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Modelling earthquake cycles using a continuum based poro-visco-elasto-plastic two-phase flow approach

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Fault slip along subduction zones, from slow slip events to large destructive megathrust earthquakes, is influenced by migrating fluids and their interaction with the surrounding host rock. To better understand fault slip or strain, it is crucial to identify the role fluid pressure plays in their nucleation and dynamics. Due to limitations of long-term records of observational data, such as GPS or earthquake catalogues, a numerical model overcoming such limitations is needed. We developed a unified numerical model, which couples solid deformation and fluid flow on an equation level and allows for a fault normal response.

A newly developed finite difference poro-visco-elasto-plastic numerical code with marker-in-cell technique, coupling inertial mechanical deformation and fluid flow, is presented. Localised brittle/plastic deformation is treated accurately through global Picard iterations. To simulate deformation on both long- and short-time scale, an adaptive time stepping is introduced allowing the resolution of large seismic events with time steps on the order of milliseconds.

This new numerical modelling tool allows to explore how the presence of migrating fluids in the pore space of a visco-elasto-plastic (de)compacting rock matrix affects elastic stress accumulation and release along a fluid-bearing subduction interface. The model is capable of simulating spontaneous quasi-periodic seismic events without requiring a reduction in friction. These events nucleate near the brittle-ductile transition and propagate along self-consistently forming highly localized ruptures. The spontaneous elastic rebound events show slip velocities ranging from μm/s to m/s, thereby covering the range from slow to seismic slip. These different forms of slip occur on the same interface and are not tuned through explicit formulations or parameters. The governing strength decrease along the propagating fracture is related to a drop in total pressure, due to shear localization, in combination with a significant increase of fluid pressure generated by deformation induced fluid flux. The reduction of the differential pressure decreases the brittle/plastic strength of fluid-bearing rocks along the rupture, thus providing a dynamic feedback mechanism for the accumulated elastic stress release at the megathrust interface. It is remarkable that the seismic behaviours for both slow slip and ordinary earthquakes can be generated within the same self-consistent poro-visco-elasto-plastic rheological framework without any involvement of rate- and state-dependent friction commonly used for subduction seismicity modelling.