Exploring seismic and aseismic slip interactions in the eastern Aleutians

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Movement between the subducting oceanic lithosphere and the overriding plate at convergent margins is accommodated by different modes of slip. At mid-crustal depths, the plates are mostly locked and movement occurs intermittently as megathrust earthquakes, and at large depths the down-going plate stably slips into the mantle continually and aseismically. In the regions between locked and stable slip, geodetic and seismic observations indicate that plate movement can be accommodated by transient slow slip, an intermediate mechanism that can generate tectonic tremor. These variations in plate coupling, from locked to continuously slipping, are now known to exist along strike as well and possibly updip of the locked zone. However, neither the physics controlling the range of slip modes nor the interaction among them is very well understood. With considerable observed slip variability along both strike and dip, the subduction zone in the eastern Aleutians is a prime scientific target for constraining the physical relationship between continuous slip, transient plate boundary slip, earthquake rupture, and tectonic tremor. Answering these fundamental questions, however, necessitates an amphibious approach.

The section of the subduction zone offshore Umnak, Unalaska, and Akutan Islands is a natural laboratory for exploring slip interaction. This region exhibits relatively high rates of interseismic earthquakes, is bounded by two historic megathrust ruptures and spans an aseismic gap that hosts the highest rates of tectonic tremor anywhere along the margin [Gomberg and Prejean, 2013; Wech and Freymueller, 2013]. A detailed understanding of why these variations exist and how they interact, however, remains elusive. The eastward 1946 and westward 1957 megathrust earthquake ruptures are roughly constrained by aftershock distributions and tsunami modeling [Johnson et al., 1994; Johnson and Satake, 1997; López and Okal, 2006], but these likely contain significant along strike uncertainties. Furthermore, locations and depths of current background earthquake seismicity have large errors due to poor azimuthal coverage offshore; and for tremor, the inherently messy nature of the signal exacerbates this problem. Seismic observations are currently limited to stations on the islands north of the seismogenic portion of the subduction zone, making it difficult to investigate the interaction among different slip modes and megathrust asperities, or even constrain whether seismicity occurs on the plate interface, in the overriding crust, or within the subducting slab [e.g. Li et al., 2013].

Nevertheless, what is known about the region invites further investigation. Both historic megathrust events demonstrated unique rupture properties. The 1946 earthquake that ruptured east of Unimak Pass was characterized by anomalously slow rupture velocity and generated a trans-Pacific tsunami that was anomalously large for its magnitude [Kanamori, 1972; López and Okal, 2006]. The 1957 event has one of the longest rupture extents of any historical great earthquake, but significant moment release and tsunami source area was confined to the western portion of the rupture [Johnson et al., 1994]. Based on current plate coupling and geometry models in this portion of the subduction zone [Cross and Freymueller, 2008], it seems likely that the eastern extent of the 1957 earthquake may have been influenced by an apparent decrease in interseismic plate coupling along strike near Unalaska Island. Information about plate boundary slip behavior in this region could illuminate strain accommodation mechanisms, megathrust and slow slip interaction and the current stress state on the plate boundary in a region where relatively little is currently known about interseismic plate locking behavior.

It is in this gap between the 1957 and 1946 ruptures that we observe the highest tremor rates along the margin. Tremor here occurs in three distinct along-strike patches. Network geometry precludes along-dip
constraints on tremor locations and the downdip extent of the potential seismogenic zone, but the patches do demonstrate a systematic along-strike change in tremor rate that may correspond to spatial variations in plate boundary coupling. This along-strike variation in tremor rate may help constrain plate coupling and define regions where seismogenic rupture is most likely. The paucity of dense long-term geodetic observations and contamination from volcanogenic crustal motion in this area make the details of plate boundary slip behavior difficult to constrain; however, Cross and Freymueller [2008] used GPS observations on the islands to determine that, in general, this area demonstrates interseismic coupling that decreases eastward (toward Akutan Island). Whether or not discrete transient slip occurs in this region, or whether there exists a sharp change in plate coupling coincident with the variable tremor rates remains unclear.

Several key questions related to the relationship between slip modes and observable seismic phenomena could be addressed by supporting an onshore-offshore effort in the eastern Aleutians. Within a relatively short (< 300 km) trench-parallel extent, spanning a seismic gap between two historical ruptures, a short-term seismic and pressure sensor deployment offshore would record abundant seismicity, tremor, and possibly aseismic slip in a region of high seismicity and tremor rates that appear to change along strike, coincident with plate locking behavior. Extending a seismic network offshore to improve azimuthal coverage in this area would provide the opportunity to characterize details of earthquake and tremor patterns and their source properties with much greater resolution than currently possible using land-based stations alone, particularly the along-dip variations in one of the most active tectonic tremor source regions in Alaska. This portion of the margin has some of the highest-quality network data available from stations maintained by the Alaska Earthquake Center (AEC), Tsunami Warning Center (TWC) and the Alaska Volcano Observatory (AVO), and it is currently the site of an Earthscope flex array deployment to characterize tremor behavior and structure (Ghosh/Thurber/USGS-AVO 2014-2016), all of which would augment offshore recordings. Exploring the shallowest portion of the megathrust in this region would also only be possible with an offshore deployment. Ocean bottom seismometers and seafloor pressure sensors deployed close to the trench could characterize the seaward extent of any seismic and aseismic deformation, using near-source measurements of earthquakes, tremor and slow slip transients in the shallow portion of the megathrust. Obtaining a comprehensive view of the slip behavior and mechanical properties within this fault zone laboratory would elucidate the physics of the different slip modes, their interactions and their role in plate convergence, improving our local and global understanding of subduction zone hazards.

References
Cross, R. S., and J. T. Freymueller (2008), Evidence for and implications of a Bering plate based on geodetic measurements from the Aleutians and western Alaska, J. Geophys. Res. Solid Earth, 113(B7).
Target area showing current land instrumentation and tremor regions together with rupture models of the 1946 and 1957 megathrust earthquakes (left) and current geodetic models of plate coupling (right).