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Northern Cascadia episodic tremor and slip: A decade of tremor observations from 1997 to 2007

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[1] We analyze continuous seismic and GPS records collected in the last decade (1997–2007) to establish the most comprehensive observational basis for northern Cascadia episodic tremor and slip (ETS) events. A simple "ETS scale" system, using a combination of a letter and a digit, is proposed to quantitatively characterize the spatial and temporal dimensions of ETS events. Clear correlation between GPS and tremor signals is observed for all A/B class episodes, but the GPS signature is less obvious for minor ones. Regular ETS recurrence can be established only for A/B class episodes in southern Vancouver Island. Halting and jumping are very common in ETS migration patterns, and along-strike migration can happen in both directions. A prominent tremor gap is observed in midisland around 49.5°N. This gap coincides with the epicenters of the only two large earthquakes beneath Vancouver Island. ETS tremors also tend to occur in places where the local seismicity is relatively sparse. The tremor depth distribution shows a peak in the 25–35 km range where strong seismic reflectors (i.e., the E layer) are documented. Detailed waveform analysis confirms the existence of shallow tremors above the currently interpreted plate interface. Our results suggest that a significant portion of the tremor activity and perhaps associated shearing are taking place along well-developed structures such as the E layer, while fewer tremor bursts are generated elsewhere in response to the induced stress variation throughout the source volume.

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1. Introduction

[2] Episodic tremor and slip (ETS) is the name given to a plate boundary phenomenon recently discovered in northern Cascadia [e.g., *Rogers and Dragert*, 2003]. It is empirically defined as "repeated, transient ground motions at a plate margin, roughly opposite to the direction of longer-term interseismic deformation, accompanied by low-frequency, emergent, semicontinuous seismic signals." Due to the nature of the three essential components of ETS events (i.e., transient ground motions, tremor-like seismic signals, and episodic occurrences), detailed ETS studies require continuous seismic and geodetic observations from a dense network over a long period of time. The first continuous GPS station in northern Cascadia was established in May 1992, and the regional seismic network completed its conversion to continuous digital recording in 1997 (Figure 1). The decade long history of continuous GPS and seismic observations provide the research community the most complete data set for detailed ETS analysis.

[3] ETS has received increasing attention from the geophysical community because it not only is an interesting natural phenomenon that may provide insights to the understanding of the mechanical behavior of earth materials as they shift from brittle (seismic) to ductile (aseismic) regimes, but also is a phenomenon that may have significant implications in the understanding of seismic hazards in subduction zones. Recent studies have shown that individual ETS episodes may have very different spatial-temporal characteristics, ranging from major events with pronounced surface displacements that migrate over hundreds of km in several weeks, to very minor ones lasting only a few hours without resolvable GPS displacements [*Kao et al.*, 2006, 2007a; *Wang et al.*, 2008]. Major ETS events in southern Vancouver Island (VI) and Washington State appear to have an average recurrence interval of 14.8 months over the last decade, but the recurrence is less regular in other part of the Cascadia [*Brudzinski and Allen*, 2007; *Dragert et al.*, 2004; *Miller et al.*, 2002; *Rogers and Dragert*, 2003]. Because the recurrence interval has a direct implication to the loading-unloading process responsible for ETS occurrences [*Dragert et al.*, 2004], it is very important to verify if the interval remains more or less a constant regardless the size and duration of each ETS episode or the interval is in fact a function of both [*Chen and Brudzinski*, 2007].

[4] It is well documented that north Cascadia ETS events migrate laterally along the strike of the subduction zone [e.g., *Kao et al.*, 2005; *Rogers and Dragert*, 2003; *Szeliga et al.*, 2008]. Based on the two major episodes in 2003 and 2004, *Kao et al.* [2006] estimate the average migrating speed to be 5–10 km/d, but acknowledge that the daily

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