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Episodic Tremor and Slip on a Frictional Interface With Critical Depinning

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Abstract

Our investigations on Episodic Tremor and Slip on a Frictional Interface With Critical Depinning have focused on the following two research directions: (1) Developing a basic understanding of model seismicity, creep and tremor generated by depth-dependent distribution of static/kinetic friction on a fault section corresponding to the San Andreas fault near Parkfield. (2) Developing a model realization of seismicity, creep and tremor in a subduction zone setting corresponding to the Guerrero region in Mexico. The model results show dramatic changes in multiple aspects of the fault response to constant and oscillatory loading when the difference between the static and kinetic friction levels is reduced below a threshold that lead to failure following a critical depinning transition. (3) We also attempted to develop an understanding of the critical depinning transition in the context of rate- and state-dependent friction. Below we provide additional details on the main results associated with each research directions. The most important conclusion in the context of hazard is probably the implication that that NVT-ETS have little predictive power on the occurrence of large events in the overriding seismogenic zone.

(1) Episodic Tremor and Slip on a Frictional Interface with Critical Zero Weakening in Elastic Solid (*Ben-Zion, 2012*)

Non Volcanic Tremor (NVT) and related relatively weak and slow slip events termed Episodic Tremor and Slip (ETS) are observed below the seismogenic sections of numerous subduction zones and several major strike-slip faults. These events have various characteristics that distinguish them from regular tectonic earthquakes. Here we show that a frictional fault in elastic solid with a region below the seismogenic zone having on average a critical (near-)zero weakening during slip provides a simple unified explanation for the diverse observed phenomenology of NVT-ETS. The results imply that NVT-ETS have little predictive power on the occurrence of large events in the overriding seismogenic zone. Additional model predictions that may be tested with future high-resolution observations are fractal slip distributions and failure areas, discrete power law frequency-moment statistics with exponent 3/2 and exponential tapering, overall scale-invariant potency/moment/magnitude time histories, triggered periodic NVT with evolving size and rate correlated with the stressing rate of the periodic triggering mechanisms, and parabolic (or exponential) source time functions for event sizes measured by duration (or moment/potency).

(2) Modeling slow slip events, non-volcanic tremor and large earthquakes in the Guerrero subduction zone (Mexico) with space-variable frictional weakening and creep (Zigone, Ben-Zion and Campillo, *2012-2013*)

We explore with numerical simulations the range of conditions leading to key observed features of NVT in relation to SSE and earthquakes along the Guerrero segment of the Mexican subduction zone. The Guerrero segment is known to produce some of the largest slow slip events (SSE) recorded so far with equivalent magnitude up to 7.5 Mw. These SSE, with apparent durations of about 4 years, are accompanied by strong activity of Non Volcanic Tremor (NVT) in central Guerrero. Recently, NVT triggered by the 8.8 Mw Maule earthquake were also been reported in that region. The geometry of the Guerrero subduction zone remains sub-horizontal between 150 km to 250 km from the coast, making it easy to model with a simple flat frictional interface. We use a model with a planar interface governed by space-varying static/kinetic friction and dislocation creep in elastic

solid. The model is tailored through the employed dimensions, distribution of rheological properties and boundary conditions to the Guerrero segment, with particular attention to conditions of the past 15 years for which observations are available. A section of the fault with zero weakening during frictional slip fails in a mode corresponding to a "critical depinning transition" that produces many observed features of NVT. When a high creep patch representing a section sustaining SSE is added, strong interactions between NVT and SSE are observed as in the natural fault system. We also examine triggering of NVT by larger remote earthquakes, implemented by adding periodic triggering oscillations to the regular tectonic loading. In addition to modeling observations of NVT and SSE made in Guerrero during the past 15 years, the simulations allow us to distinguish aspects of the observed behavior that are robust over long time intervals from aspects that change during intervals longer than the observational period.

(3) Modeling Tectonic Tremor and Slow Slip Events with rate-and-state friction close to critical zero weakening *(Hillers and Ben-Zion, 2013)*

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. The critical depinning 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. 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. Within the limits dictated by resolution and the computationally efficient quasi-dynamic approach, 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 ETS also show different properties compared to earthquake scaling, displaying a steeper slope and exponential tapering. 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 overlying 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.

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