Cross-Time-Scale Dynamics of Subduction Seismic Cycles: From Megathrust Ruptures to Large-Scale Plate Motion

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Subduction zones host great earthquakes. The spatiotemporal variability of these earthquakes is thought to be intimately coupled to plate tectonics and underlying mantle dynamics. Here we develop a 2D self-consistent subduction zone model using the finite element code, Underworld, that simultaneously captures short-time-scale and long-time-scale features in megathrust earthquake cycles. This system is driven by negative buoyancy of a denser slab and employs a nonlinear viscoelastoplastic. A thin shear zone is implemented between subducting and overriding plates to mimic the fault interface, with a velocity-weakening rate-and-state friction law to trigger spontaneous slip instability and generate earthquake sequences.

With adaptive time steps from seconds to years, the model reproduces multiple megathrust earthquake events and multiscale processes at different stages of seismic cycles. We further examine the influence of rheological and frictional parameters on megathrust earthquake cycles. By controlling the mantle viscosity and plate interface friction coefficient, these parameters greatly affect the background plate motion, as well as the earthquake period and magnitude. These variations are consistent with theory and observations. This model, which closes the gap between geodynamical underpinning and great earthquake rupture, demonstrates the potential in investigating cross-time-scale subduction dynamics.