Exploring slow slip events and their scaling in 3D simulations of fault slip

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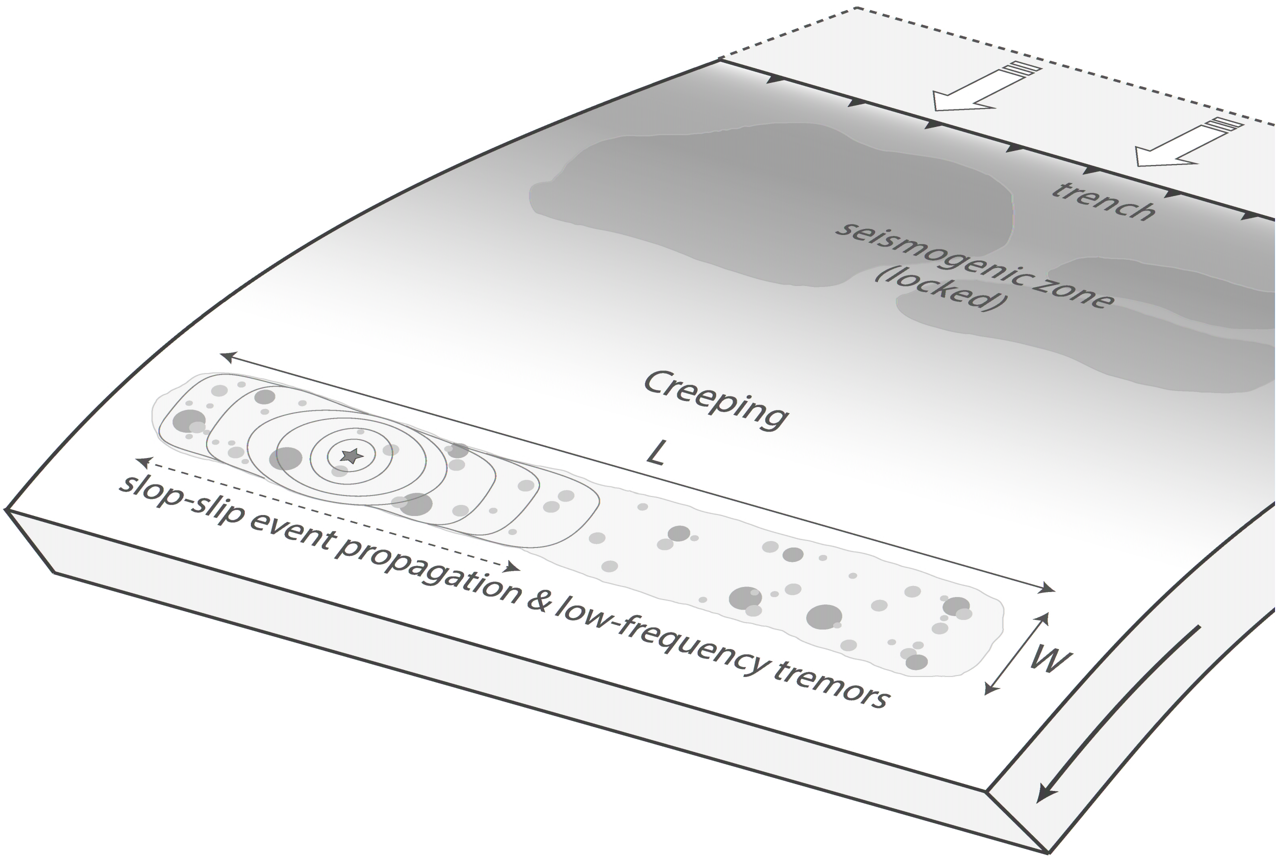
Tectonic faults accommodate a wide spectrum of slip modes, ranging from earthquakes to slow slip events (SSEs). While regular earthquakes are events with rupture velocities governed by inertial stress transfer with elastic wave speeds, the physical mechanisms responsible for underlying slow fault slip phenomena are less understood. In particular, key questions remain about how SSEs nucleate and propagate and whether they follow different scaling laws from ordinary earthquakes. Observations have shed light on these issues. However, due to significant noise in the time series and uncertainties related to the relatively short observational timespan, there is no unique way to interpret observations and determine the underlying mechanism of such SSEs. To overcome this limitation and to investigate synthetic data of longer timescales, here we apply a rate-and-state friction law and dilatancy effects to a three dimensional model of a subduction megathrust. By testing a wide spectrum of frictional properties, we investigate under which conditions sliding instability develops into sustained slow slip events. In particular, we study the processes that control variations in slip velocity, propagation speed, stress drop, as well as the aspect ratio of individual uni- and bi-directional SSEs.

Our model explains the earthquake-like cubic moment-duration scaling of SSEs recently observed in Cascadia subduction zone. Our results suggest that regular earthquakes and SSEs are both the result of frictional stick-slip motion. The pulse-like propagation, along-strike segmentation, and frequency-magnitude distribution of our simulated SSEs are remarkably similar to those observed on the Cascadia subduction zone. However, in contrast to the traditional assumptions, the cubic moment-duration scaling of SSEs arises not because the average rupture velocity and the stress drop of SSEs are magnitude-invariant, but rather because they increase with the increasing SSE magnitude. These results not only illuminate the dynamics of SSEs but also demonstrate that the same scaling can arise for different underlying reasons. The traditional circular crack model with magnitude-invariant rupture velocities and stress drops, which is the standard explanation for the cubic moment-duration scaling, does not apply to SSEs. This finding raises the question whether this traditional model and its assumptions hold even for regular earthquakes.

Keywords: Slow-slip events, Cascadia subduction zone, Scaling Properties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