoretically expected Q_S values based on the 3D anelastic attenuation model of Ventouzi et al. (2018). The results were compared with the corresponding anelastic attenuation coefficient values of the GMPE from Skarlatoudis et al. (2013), showing a good agreement.

In order to predict several expected ground motion measures, for example peak ground acceleration (PGA) and peak ground velocity (PGV) as a function of distance and magnitude, we used the results obtained from the stochastic simulation approach. These simulations were performed with the EXSIM code (Motazedian and Atkinson, 2005), as adapted by Boore (2009), taking into account finite-fault effects for ground-motion modelling. The main concept is based on the summation of the contributions to ground motion over all of the sub-sources comprising the fault at the observation site, considering proper delays of sub-sources due to rupture propagation. Several researchers have investigated the seismotectonic setting, strong ground motion attenuation and source properties that control seismic motions for the intermediate-depth earthquakes of the south Aegean Sea (e.g. Boore et al., 2009; Skarlatoudis et al., 2009, 2013; Kkallas et al., 2013, 2018a, b). These studies provide constraints on several source and propagation path parameters for this class of events, namely the stress parameter, expected fault dimensions, quality factor of the Aegean mantle, geometrical spreading etc. In the present study, these results have been incorporated in order to perform a realistic stochastic finite-fault modelling of intermediate depth earthquakes in the South Aegean Sea.

To confirm the stability and effectiveness of the employed 3D attenuation model, we model the PGA and PGV distribution of three intermediate depth earthquakes of the southern Aegean Sea subduction zone, namely the 2011 intermediate-depth earthquake (M 6.1, h~75 km), the 2004 M = 5.5 event (southeast of Astypalaia), and the more recent 2015 M = 5.0 Nisyros intermediate earthquake (h~130km), which all exhibit spatially anomalous seismic motion and macroseismic (damage) patterns. In general, there is a good agreement between peak ground-motion measures (PGA/PGV) and synthetic values for the entire dataset. Finally, the approach allowed us to explore simulation for future, larger magnitude events in the study area. A typical application example of the proposed methodology was considered for the scenario of a Mw=7.5 intermediate-depth event which will occurr near the islands of Kos and Nisyros (eastern Hellenic arc). The obtained results are promising, confirming the significant differences of fore-arc and back-arc damage distributions, suggesting that the role of intermediate-depth earthquakes should be further explored using the updated 3D attenuation model.

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