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Seismo-mechanical modelling of megathrust earthquake cycles: influence of rate-and state-dependent friction

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Our long-term goal is to explore the cause-and-effect relationships between subduction dynamics and the megathrust earthquake potential. Therefore we are developing a 2D continuum mechanics-based numerical seismic cycle model that bridges the gap between processes on geodynamic and earthquake time scales. The initial step towards this goal was the implementation of a purely slip rate-dependent friction (Van Dinther et al. 2013) into the visco-elasto-plastic, finite difference code I2ELVIS, which uses a marker-in-cell technique. This seismo-mechanical modelling approach was validated for seismic cycle applications through a comparison against scaled analogue subduction experiments (Corbi et al. 2013). However, this comparison revealed large differences in terms of the slip behaviour in the periods between fast slip events. While diminishing interseismic creep occurs within the seismogenic zone in our numerical models, large aseismic slip was present in the analogue experiments. Here we want to overcome this mismatch by implementing the laboratory-based rate-and state dependent friction (RSF) formulation into our modelling approach.

We choose the RSF formulation because, in contrast to our previous friction formulation, it takes the dependency of frictional strength on a state variable into account. The evolution of the state variable as a function of time or slip allows aseismic slip during the interseismic period within the seismogenic zone. In addition, RSF can potentially explain the transition from stick-slip behaviour to stable sliding with increasing loading velocity, which is observed in related friction experiments (Corbi et al. 2011). Here we implement the regularised version of RSF into our seismo-mechanical modelling approach by calculating and storing the analytical solution of the state evolution on each marker. In contrast to the conventional RSF formulation, we relate slip velocities to strain rates and use an invariant formulation. Thus we do not require the a priori definition of an infinitely thin, planar plate interface in a homogeneous elastic medium. These assumptions, otherwise usually made in applications of RSF, are typically not valid for the long-term subduction dynamics.

With this new implementation of RSF we succeed to produce instabilities towards which strain rates increase, while the state variable and second invariant of the deviatoric stress tensor change from increasing to decreasing. We extend the previous comparison against the scaled analogue subduction experiments, which cover a range of loading velocities. We adapt the frictional parameters of RSF in our numerical models to agree both with the constraints from friction experiments (Corbi et al. 2011), the amount of aseismic slip in the seismogenic zone, and source parameters in the analogue experiments. In addition, we analyse the dependency of the results on numerical parameters such as the grid size, the width of the frictional boundary layer, and the adaptive time-stepping scheme.