Bayesian parameter estimation of a physics-based model of postseismic crustal deformation

*Jun'ichi Fukuda[1], Kaj Johnson[2]

1. Earthquake Research Institute, University of Tokyo, 2. Department of Earth and Atmospheric Sciences, Indiana University

Recent development GPS and other 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. Two primary processes that are responsible for observed postseismic deformation are viscoelastic relaxation of in the asthenosphere and afterslip on the plate interface surrounding the coseismic rupture. Both of the processes are triggered by stress changes induced by an earthquake and the evolution of the two processes is governed by rheological properties of the asthenosphere and frictional properties of the plate interface as well as coseismic stress perturbations.

In this study, we develop a physics-based model of postseismic deformation following the 2011 Mw9.0 Tohoku-oki earthquake that incorporates stress-driven afterslip and viscoelastic relaxation. In this model, the evolution of afterslip is assumed to be governed by a velocity-strengthening friction law that is characterized with a friction parameter. Viscoelastic relaxation of the asthenosphere is modeled with a biviscous Burgers rheology that is characterized with steady-state and transient viscosities. The evolution of afterslip and viscoelastic relaxation is calculated using coseismic slip distribution as an initial condition. We treat the friction parameters, viscosity parameters, coseismic slip distribution, and a smoothing parameter for coseismic slip distribution as unknown parameters and estimate them using coseismic and postseismic GPS and seafloor geodetic data.

In order to quantify uncertainties of the model, we adopt a Bayesian approach and estimate the posterior probability density function (PDF) of the model parameters. In principle, the Markov chain Monte Carlo (MCMC) methods can be used for this purpose. However, the MCMC methods require many forward calculations and the forward model employed in this study is computationally intensive. Therefore, it is difficult to sample the posterior PDF within a realistic computation time. We thus combine a surrogate modeling approach with the MCMC methods to efficiently sample the posterior PDF. In this approach, we first obtain a function approximation to the posterior PDF by fitting a surrogate function to the posterior probability densities calculated for sample points in the model parameter space. Then a MCMC method is used to sample the surrogate posterior PDF. By using this approach, we obtain the posterior PDFs of the model parameters that successfully reproduce the observed coseismic and time-dependent postseismic displacement fields. Our results suggest that such approaches may be useful for parameter estimation and uncertainty quantification of computationally intensive forward models.

Keywords: Bayesian inference, parameter estimation, GPS, postseismic crustal deformation