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Correlation of tremor activity with tidal stress in the northern Cascadia subduction zone

Anthony Lambert,[1] Honn Kao,[1] Garry Rogers,[1] and Nicholas Courtier[1]

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[1] We analyze hourly data from five tremor episodes in the northern Cascadia subduction zone over the period 2003–2005 provided by the Tremor Activity Monitoring System (TAMS). All five tremor episodes correspond to slow slip events observed by GPS. Fourier decomposition is used to separate the hourly tremor counts for each episode into "long-period" ($0 < f < 0.8$ cpd), "tidal" ($0.8 < f < 2.2$ cpd), and "short-period" ($f > 2.2$ cpd) components. The tidal component of the observations is compared with theoretical stress variations at depths of 20, 30, and 40 km, with 40 km being the depth of the interpreted subduction thrust interface. The stress variations are predicted by a 2-D ocean tide loading model combined with estimates of stress variations from Earth tides. We find that the shear stress in the thrust direction and the compressive normal stress on shallow dipping surfaces correlates with the data significantly better than the confining stress over the range of depths investigated. The relative amplitudes of tidal shear stress and compressive normal stress result in positive Coulomb stress favoring slip. Peak tremor activity occurs at times of maximum tidal shear stress in the thrust direction, which would assist slow slip and would suggest that tidal tremor and slip are colocated. The response of the tremor to tidal shear stress is roughly proportional to the mean activity level, controlled by tectonic conditions of stress and pore pressure. A significant, nontidal, daily variation in tremor activity of unknown origin is identified.

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1. Introduction

[2] The discovery of nonvolcanic tremor associated with subduction in southwest Japan [*Obara*, 2002] and the recognition of the coincidence of tremor and slip in the Cascadia subduction zone and in the western Shikoku area, Japan [*Rogers and Dragert*, 2003; *Obara et al.*, 2004] has stimulated numerous investigations of the possible physical relationship between these two phenomena. In the northern Cascadia subduction zone the combined phenomenon, called episodic tremor and slip (ETS), exhibits an average recurrence interval beneath southern Vancouver Island of about 14.5±2 months coincident with transient slip along the deep portion of the interplate thrust zone just downdip of the locked zone [*Dragert et al.*, 2001; *Miller et al.*, 2002; *Wang et al.*, 2003]. In plan view the tremors occur in a band bounded approximately by the surface projections of the 30 and 50 km depth contours of the interpreted subduction thrust interface [*Flück et al.*, 1997] (Figure 1) and in cross section they occur over a depth interval of about 40 km with most tremors occurring in the continental crust [*Kao et al.*, 2005; *McCausland et al.*, 2005]. The horizontal migration of tremors during an episode in the northern Cascadia subduction zone is typically from southeast to northwest under Vancouver Island starting in central Puget Sound and moving with a relatively steady velocity interrupted from time to time by "halting and jumping" [*Kao et al.*, 2006, 2007a].

[3] Recently, it has been recognized that tremor in subduction zones is modulated by stress variations associated with Earth tides and ocean tide loading [*Nakata et al.*, 2006, 2007; *Rubinstein et al.*, 2008; *Shelly et al.*, 2007] and can be stimulated by the stress associated with surface waves (10–40 kPa) from large, distant earthquakes [*Miyazawa and Mori*, 2006; *Rubinstein et al.*, 2007; *Miyazawa and Brodsky*, 2008]. Nonvolcanic tremor can also be triggered in other tectonic environments other than subduction zones [*Gomberg et al.*, 2008]. In southwest Japan slow slip and tremor appear to be spatially and temporally coupled at or near the subduction thrust interface [*Obara et al.*, 2004; *Obara and Hirose*, 2006; *Shelly et al.*, 2006, 2007]. In contrast, tremor in northern Cascadia is found over a wider depth range, mostly above the interpreted subduction thrust interface, with temporally related slow slip occurring on the plate interface or possibly at a shallower depth [*Kao et al.*, 2005; *McCausland et al.*, 2005; *Wech and Creager*, 2007].

[4] The triggering of tremor by tidal stresses appears to require the additional influence of slow slip in subduction zones [cf. *Nakata et al.*, 2007], whereas the stresses associated with surface waves from large earthquakes seem to be large enough to trigger tremor independently of the local

[1]Geological Survey of Canada, Pacific Geoscience Centre, Sidney, British Columbia, Canada.