EGU21-15257
https://doi.org/10.5194/egusphere-egu21-15257
EGU General Assembly 2021

3D linked megathrust, dynamic rupture and tsunami propagation and inundation modeling: Dynamic effects of supershear and tsunami earthquakes

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Earthquake rupture dynamic models capture the variability of slip in space and time while accounting for the structural complexity which is characteristic for subduction zones. The use of a geodynamic subduction and seismic cycling (SC) model to initialize dynamic rupture (DR) ensures that initial conditions are self-consistent and reflect long-term behavior. We extend the 2D geodynamical subduction and SC model of van Zelst et al. (2019) and use it as input for realistic 3-dimensional DR megathrust earthquake models. We follow the subduction to tsunami run-up linking approach described in Madden et al. (2020), including a complex subduction setup along with their resulting tsunamis. The distinct variation of shear traction and friction coefficients with depth lead to realistic average rupture speeds and dynamic stress drop as well as efficient tsunami generation.

We here analyze a total of 14 subduction-initialized 3D dynamic rupture-tsunami scenarios. By varying the hypocentral location along arc and depth, we generate 12 distinct unilateral and bilateral earthquakes with depth-variable slip distribution and directivity, bimaterial, and geometrical effects in the dynamic slip evolutions. While depth variations of the hypocenters barely influence the tsunami behavior, lateral varying nucleation locations lead to a shift in the on-fault slip which causes time delays of the wave arrival at the coast. The fault geometry of our DR model that arises during the SC model is non-planar and includes large-scale roughness. These features (topographic highs) trigger supershear rupture propagation in up-dip or down-dip direction, depending on the hypocentral depth.

In two additional scenarios, we analyze variations in the energy budget of the DR scenarios. In the SC model, an incompressible medium is assumed (ν=0.5) which is valid only for small changes in pressure and temperature. Unlike in the DR model where the material is compressible and a

different Poisson's ratio (ν=0.25) has to be assigned. Poisson's ratios between 0.1 and 0.4 stand for various compressible materials. To achieve a lower shear strength of all material on and off the megathrust fault and to facilitate slip, we increase the Poisson ratio in the DR model to ν=0.3 which is consistent with basaltic rocks. As a result, larger fault slip is concentrated at shallower depths and generates higher vertical seafloor displacement and earthquake moment magnitude respectively. Even though the tsunami amplitudes are much higher, the same dynamic behavior as in the twelve hypocenter-variable models can be observed. Lastly, we increase fracture energy by changing the critical slip distance in the linear slip-weakening frictional parameterization. This generates a tsunami earthquake (Kanamori, 1972) characterized by low rupture velocity (on average half the amount of s-wave speed) and low peak slip rate, but at the same time large shallow fault slip and moment magnitude. The shallow fault slip of this event causes the highest vertical seafloor uplift compared to all other simulations. This leads to the highest tsunami amplitude and inundation area while the wavefront hits the coast delayed compared to the other scenarios.