

The role of power-law viscoelastic flow and fault friction in post-earthquake deformation after the 2011 Tohoku-Oki earthquake

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The deformation transient that follows the 2011 Tohoku-Oki earthquake is thought to be the response of a large-scale nonlinear system where slip on the megathrust and viscoelastic flow in the asthenospheric mantle were accelerated by the sudden coseismic stress change. However, as numerical models of such complex systems are still in their infancy, taking such physics into account is still a major challenge. Here, we consider the post-earthquake deformation of the Tohoku-Oki earthquake based on numerical simulations incorporating a non-linear viscoelastic model and stress-driven afterslip in a fully three-dimensional (3D) heterogeneous structure of the subduction zone, using state-of-the-art techniques of computational science. The proposed method incorporates a laboratory-derived power-law viscoelastic constitutive relation and the rate- and state-dependent friction law together in 3D finite element modeling of post-earthquake deformation. A simulation of three-year deformation using the method results in good agreement in horizontal component of the calculated displacements with observation data, despite a large spatial variation in both trench-normal and parallel direction: Viscoelastic flow associated with transient spatial variation of effective viscosity is dominant in overall deformation pattern on the seafloor and the land, while afterslip seemed to play an important role in eastward seafloor displacements. Our results imply that the frictional and rheological properties of lithosphere rocks derived from laboratory experiments can explain well complex post-earthquake deformation of a large subduction zone earthquake. At the same time, discrepancies in the simulation results and measurement suggest that it is essential to consider the 3D nonlinear interaction of coseismic slip, afterslip and nonlinear viscoelastic flow to interpret densely and widely measured displacement of a post-earthquake deformation of a megathrust subduction zone earthquake.

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