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Coupling a geodynamic seismic cycle to a dynamic rupture model with an application to splay fault propagation

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Numerical methods that span a large range of spatial and temporal scales are required to accurately study the seismicity in subduction zones. Whereas the stresses on the fault need hundreds to thousands of years to build up on a tectonic scale, the consequent earthquake rupture propagation is determined by both these initial fault conditions and the feedback of seismic waves over time scales up to minutes. Spatial scales are also challenging, because the stress state of the fault can be affected by the subducting slab on scales of tens to hundreds of kilometers, while reflecting waves can influence (splay fault) rupture propagation in the hundred-meter-scale close to the tip of the wedge. To accurately model the physics involved over al temporal and spatial scales, we couple a geodynamic seismic cycle (SC) model to a dynamic rupture (DR) model. The SC models have the advantage of solving earthquake cycles in a self-consistent manner concerning stress, strength and fault geometry, but lack a high enough spatial and temporal resolution to resolve wave propagation. In contrast, dynamic rupture models solve for dynamic fault rupture and seismic wave propagation, but their initial conditions cannot be constrained in a self-consistent manner. By coupling these two codes, the advantages of both can be exploited.

The initial stresses and geometry from a reference megathrust rupture from the SC model are used as input in the DR model, resulting in the spontaneous nucleation of dynamic rupture. This fully resolved earthquake is qualitatively similar to its unresolved SC equivalent in terms of stress drop and upward rupture propagation. To explore the effects of the differences between the two models on the subsequent rupture behaviour in the DR model, a comparison of models with different initial stress conditions and off-fault plasticity is presented.

We exploit the advantages of our coupled model by studying when and how often a rupture favours propagation on the splay fault over the megathrust. This question of rupture path selection is of importance when assessing a region's tsunami hazard. The SC models show that subduction zones with a larger sediment thickness and with relatively weaker sediments favour splay fault formation with corresponding splay fault ruptures. Our coupled method allows us to verify whether these conclusions and splay fault selection in general, are influenced by seismic waves reflecting strongly within the confined accretionary prism.