AGU Abstract: Subduction Normal EQs
Final version
T041: Physics Based Modeling of the Earthquake Cycle. Do Observations Matter?

Causes of extensional deformation in subduction zones following megathrust earthquakes

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Great (moment magnitude Mw 8.0 and larger) megathrust earthquakes are commonly followed by normal faulting aftershocks and other extensional deformation processes visible at the surface. We examine the spatial and temporal patterns of extension in subduction zones as they relate to 13 recent great earthquakes to identify common processes. The megathrust events with co-seismic slip near the trench trigger normal faulting aftershocks in the slab, whereas deeper events trigger no intraslab aftershocks. Mw ~8.5+ megathrust earthquakes trigger normal faulting aftershocks and surface extension in the upper plate. Smaller events have no upper plate extensional aftershocks but normal faulting and tension cracking at the surface can still be seen. We aim to identify a single cause for this co-seismic extension in the subduction system.

We develop a 3-D earthquake cycle model, based on the 2011 Mw 9.0 Tohoku, Japan, earthquake and aftershock sequence. New in this model is a realistic slab geometry and the development of tectonic stresses that are consistent with slip on the plate interface and bulk viscous relaxation. We find that the spatial patterns of normal faulting aftershocks correlate well with the modeled co-seismic stress changes greater than 1 MPa. The tectonic stress magnitude is sensitive to the distribution of locking, particularly at the base of the seismogenic zone. If the base of the seismogenic zone remains unlocked throughout the earthquake cycle, then the tectonic stresses have similar magnitudes to the co-seismic stress changes. Thus, after the earthquake, the tectonic stresses are close to zero in the regions where extensional aftershocks are observed. Our models and the observed aftershocks suggest that primary afterslip down-dip of the megathrust rupture expands the region of extension, but reduces its magnitude, indicating that normal faulting aftershocks are related to only the initial stress changes and may be restricted to a short time period after the mainshock. Bulk viscous relaxation does little to the state of stress in the elastic parts of the model; continued convergence across a re-locked interface returns the system to the pre-earthquake state of compression. We can explain the observed extension in different parts of the subduction system with the patterns of stress changes in our model.

Plain Language Summary

The largest earthquakes occur on the boundaries between two converging tectonic plates. Because of the convergent motion at these locations, most of the time the plates in these regions are being compressed. However, after large earthquakes, some parts of the plates become extended, and relatively rare extensional earthquakes can occur. To understand where, how many, and how long these unusual events will occur, we run computer simulations of two plates moving past each other, and include the plate interactions (alternately locking and unlocking parts of the boundary between the plates) before, during, and after big earthquakes. By modeling the entire earthquake cycle, we quantify how much compression builds up next to a locked plate boundary in the centuries before a big earthquake, and how much extension occurs because of the earthquake as the boundary is unlocked. The magnitude of compression accumulated between earthquakes depends strongly on the details of locking and unlocking. In particular, when the plate boundary around a depth of 40-50 km remains unlocked over the entire earthquake cycle, then the compression is lowest. Then, the earthquake causes the compression to go to zero over large regions of the plates, explaining the spatial pattern of extensional earthquakes.