

Postseismic displacement field associated with the 2011 Tohoku-oki earthquake by temperature dependent viscosity model

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Viscoelastic relaxation makes up a significant portion of postseismic deformation associated with a megathrust earthquake in subduction zones, where the mantle wedge is hot enough to exhibit non-elastic behavior. In some subduction zones, such as northeast Japan, there is substantial lateral variation in rheology, including viscosity, due to lateral warping of the cold slab.

Our goal was to assess the contribution to postseismic displacement field of each process –afterslip, viscoelastic relaxation and fault locking –after the 2011 Tohoku-oki earthquake based on a 3-D realistic, heterogeneous, temperature dependant viscosity distribution. To calculate viscosity distribution, we used a 3-D thermal convection model with realistic slab shape and subduction velocity distribution. Viscosity was calculated at each grid as the composite effect of diffusion and dislocation creep. The resulting realistic viscosity field, mainly depending on temperature, was used in the earth model for a 3D finite element postseismic viscoelastic model. A model of uniform viscosity was also made for comparison. Displacement field associated with afterslip and fault locking were estimated by calculating the residuals between model results and observed postseismic GPS displacement for a 6.75 year time period. Trenchward and landward residuals were considered to be indications for afterslip and fault locking, respectively.

Our model results show trenchward horizontal displacements in the Tohoku region, with the largest values at the east coast of central Tohoku, and a trench parallel component at the northwesternmost and southwesternmost parts of the Tohoku region. These results are consistent with the observed GPS displacement for the same time period. Compared with a standard uniform viscosity model, the realistic model had smaller magnitudes of trenchward postseismic displacement field. The realistic model over predicted the horizontal displacement in east Tohoku by up to 2 m. Therefore, it gives a lower estimation than the standard model for the contribution of fault locking to overall horizontal displacement. On the other hand, in west Tohoku the observed displacements were larger than the realistic model results. Therefore, the effect of fault locking has yet to reach this far from the hypocentre, and afterslip has a significant contribution. The residuals of horizontal displacements in southeast Tohoku are nearly trench parallel, indicating the effects of fault locking and afterslip have balanced after 7 years. Both models exhibit uplift in all the land area of Tohoku, with subsidence offshore in both the Pacific and Sea of Japan sides. But, the realistic model had mostly larger amounts of uplift, especially in the east coast area in near the rupture zone, where large amounts of uplift were observed. Compared with GPS data, both models underestimated uplift in that area, while overestimating uplift elsewhere and showing uplift where subsidence was observed, on the west side of Tohoku. In this sense, the realistic model results were closer to observations in the central east coast, but not elsewhere.

In conclusion, compared to a model with uniform mantle viscosity, our realistic model portrays a different postseismic displacement field, and demonstrates that small scale viscosity variations are worth taking into account in viscoelastic modelling. It is also shown that for the time period considered in this study, viscoelastic relaxation is the dominant mechanism of postseismic deformation associated with the

Tohoku-oki earthquake, with fault locking playing a significant role and overshadowing the effect of afterslip at the central east coast area, but not yet balancing afterslip in the west coast area.

Keywords: Postseismic deformation, Subduction zone, Crustal deformation, Numerical simulation, GNSS, Rheology

