Slow slip and tremor in northern Cascadia: Implications for along-dip trends in stress and strength

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Slow slip extended updip of tremor during six large (M~6.8) ETSs in northern Cascadia, based on inversions of GPS displacements with a realistic plate interface. Our results (Hall, Houston and Schmidt, 2018, G-cubed) indicate that slow slip of up to 2 cm extends updip of tremor by about 15 km beneath the Olympic Peninsula. In these ETSs, slow slip extends from the downdip portion of the tremorgenic region beyond the updip extent of tremor, although still downdip of the inferred locked megathrust. Slip updip of tremor is a persistent feature of all six ETS events. Restricted inversions that permit slip to occur only in the regions that generated tremor produced slip distributions with unphysical characteristics, such as 8 cm slip concentrated at the updip part of the tremor footprint.

I will discuss two interpretations of this observation. First, farther updip tremor is possible, but has not yet been seen due to the limited observation period. Alternatively, physical conditions (such as pore pressure differences), for example, controlled by the intersection of the crustal Moho with the plate interface, prohibit tremor from occurring updip of that intersection even during substantial slow slip. The first interpretation would follow from an updip extrapolation of observed along-dip trends. Tremor and LFE activity become less frequent towards the updip region, occurring only during the large ETSs (e.g., Wech and Creager, 2011; Sweet, PhD thesis, 2014). This implies that the difference between the strength and stress of tremorgenic patches increases updip, requiring larger stress perturbations to fail. It further suggests that farther updip tremor will eventually be observed during an even larger, but less frequent, ETS than seen so far in the limited record. Although it is appealing to extrapolate these observed along-dip trends, it should be noted that long-term SSEs in Nankai do not appear to activate tremor updip of where it occurs in short-term SSEs, supporting the second interpretation. In either case, the observation of episodic slow slip farther updip than tremor in Cascadia implies that strain in that region adjacent to the megathrust is accumulating more slowly than we might otherwise infer.

We further explore how fault stress evolves on the Cascadia megathrust during an ETS, with time-dependent inversions of the 2010 and 2012 events, which propagated along strike in opposite directions under northern Washington. For both events, the slip-pulse nature of the ETS process is clearly imaged by the inversions, with fault patches continuing to slip for several days, but not through the entire duration of the event. Notably, for both events, i.e., for opposite along-strike propagations directions, small amounts of tremor are observed occurring ahead of the slipping region. We hypothesize that the initial bursts of tremor are triggered by the small leading stresses ahead of the propagating slip pulse.

Integrated with other observations including tremor sensitivity to tidal stresses (e.g., Houston, 2015), the overall stress drop of the ETSs, and observed along-dip trends in LFE/tremor recurrence periods, the slip inversion results provide additional constraints on stress and strength evolution during large ETSs. I will discuss models of the evolution of strength and stress through entire slow slip cycles that are consistent with observed along-dip trends.

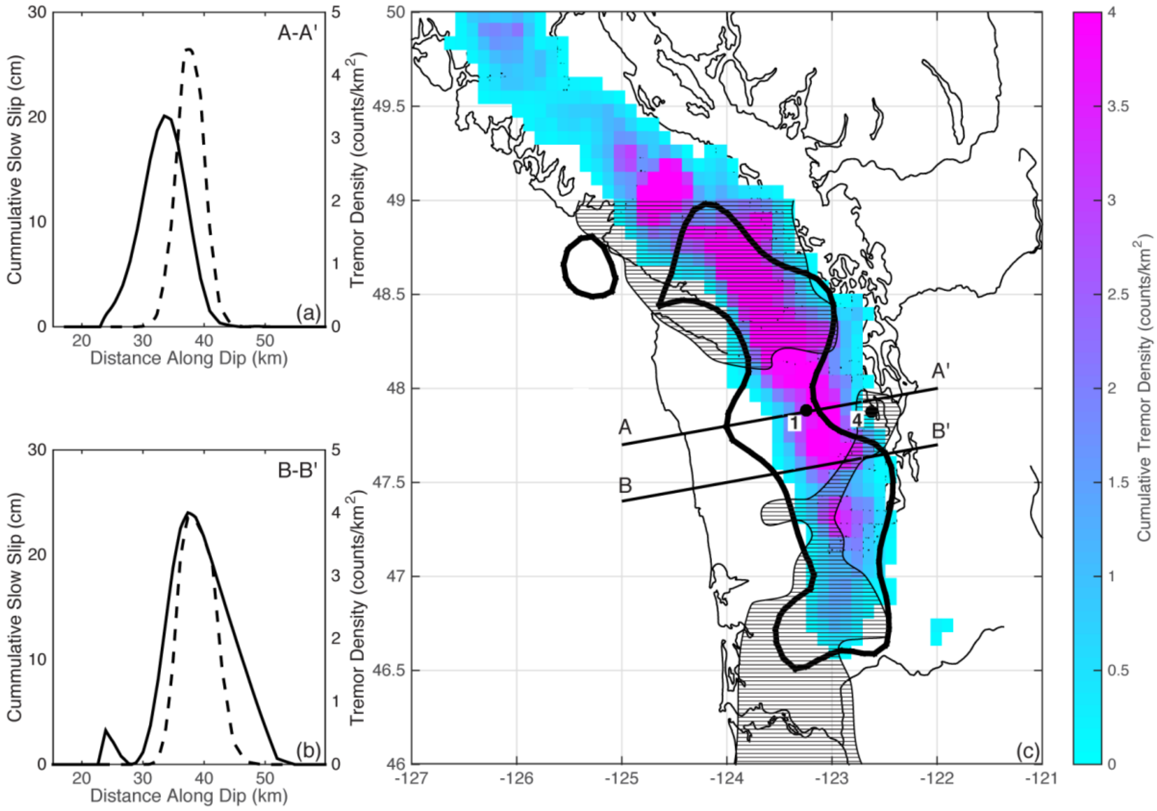

Figure 1. (left) Tremor density (solid) and slow slip (dashed) along two cross-sections for six large ETSs (2007, 2008, 2010, 2011, 2012, 2015). (right) Map of total tremor counts per area (blue to pink) and total cumulative slip for the six ETSs. The black contour shows 9 cm of slip. Gray shaded region denotes the gravity high marking the Crescent Terrane.