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Time-Varying Upper-Plate Deformation during the Megathrust Subduction Earthquake Cycle

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Over the past several decades of the WEGENER era, our abilities to observe and image the deformational behavior of the upper plate in megathrust subduction zones has dramatically improved. Several intriguing inferences can be made from these observations including apparent lateral variations in locking along subduction zones, which differs from interseismic to coseismic periods; the significant magnitude of post-earthquake deformation (e.g. following the 20U14 Mw Iquique, Chile earthquake, observed on-land GPS post-EQ displacements are comparable to the co-seismic displacements); and incompatibilities between rates of slip deficit accumulation and resulting earthquake co-seismic slip (e.g. pre-Tohoku, inferred rates of slip deficit accumulation on the megathrust significantly exceed slip amounts for the $\sim$ 1000 year recurrence.)

Modeling capabilities have grown from fitting simple elastic accumulation/rebound curves to sparse data to having spatially dense continuous time series that allow us to infer details of plate boundary coupling, rheology-driven transient deformation, and partitioning among inter-earthquake and co-seismic displacements. In this research we utilize a 2D numerical modeling to explore the time-varying deformational behavior of subduction zones during the earthquake cycle with an emphasis on upper-plate and plate interface behavior. We have used a simplified model configuration to isolate fundamental processes associated with the earthquake cycle, rather than attempting to fit details of specific megathrust zones. Using a simple subduction geometry, but realistic rheologic layering we are evaluating the time-varying displacement and stress response through a multi-earthquake cycle history. We use a simple model configuration - an elastic subducting slab, an elastic upper plate (shallower than 40 km), and a visco-elastic upper plate (deeper than 40 km). This configuration leads to an upper plate that acts as a deforming elastic beam at inter-earthquake loading times and rates with a viscously relaxed regime at depths greater than 40 km. Analyses of our preliminary model results lead to the following:

1. Co-seismic stress transfer from the unloading elastic layer (shallow) into an elastically loading visco-elastic layer (deeper) - extends $\sim$ 100 km inboard of locked zone. This stress transfer affects both coseismic and post-seismic surface displacements.
2. Post-seismic response of upper plate involves seaward motion for initial 10-20 years ($\sim$ 2 Maxwell times) after EQ. This occurs in spite of there being no slip on locked plate boundary - i.e. this is not plate boundary after-slip but rather is a consequence of stress relaxation in co-seismically loaded visco-elastic layer. However standard inversions of the surface displacement field would indicate significant after-slip along the locked plate interface.
3. By approximately 80 years (8 Maxwell times) system has returned to simple linear displacement pattern - the expected behavior for a shortening elastic beam. Prior to that time, the surface (observable) displacement pattern changes substantially over time and would result in an apparent temporal variation in coupling - from near-zero coupling to fully locked over $\sim$ 80 years post-earthquake.

These preliminary results indicate that care is needed in interpreting observed surface displacement fields from GPS, InSAR, etc. during the interseismic period. temporal variations in crustal deformation observed in regions such as the recent Tohoku, Maule, and Iquique megathrust events which are ascribed to fault plane after-slip may in fact reflect processes associated with re-equilibration of the visco-elastic subduction system.