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Linking geodynamic subduction models to self-consistent 3D dynamic earthquake rupture and tsunami simulations

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3D imaging reveals striking along-trench structural variations of subduction zones world-wide (e.g., Han et al, JGR 2018). Subduction zones include basins, sediments, splay and back-thrusting faults that evolve over a large time span due to tectonic processes, and may crucially affect earthquake dynamics and tsunami genesis. Such features should be taken into account for realistic hazard assessment. Numerical modeling bridges time scales of millions of years of subduction evolution to seconds governing dynamic earthquake rupture, as well as spatial scales of hundreds of kilometers of megathrust geometry to meters of an earthquake rupture front.

Recently, an innovative framework linking long-term geodynamic subduction and seismic cycle models to dynamic rupture models of the earthquake process and seismic wave propagation at coseismic timescales was presented (van Zelst et al., JGR 2019). This workflow was extended in a simple test case to link the 2D seismic cycle model to a three-dimensional earthquake rupture mode, which was then linked to a tsunami model (Madden et al., EarthArxiv, doi:10.31223/osf.io/rzvn2). Here, we couple a 2D seismic cycle model to 3D earthquake and tsunami models and assess the geophysical aspects of this coupling. We extract all 2D material properties, stresses and the strength of the megathrust, and its geometry, from the seismic cycling model at a time step right before a typical megathrust event to use as initial conditions for the 3D dynamic rupture models. We explore the effects of along-arc variations of megathrust curvature, sediment content, and closeness to failure of the wedge on earthquake dynamics by studying the effects on slip, rupture velocity, stress drop and seafloor deformation.

In a next step, the dynamic seafloor displacements are linked to tsunami simulations that use depth-integrated (hydrostatic) shallow water equations. This approach efficiently models wave propagations and large-scale horizontal flows. We also present novel, fully coupled 3D dynamic rupture-tsunami simulations (Krenz et al., AGU19; Abrahams et al., AGU19; Lotto and Dunham et al., 2015, Computational Geosciences) which solve simultaneously for the solid earth and ocean response, taking gravity into account via a modified free surface boundary condition.

Earthquake rupture modeling and the fully-coupled tsunami modeling utilize SeisSol (www.seissol.org), a flagship code of the ChEESE project (www.cheese-coe.eu). SeisSol is an open source software package using unstructured tetrahedral meshes that are optimally suited for the complex geometries of subduction zones. The here presented links between geodynamic subduction and seismic cycling model with earthquake dynamics and tsunami models better account for the complexity of subduction zones and help evaluate the effects of along arc heterogeneities on earthquake and tsunami behavior and advance physics-based assessments of earthquake-tsunami hazards.