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Simulating spontaneous aseismic and seismic slip events on evolving faults

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Plate motion along tectonic boundaries is accommodated by different slip modes: steady creep, seismic slip and slow slip transients. Due to mainly indirect observations and difficulties to scale results from laboratory experiments to nature, it remains enigmatic which fault conditions favour certain slip modes. Therefore, we are developing a numerical modelling approach that is capable of simulating different slip modes together with the long-term fault evolution in a large-scale tectonic setting.

We extend the 2D, continuum mechanics-based, visco-elasto-plastic thermo-mechanical model that was designed to simulate slip transients in large-scale geodynamic simulations (van Dinther et al., JGR, 2013). We improve the numerical approach to accurately treat the non-linear problem of plasticity (see also EGU 2017 abstract by Pranger et al.). To resolve a wide slip rate spectrum on evolving faults, we develop an invariant reformulation of the conventional rate-and-state dependent friction (RSF) and adapt the time step (Lapusta et al., JGR, 2000). A crucial part of this development is a conceptual ductile fault zone model that relates slip rates along discrete planes to the effective macroscopic plastic strain rates in the continuum.

We test our implementation first in a simple 2D setup with a single fault zone that has a predefined initial thickness. Results show that deformation localizes in case of steady creep and for very slow slip transients to a bell-shaped strain rate profile across the fault zone, which suggests that a length scale across the fault zone may exist. This continuum length scale would overcome the common mesh-dependency in plasticity simulations and question the conventional treatment of aseismic slip on infinitely thin fault zones. We test the introduction of a diffusion term (similar to the damage description in Lyakhovsky et al., JMPS, 2011) into the state evolution equation and its effect on (de-)localization during faster slip events. We compare the slip spectrum in our simulations to conventional RSF simulations (Liu and Rice, JGR, 2007).

We further demonstrate the capability of simulating the evolution of a fault zone and simultaneous occurrence of slip transients. From small random initial distributions of the state variable in an otherwise homogeneous medium, deformation localizes and forms curved zones of reduced states. These spontaneously formed fault zones host slip transients, which in turn contribute to the growth of the fault zone.