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Earthquake scenarios for the Hellenic Arc from 3D dynamic rupture modeling: implications for tsunami hazard

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The Hellenic Arc is an active seismogenic zone in the Mediterranean Sea that hosted at least two historical M≥8 earthquakes, which both caused destructive tsunamis. The low-angle geometry of its subduction interface could promote shallow slip amplification, enhancing seafloor displacement.
Long-term seismic-probabilistic tsunami hazard assessment (S-PTHA, e.g., Scala et al., 2020) and early warning systems typically rely on kinematic models and Okada's analytical solution to compute static seafloor displacements. The static displacement is then used to source tsunami models. However, the complex interaction of earthquake dynamics and tsunami-genesis may not be fully captured.

We recently demonstrated mechanically consistent dynamic rupture models in generic megathrust settings informed from long-term geodynamic modeling that can provide building blocks toward integrating physics-based dynamic rupture modeling in Probabilistic Tsunami Hazard Analysis (Wirp et al., 21). We here present a range of 3D multi-physics, high-resolution dynamic rupture subduction earthquake scenarios accounting for the complex slab geometry of the Hellenic Arc. We vary hypocenter locations, which leads to a wide range of rupture speeds, extent of shallow fault slip, and moment magnitudes.
Our dynamic rupture models include highly resolved bathymetry and topography data and detailed knowledge of the tectonic structure of the Hellenic Arc (seismic velocity structure, stresses, and strengths). We use the slab geometry from the European Database of Seismogenic Faults (EDSF, Basili et al., 2013) to create a 3D dynamic rupture scenario that covers great parts of the Mediterranean Sea. The initial conditions in our models are constrained on the subduction zone scale (Ulrich et al., 2021) and specified for the Hellenic Arc region.

Only part of the Hellenic Arc is fully seismically coupled (e.g., Laigle et al., 2004) and most of the convergence is assumed to occur as aseismic creep. We follow Ramos et al. (2021) and apply different friction parameters accounting for high or low coupling of the plate interface.
Our modeling suggests that margin-wide rupture would yield an Mw 9.3 earthquake. More reasonable smaller magnitude earthquakes are obtained by increasing the along-arc complexity of

the reference model. Different hypocenter locations result in remarkable differences in shallow fault slip penetrating into velocity-strengthening regions, which translate into strong variations of the final seafloor displacement across scenarios.
In additional models with partially consolidated and totally unconsolidated sediments (Ulrich et al., 2021) we show that off-fault plastic yielding, which limits shallow fault slip, may drastically increase the seafloor uplift.
Finally, we explore a novel 3D fully coupled earthquake-tsunami modeling approach (Lotto and Dunham, 2018; Krenz et al., 2021) by adding a water layer to the modeling domain. This enables simulating earthquake dynamics, acoustic waves, and the resulting tsunami simultaneously. The fully coupled model will capture the dynamics of the entire tsunami-genesis in a single simulation, overcoming typical approximations for standard earthquake-tsunami coupling workflows.

We envision that mechanically consistent dynamic rupture models can provide building blocks toward combined, self-consistent, and physics-based Seismic and Tsunami Hazard Analysis.