Episodic fluid pressure cycling controls the interplay between Slow Slip Events and Large Megathrust Earthquakes

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Slow slip events (SSEs) are part of a spectrum of aseismic processes that relieve tectonic stress on faults. Their occurrence in subduction zones have been suggested to trigger megathrust earthquakes due to perturbations in fluid pressure. However, examples to date have been poorly recorded and physical observations of temporal fluid pressure fluctuations through slow slip cycles remain elusive. Here, we use a newly developed two-phase flow numerical model — which couples solid rock deformation and pervasive fluid flow — to show how crustal stresses and fluid pressures within subducting megathrust evolve before and during slow slip and regular events. This unified 2D numerical framework couples inertial mechanical deformation and fluid flow by using finite difference methods, marker-in-cell technique, and poro-visco-elasto-plastic rheologies. Furthermore, an adaptive time stepping allows the correct resolution of both long- and short-time scales, ranging from years to milliseconds during the dynamic propagation of earthquake rupture.

Here we show how permeability and its spatial distribution control the degree of locking along the megathrust interface and the interplay between seismic and aseismic slip. While a constant permeability leads to more regular seismic cycles, a depth dependent permeability contributes substantially to the development of two distinct megathrust zones: a shallow, locked seismogenic zone and a deep, narrow aseismic segment characterized by SSEs. Furthermore, we show that without requiring any specific friction law, our model shows that permeability, episodic stress transfer and fluid pressure cycling control the predominant slip mode along the subduction megathrust. Specifically, we find that the up-dip propagation of episodic SSEs systematically decreases the fault strength due to a continuous accumulation and release of fluid pressure within overpressured subducting interface, thus affecting the timing of large megathrust earthquakes. These results contribute to improve our understanding of the physical driving forces underlying the interplay between seismic and aseismic slip, and demonstrate that slow slip events may prove useful for short-term earthquake forecasts.