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The seismic cycle on subduction thrusts: a laboratory validation and implications from large-scale geodynamic simulations

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The physics governing the seismic cycle at seismically active subduction zones remains poorly understood due to restricted direct observations in time and space. In this study, we present visco-elasto-plastic continuum numerical simulations as a new tool that may help to shed light onto the interaction of subduction mechanics and associated seismicity.

First, we validate that these models, typically used in long-term geodynamic simulations, are able to reproduce seismological observables. Its ability to model cycles of large analogue earthquakes is demonstrated through a validation with innovative laboratory models (van Dinther et al., 2013). This benchmark shows cycles of fast frictional instabilities can be simulated (and matched), if velocity-weakening (and velocity-strengthening) friction are incorporated in the analogue seismogenic zone (and up- and downdip of it). The resulting model captures a wide range of physical phenomena observed in nature, including a) ruptures propagating as cracks or self-healing pulses; b) repeated slip on a single patch; and c) afterslip leading to postseismic surface displacements that complement a qualitative agreement with geodetic observations.

In subsequent large-scale simulations, we include slip rate dependent friction into a thermo-mechanical model of a petrologically realistic continental margin to simulate earthquake-like events with recurrence intervals of a thousand years. These events exhibit surface displacements and earthquake source parameters comparable to nature, including the amount of slip, stress drop, and rupture width. However, rupture propagation is much slower than observed. These models reveal interesting geodynamic and seismological implications, including a) a reconciliation of low effective friction expected from geodynamic models ($\mu < 0.1$) with high strengths attained in laboratory experiments (static friction of ~ 0.7); b) a spontaneous downdip seismogenic limit near the Moho due to plastic strength increase and stress decrease as ductile flow becomes dominant; and c) a spontaneous deceleration of the rupture speed in the up-dip direction, though velocity-strengthening friction is needed to prevent the rupture from regularly breaking the trench.