Extension of postseismic geodetic observations constrains on coseismic slip distribution through viscoelastic relaxation

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The 2011 Tohoku-oki earthquake is among the largest megathrust earthquakes in the world, with a magnitude of 9.0. A number of studies have showed coseismic slip models from various observation data, which generally showed that giant coseismic slip was concentrated in the off-Miyagi region. However, the along-trench extent of the shallow coseismic rupture has not been well constrained. One of the critical causes of this issue is shortage of the offshore geodetic sites; the offshore geodetic sites in the coseismic period were concentered in the off-Miyagi region [e.g., Kido et al., 2011, GRL; Sato et al., 2011, Science], and they did not have sufficient sensitivity to the shallow coseismic rupture far from the off-Miyagi region [e.g., Iinuma et al., 2012, JGR].

Whereas the previous coseismic slip models basically considered coseismic observational data alone, it is expected that the coseismic slip distribution can be also constrained by postseismic geodetic observation data. Because viscoelastic relaxation, which is one of the postseismic deformation mechanism, is caused by stress perturbation associated with coseismic rupture, postseismic displacements should contains information on coseismic rupture. Although a number of studies have utilized postseismic geodetic data in estimating afterslip distributions after removing viscoelastic responses to reference coseismic slip models, it is preferable to simultaneously invert co- and post-seismic displacements using Green’s functions considering viscoelastic responses (called as the “viscoelastic inversion” method) as investigated by some modeling studies [e.g., Hoechner et al., 2011, G3].

In this study, we simultaneously estimate the co- and post-seismic slip distributions of the 2011 Tohoku-oki earthquake from the co- and post-seismic geodetic observational data by the viscoelastic inversion assuming a simple two-layered viscoelastic half-space [Fukahata & Matsu’ura, 2006, GJI]. Although Yamagiwa et al. [2015, GRL] already estimated them by a similar approach, we utilize GPS-A observational data measured by our recent study [Tomita et al., 2017, Sci. Adv.] which were not used in Yamagiwa et al. [2015]. The data were obtained from a new GPS-A observational network that were constructed after the 2011 Tohoku-oki earthquake and are located along the Japan trench.

As a result, due to the introduction of the postseismic observational data, the estimated coseismic slip distribution has better spatial resolution in the shallow plate interface along the Japan trench compared with that estimated from the coseismic observational data alone. The estimated coseismic slip distribution demonstrates that the along-trench extent of the shallow coseismic rupture maximally extended from ~37° N to ~39.2° N. Although some previous studies using the tsunami data indicated the shallow coseismic rupture extended further north up to ~40.0° N [e.g., Satake et al., 2013, BSSA], the inconsistency between the previous studies and this study may suggest that the tsunamigenic deformation at the north of 39.2°N was caused by a mechanism other than interplate fault slip, such as submarine landslide, inelastic deformation, or subsidiary faulting. Moreover, along-trench variation of the shallow postseismic slip is also constrained in this study. The estimated postseismic slip model clearly shows localized areas of the shallow afterslip in the off-Fukushima and the off-Ibaraki regions.

Thus, this study successfully showed that the viscoelastic inversion provides a concreated model of co- and post-seismic slip distributions of the 2011 Tohoku-oki earthquake by employing the extensive postseismic offshore geodetic data. It is expected that an extension (or construction) of a geodetic observation network even after a mainshock is quite important to reveal coseismic slip behavior for other large earthquakes.

Keywords: postseismic deformation, the 2011 Tohoku-oki earthquake, viscoelastic relaxation, afterslip, GPS-Acoustic observation

