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On the cause of enhanced landward motion of the overriding plate after a major subduction earthquake

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During and after a large megathrust earthquake, the overriding plate above the rupture zone moves oceanward. Enigmatically, the post-seismic motion of the overriding plate after several recent large earthquakes, further along strike from the rupture zone, was faster in the landward direction than before the event. Previous studies interpreted these changes as the result of increased mechanical coupling along the megathrust interface, transient slab acceleration, or bulk postseismic deformation with elastic bending mentioned as a possible underlying mechanism. Before invoking additional mechanisms, it is important to understand the contribution of postseismic deformation processes that are inherent features of megathrust earthquakes. We thus aim to quantify and analyse the deformation that produces landward motion during afterslip and viscous relaxation.

We use velocity-driven 3D mechanical finite element models, in which large megathrust earthquakes occur periodically on the finite plate interface. The model geometry is similar to most present-day subduction zones, but does not exactly match any specific subduction zone.

The results show increased post-seismic landward motion at (trench-parallel) distances greater than 450 km from the middle of the ruptured asperity. Similar patterns of landward motion are generated by viscous relaxation in the mantle wedge and by deep afterslip on the shear zone downdip of the brittle megathrust interface. Landward displacement due to postseismic relaxation largely accumulates at exponentially decaying rates until ~ 6 Maxwell relaxation times after the earthquake. The spatial distribution and magnitude of the velocity changes is broadly consistent with observations related to both the 2010 Maule and the 2011 Tohoku-oki earthquakes.

Further model experiments show that patterns of landward motion due to afterslip and to viscous relaxation are insensitive to the locking pattern of the megathrust. However, the locking distribution does affect the magnitudes of the displacements and velocities. Results show that the increased landward displacement due to postseismic deformation scales directly proportionally to seismic moment.

We conclude that the landward motion results from in-plane horizontal bending of the overriding plate and mantle. This bending is an elastic response to oceanward tractions near the base of the plate around the ruptured asperity, causing extension locally and compression further away along-trench. This elastic in-plate bending consistently contributes to earthquake-associated changes in surface velocities for the biggest megathrust earthquakes, producing landward motion along strike from the rupture zone.