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Earthquakes as plastic failure on spontaneously evolving faults

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Subduction zones evolve over millions of years. The state of stress, the distribution of materials, and the strength and structure of the interface between the two plates is intricately tied to a host of time-dependent physical processes, such as damage, friction, (nonlinear) viscous relaxation, and fluid migration. In addition, the subduction interface has a complex three-dimensional geometry that evolves with time and can adjust in response to a changing stress environment or in response to impinging topographical features, and can branch off as a splay fault. All in all, the behaviour of (large) earthquakes at the millisecond to minute timescale is heavily dependent on the pattern of stress accumulation during the $\sim$100 year inter-seismic period, the events occurring on or near the interface in the past thousands of years, as well as the extended geological history of the region.

We try to deal with all of these considerations by developing a self-consistent 2D/3D staggered grid finite difference continuum description of motion, thermal advection-diffusion, and poro-visco-elastic two-phase flow. Faults are modelled as plastic shear bands that can develop and evolve in response to a changing stress environment without having a prescribed geometry. They obey a Mohr-Coulomb or Drucker-Prager yield criterion and a rate-and-state friction law. For a sound treatment of plasticity, we borrow elements from mechanical engineering, and extend these with high-quality nonlinear iteration schemes and adaptive time-stepping to resolve the rupture process at all time scales. We will present these techniques and demonstrate its applicability via several examples showing the development of self-consistent fault rupture in 2D and 3D.