Post-seismic recovery of subsided coastal northeast Japan after the 2011 Tohoku-oki earthquake

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During the 2011 Tohoku-oki earthquake the pacific coast of northeast Japan experienced significant subsidence, while in the years after it has undergone a continuous phase of uplift during the post-seismic period. The dense geodetic network deployed by GEONET and Tohoku university between 2011 and 2016 have captured variations in surface deformation along the coast, highlighting rapid uplift rates of ~7 cm/year on the Miyagi coast (Muto et al., 2019, Sci.Adv.) and ~3-4 cm/year on the Fukushima and Iwate coasts. Previous studies in the last decade have revealed the post-seismic deformation is due to a combination of both rapid viscoelastic flow and stress-driven afterslip, explaining the post-seismic vertical deformation pattern over northeast Japan as well as unravel its associated rheological complexity (e.g., Agata et al., 2019, Nat. Commun; Freed et al., 2017, EPSL; Hu et al., 2016, JGR; Muto et al., 2019, Sci.Adv.). Furthermore, continuous coastal uplift has had societal consequences, where the piers at the port are no longer suited to conduct many activities, particularly those for the fish industry. The large co-seismic subsidence of coastal areas caused the submersion of port piers, with rapid rebuilding to return the now submerged piers to sea-level. Nevertheless, the continuous uplift in the post-seismic period has now raised these rebuild piers above sea level and necessitates reduction in height back to sea level again (Iinuma, 2018, JDR). In this presentation, we employ forward modeling to improve estimates of future uplift and the time required for full recovery of coastal regions to their pre-event relative sea level.

We present a numerical model using laboratory-derived constitutive laws and compare our modeled displacement with the geodetic observations (Ozawa et al., 2012, JGR; Tomita et al., 2017, Sci.Adv.; Watanabe et al., 2014, GRL). The model is constrained by terrestrial and seafloor geodetic observations in both horizontal and vertical components and incorporates a three-dimensional heterogeneous viscoelastic rheology fully coupled with stress-driven afterslip on the plate interface.
Our model exhibits good agreement with the cumulative displacements, both in magnitude and azimuthal direction. We extend the time-series simulation for a further 20 years and estimate the recovery time to pre-event levels for the GNSS sites along the coastal areas. Our results show a recovery period of ~18 years after the mainshock for Ishinomaki site in Miyagi prefecture, which had the largest coseismic subsidence (up to ~1.2 m). We also estimate a recovery period of ~14-16 years for the coastal areas of Iwate and Fukushima prefectures, which experienced coseismic subsidence of ~0.5 m. The model adds an improvement to the previous estimates (Iinuma, 2018, JDR) by incorporating consideration of the coupling of viscoelastic relaxation and stress-driven afterslip.