Modeling crustal deformation with mechanical models and geodetic data

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Over the past two decades, development of dense and continuous geodetic networks makes it possible to capture transient crustal deformation at high resolution in both space and time. A primary example of geodetically observed transient deformation in plate boundary zones is postseismic deformation following large earthquakes. Postseismic deformation observed at the surface reflects mechanical properties of faults, crust, and upper mantle. Thus mechanical models that are designed to fit the observed postseismic deformation may provide insights into these mechanical properties at depth.

Two primary processes that are responsible for postseismic deformation are viscoelastic relaxation of coseismic stress changes in the upper mantle and afterslip on the plate interface surrounding the coseismic rupture. Viscoelastic relaxation is governed by the rheological properties of the crust and upper mantle, while afterslip is governed by frictional properties of the plate interface. Both of the processes are initiated by stress changes due to coseismic slip. Therefore, geodetic observations of postseismic deformation could be used to constrain the frictional properties on the plate interface and upper mantle rheology.

In this talk, we present a three-dimensional coupled model of stress-driven frictional afterslip and viscoelastic stress relaxation for postseismic deformation following the 2011 Mw9.0 Tohoku-oki earthquake. In this model, we assume that afterslip is governed by a velocity-strengthening friction law that is characterized with a friction parameter (a-b) σ. Viscoelastic relaxation of the upper mantle is modeled with a biviscous Burgers rheology that is characterized with the steady-state and transient viscosities. We calculate the evolution of afterslip and viscoelastic relaxation using an assumed coseismic slip model as the initial condition.

We examine the effects of the friction parameters, mantle viscosities, elastic thickness of the slab and upper plate, and coseismic slip distribution on the model prediction and find that these parameters significantly affect the predicted surface postseismic displacements. Postseismic deformation following the 2011 Tohoku-oki earthquake has been captured by both on-land GNSS and seafloor GPS/Acoustic networks. We thus explore the range of the model parameters that can fit the postseismic observations. At this moment, we employ a trial-and-error approach to estimate the parameters. However, given the complexity of the model and the abundance of the observations, it is difficult to completely characterize uncertainties and trade-offs between the parameters by the trial-and-error approach, although such information is critically important for better understanding of the postseismic processes. A more complete model that fully accounts for uncertainties and trade-offs between the parameters could be obtained by building posterior probability distributions of the parameters using Bayesian inverse methods. Such Bayesian methods, however, require many forward calculations and thus it would not be easy to implement those methods with our model within a realistic computation time. It is therefore essential to reduce the computational costs of the forward model simulations and Green’s functions calculations, as well as to develop more efficient Bayesian methods to estimate posterior probability distributions, in order to develop more advanced models of geodetically observed postseismic deformation.

Keywords: crustal deformation, mechanical model, geodetic data

