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Insights on the postseismic surface displacement field of the 2011 Tohoku earthquake via 3D viscoelastic seismic-cycle FEM models

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The 2011 Tohoku-oki earthquake occurred in the well-studied Japan convergent margin and produced coseismic and postseismic surface displacements well observed at several GPS sites, including a dense onshore network and offshore GPS-A stations. Such geodetic data, particularly large landward postseismic displacements in the primary rupture area, suggest that relocking occurred shortly after the earthquake. This has clear implications for the slip deficit accummulation and thus the seismic hazard in the region. However, the landward motion recorded at the sites closest to the trench is significantly faster than the plate convergence rate, which suggests that it cannot be attributed solely to relocking. Instead, it has been explained through numerical modelling as due to viscoelastic relaxations of the stresses induced by coseismic displacement.

Numerical modelling is valuable as it can quantitatively connect the surface displacement field to the relocking history of the megathrust interface as well as to the postseismic relaxation history. We thus construct a finite-element model of the Japan subduction zone with a simplified, spherical-shell 3D geometry. The model is driven to realistic preseismic stresses and strains by imposing the earthquake history of the last several decades. We then use it to investigate the geodetic signature of relocking history in the context of specific subduction zone geometry and physical features. The hypothesis is that a combination of rapid relocking and significant viscous relaxation is needed to explain the observed postseismic surface velocities.

The lithospheres in the model have linear elastic rheology, neglecting the minor anelastic component of deformation, while the asthenospheres have Maxwell viscoelastic rheologies. The areas of the megathrusts modelled as non-seismogenic are also viscoelastic and thus allow for afterslip in response to stresses induced during coseismic slip. The lithospheric structure is imported from the Slab2 dataset, derived from seismological data. The effect of different lithospheric thicknesses of both the overlying and downgoing plates is then explored. This accounts for uncertainties, heterogenity and the discrepancy between different definitions of plate thickness. The spatial extent of the coseismically slipping patch in the megathrust is varied in different models, especially its updip limit. This is crucial in attempting to reproduce the surface displacement close to the trench. Furthermore, it reflects uncertainties and possible variations in locking behaviour of peripheral areas of the interface.

Preliminary results show that rapid relocking is not sufficient to explain the landward and downward displacements observed offshore on the upper plate. Work is ongoing to fully characterize the primary features of the subduction zone responsible for the observed surface displacements.