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Afterslip and viscoelastic relaxation due to the 2004 Sumatra earthquake seen from GRACE gravity field

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Geodetic observations have revealed that a large earthquake can cause post-seismic crustal deformation that continues for more than a decade. Investigating mechanisms of post-seismic deformation gives a clue to infer the stress change in space and time on a plate boundary. To elucidate the stress history is important to identify if we are already in the preparation stage for the next event or still in the post-seismic stage of the previous event in the context of earthquake cycle. The diagnosis becomes complicated because various mechanisms displaying different stress behaviors have been proposed, such as afterslip, poroelastic rebound, and viscoelastic relaxation. Surface crustal deformation data have frequently indicated that contributions from different mechanisms are superimposed. The combination of short-term afterslip and long-term viscoelastic relaxation is considered as a representative mechanism for a thrust-type large earthquake in a plate subduction zone. However, when the epicenter is surrounded by the ocean, as often seen in island arc, a clear separation is prevented because a sufficient spatial coverage cannot be obtained by terrestrial observation to distinguish surface deformations expected from those mechanisms. Recently, GRACE satellites have detected post-seismic gravity variations due to the 2004 Sumatra-Andaman earthquake. Satellite gravity data can be obtained over the ocean. In addition, measuring the density redistribution which reflects deformation in a deeper portion of the earth emphasizes the difference between afterslip and viscoelastic relaxation. In the presentation, we use GRACE data for 2003-2010 and show that afterslip and viscoelastic relaxation by the 2004 event can be effectively separated. To accurately model a long-wavelength gravity variation caused by those mechanisms, we develop a spectral finite-element method based on FEM and analytic expression by spherical harmonic tensors. This allows us to consider effects of compressibility of crust and mantle, a strong lateral heterogeneity in the viscosity due to the presence of a slab, and self gravitation in a spherical earth that have not been simultaneously considered in most previous models. GRACE data are corrected for using ECCO Ocean model and GLDAS hydrological models. Most of the remaining signal can be explained by viscoelastic relaxation for a mantle viscosity of 3 x 10ˆ18 Pas. The spatial pattern in the observed gravity field obtained by subtracting the estimated viscoelastic relaxation agrees with that predicted by afterslip. In particular, the trend expected from afterslip and that expected from viscoelastic relaxation is reverse in a region over the ocean. This indicates that the both mechanisms are needed to explain the observed data. The superposition of short-term afterslip and viscoelastic relaxation is consistent also with a result by GPS observation. Our result indicates a validity of satellite gravity observation data for studying mechanisms of post-seismic deformation.

Keywords: crustal deformation, gravity, postseismic deformation, viscoelasticity, satellite gravity mission, geodesy