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Modeling Tectonic Tremor and Slow Slip Events with rate-and-state friction close to critical zero weakening

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Tectonic Tremor and frequently accompanied Slow Slip Events, collectively described as Episodic Tremor and Slip (ETS), are observed in a large number of subduction zones and strike-slip faulting environments. Compared to regular seismicity occurring in the upper seismogenic part of the crust, basic properties of ETS are fundamentally different, such as low frequency content of seismic and geodetic signals associated with slow slip velocities, size-duration scaling, and frequency-size and interevent time statistics. Since this failure mode is associated with a frictional transition zone at the downward extension of the seismogenic part of the crust, understanding the source processes of ETS provides an important opportunity to probe the rheology and physical properties at depths that are otherwise inaccessible to seismological observations. Recent work—based on analytical mean-field results and numerical simulations on a discrete fault with static/kinetic friction in an elastic solid—has shown that the entire observed diverse phenomena that distinguish ETS from regular earthquakes can potentially be explained as associated with a critical depinning transition of a sliding interface. This transition occurs for zero (or in a finite system near zero) weakening during slip, and is assumed to characterize a spatially extended region between an overriding brittle seismogenic zone with weakening rheology and underlying aseismic region with strengthening rheology. Here we implement and study this process in a model of a 2D planar, vertical strike-slip fault governed by rate-and-state (RS) friction, embedded in a 3D elastic half space. We apply the (average) RS dynamic weakening parameter a-b=0 to the transitional zone sandwiched between the overriding weakening and lower strengthening region parameterized by a-b<0 and a-b>0, respectively. Our model demonstrates that characteristics of the almost-constant, 'flickering' small scale failures, that emerge in response to a RS parameterization close to a critical state, exhibit fundamental differences compared to regular seismicity produced in the overriding weakening regime. Within the limits dictated by resolution and the computationally efficient quasi-dynamic approach, the model reproduces the various analytical expectations associated with critical phenomena. In particular, slip distributions measured in the zone with average critical zero weakening are better described by fractal metrics, in contrast to the compact geometries of regular earthquakes associated with net dynamic weakening. The scaling relations between potency and area, area and duration, and interevent time statistics are consistent with characteristics of critical phenomena. The frequency-size statistics of synthetic ETS also show different properties compared to earthquake scaling, displaying a steeper slope and exponential tapering. Our simulations suggest that the migration patterns of larger ETS events are likely controlled by the finite extent of the critical depinning zone, while short duration tremor episodes exhibit uncorrelated spatial properties. Together with overall scale-invariant potency/magnitude time histories, this implies that ETS activity has very limited predictive power on the occurrence of large events in the upper frictional weakening zone. Our results and those of the earlier related work indicate that critical depinning process provides a simple unifying explanation for slip phenomena between the regular seismic and deep aseismic sections of faults.