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Building a Framework Earthquake Cycle Deformational Model for Subduction Megathrust Zones: Integrating Observations with Numerical Models

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Subduction zone megathrusts host the largest and deadliest earthquakes on the planet. Over the past decades (primarily since the 2004 Sumatra event) our abilities to observe the build-up in slip deficit along these plate boundary zones has improved substantially with the development of relatively dense observing systems along major subduction zones. One, perhaps unexpected, result from these observations is a range of present-day behavior along the boundaries. Some regions show displacements (almost always observed on the upper plate along the boundary) that are consistent with elastic deformation driven by a fully locked plate interface, while other plate boundary segments (oftentimes along the same plate boundary system) show little or no plate motion directed displacements. This latter case is often interpreted as reflecting little to no coupling along the plate boundary interface. What is unclear is whether this spatial variation in apparent plate boundary interface behavior reflects true spatial differences in plate interface properties and mechanics, or may rather reflect temporal behavior of the plate boundary during the earthquake cycle. In our integrated observational and modeling analyses, we have come to the conclusion that much of what is seen as diverse behavior along subduction margins represents different time in the earthquake cycle (relative to recurrence rate and material properties) rather than fundamental differences between subduction zone mechanics.

Our model-constrained conceptual model accounts for the following generalized observations:
1. Coseismic displacements are enhanced in “near-trench” region
2. Post-seismic relaxation varies with time and position landward - i.e. there is a propagation of the transition point from “post” (i.e. trenchward) to “inter” (i.e. landward) seismic displacement behavior.
3. Displacements immediately post-EQ (interpreted to be associated with “after slip” on megathrust?).
4. The post-EQ transient response can last for decades after a major event (e.g. Alaska 1964)

We have integrated the observed patterns of upper-plate displacements (and deformation) with models of subduction zone evolution that allow us to incorporate both the transient behavior associated with post-earthquake viscous re-equilibration and the underlying long term, relatively constant elastic strain accumulation. Modeling the earthquake cycle through the use of a visco-elastic numerical model over numerous earthquake cycles, we have developed a framework model for the megathrust cycle that is constrained by observations made at a variety of plate boundary zones at different stages in their earthquake cycle (see paper by Govers et al., this meeting). Our results indicate that the observed patterns of co- and post- and inter-seismic deformation are largely controlled by interplay between elastic and viscous processes. Observed displacements represent the competition between steady elastic-strain accumulation driven by plate boundary coupling, and post-earthquake viscous behavior in response to the coseismic loading of the system by the rapid elastic rebound. The application of this framework model to observations from subduction zone observatories points up the dangers of simply extrapolating current deformation observations to the overall strain accumulation state of the subduction zoned allows us to develop improved assessments of the slip deficit accumulating within the seismogenic zone, and the near-future earthquake potential of different segments of the subduction plate boundary.