# Potential contributions of Seafloor Geodesy to understanding slip behavior along the Cascadia Subduction Zone

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**Proposed site:** Cascadia Subduction Zone

**Themes addressed:** (GeoPRISMS [1]Draft Science Plan; [2]Draft Implementation Plan)

4.1[1] What governs the size, location and frequency of great subduction zone earthquakes and how is this related to the spatial and temporal variation of slip behaviors observed along subduction faults?

4.2[1] How does deformation across the subduction plate boundary evolve in space and time, through the seismic cycle and beyond?

2.3.4.B[2] Cascadia Margin-Critical research efforts for GeoPRISMS studies: Seafloor Geodesy

**Key existing and forthcoming data/infrastructure:** 1) Moored-buoy for continuous GPS-Acoustic measurements of horizontal deformation and continuous seawater pressure measurements at the seafloor with a low-drift sensor and in-situ physical oceanographic measurements for sounds speed and density. 2) Autonomous sea-surface platforms for collecting campaign-style GPS-Acoustic data. 3) Seafloor benchmarks for long-term horizontal and vertical deformation measurements. 4) Earthscope, Plate Boundary Observatory, Ocean Observatories Initiative-Regional Scale Nodes (seafloor cable) and -Endurance Array (buoys), Cascadia Initiative Ocean Bottom Seismometer array. (See Poster for details).

Discussion:

We propose an experiment to measure crustal deformation along Cascadia that crosses the entire region of a subduction zone from the incoming plate, the offshore continental slope and the sub-aerial continent (Figure 1). There are two primary objectives to address with seafloor geodetic monitoring of Cascadia. What is the stick slip behavior along the subduction thrust fault from the deformation front toward the coast where land geodetic data are controlling? Where is this offshore behavior located? Generally there are three possibilities. Stable sliding could occur from the deformation front to landward, i.e., no stick behavior and no transfer of elastic strain to the upper plate. This has a low probability as elastic strain is observed onshore along Cascadia, except at approximately 44°40´ where *[Burgette et al., 2009]* observe no significant uplift along a leveling line and note that no stick or locking is required on the thrust fault to fit their data.

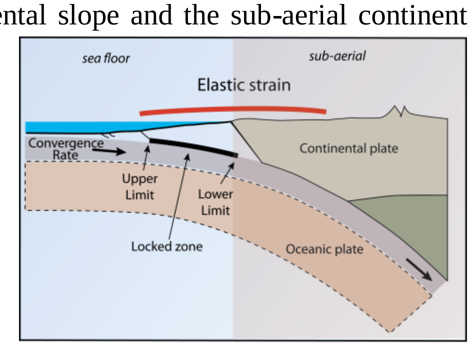

Figure 1: Subduction Profile showing offshore and onshore strain.

The second possibility is reported in most of the published models *[Fluck et al., 1997; Wang et al., 2003; McCaffrey et al., 2007; Burgette et al., 2009]*. They assume stick behavior from the deformation front to some distance landward where it decays linearly or exponentially to completely stable sliding. Land geodetic data are too far from the deformation front to resolve whether or not stick starts at the front. Likewise, though land geodetic data are best fit with a transition from fully stick or locked to a decay and ultimately fully stable sliding, this boundary occurs offshore and is not strongly resolved leading to variability among the published models as shown in Figure 2. Seafloor geodetic data located directly above the thrust fault where the changes in slip behavior occur should be able to resolve more strongly their magnitude and location.

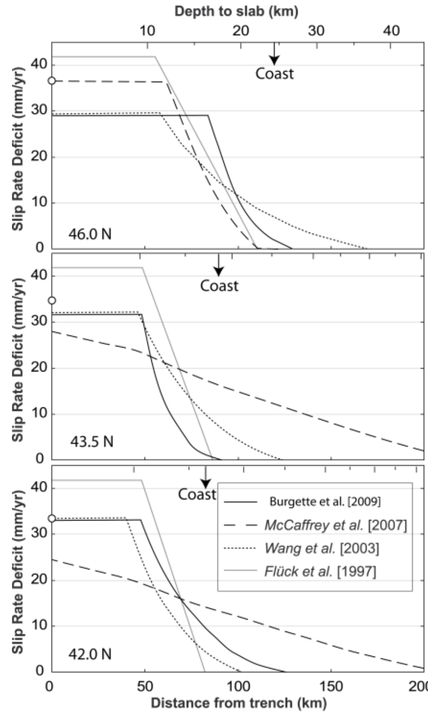

Figure 2: Slip at profiles along Cascadia [Burgette et al., 2009].

The third possibility is a variation of the second where at the toe material is assumed to require some time and space to consolidate before supporting stick-like behavior. The situation is a subtle one because even though the material at the toe may not be under elastic strain it most likely moves with the material that is just downdip and locked. *Wang [2007]* has shown three scenarios (Figure 3). *Gagnon et al., [2005]* observed the toe offshore Lima Peru contracting significantly. This suggests it is reasonable to conclude the toe is not stationary with respect to the upper plate, but that generally it must move either under elastic strain or simply kinematically with the material downdip. Though the difference is small between frictionless and locked it could be detected with sufficient duration of seafloor geodetic monitoring. This would address the question directly as to the state of stick slip behavior out near the front as noted by *[Avouac, 2011]*.

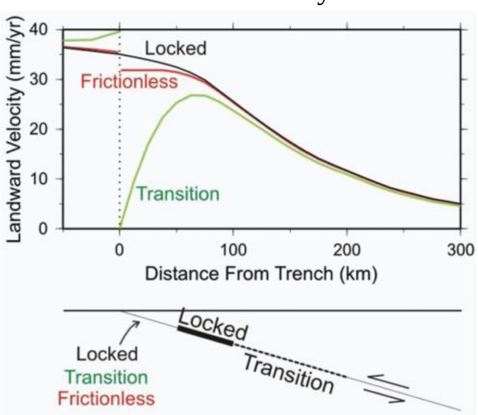

Figure 3: Possible slip behavior models [Wang, 2007]

An additional target for seafloor geodesy is measuring any interseismic elastic deformation of the incoming plate and what role this may have in understanding the stick slip behavior on the thrust fault near the deformation front. This topic has received scant attention to date primarily due to a lack of observations. There are two recent examples, however, that suggest that some amount of the elastic strain due to convergence is accumulated in the incoming plate. *Lay et al. [2009]* observed in the Kuril Islands a subduction thrust fault earthquake in 2006 followed by a normal fault earthquake in 2007 in the incoming plate. They suggest that about half of the interseismic strain accumulation was accommodated elastically within the incoming plate (Figure 4). *Chadwell [2007]* reported an observation with GPS-Acoustics at 44°40´ offshore central Oregon that is about half the expected long-term rate based

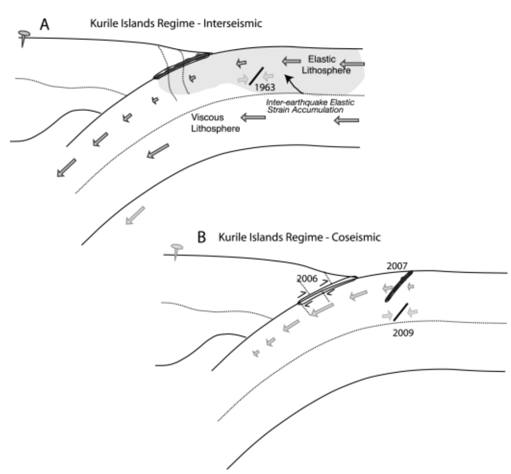

Figure 4: Incoming plate elastic strain cycle [Lay et al., 2009]

on the geomagnetic anomaly reconstructions. A likely interpretation is that a significant amount of the convergent motion is accumulated as elastic strain in the plate offshore. Interestingly, this would be consistent with *Burgette et al., [2009]* finding that no stick (or locking) is required to fit the leveling data at this same latitude along the CSZ.

In closing, geodetic arrays in place before a subduction thrust earthquake provide more direct measurements of slope response than relying on land geodetic data alone. This was first demonstrated by *Matsumoto et al. [2006]* offshore Japan and of course most recently following the Tohoku-Oki Earthquake where 24 m was observed at one GPS-A site and 31 at another *[Sato et al., 2011; Kido et al., 2011]*. These measurements on the sea floor along with modeling of tsunami waves passing over deep sea pressure sensors imply 40-50 m displacement on the thrust fault. Early result based solely on land geodetic data estimated only about 25 m of shift along the thrust fault. The direct observation of the co-seismic displacement is unprecedented. However, the more important contribution from seafloor geodesy may be measurements of interseismic strains in the slope and incoming plate and using these observations to map the behavior of stick-slip for estimating more precisely the rupture potential. Figure 5 is a notional design of a seafloor geodetic array for Cascadia to be further refined with community input.

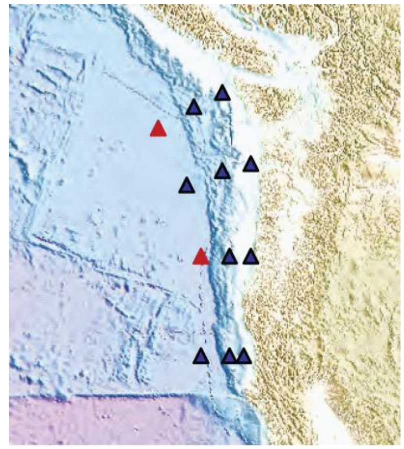

Figure 5: Notional array seafloor array (black triangles). Red existing, but presently inoperable GPS-A sites that could be reactiviated.

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