Vertical seafloor movement after the 2011 Tohoku earthquake and remarkable uplift near the trench axis off Sanriku

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We have continuously conducted GNSS-Acoustic observation since September 2012 at the 20 benchmarks distributed off Aomori to Ibaraki. Tomita et al. (2017) first revealed the broad distribution of horizontal seafloor movement and thereby discussed viscoelastic relaxation and afterslip of the 2011 Tohoku earthquake. The horizontal movement has been improving through revision of analysis method (Honsho and Kido, 2017; Honsho et al., 2019) and continued observation. Recently, by the application of a revised method for the traveltime determination in acoustic ranging (Honsho et al., 2021), the distribution of vertical movement has been revealed. Overall, it shows uplift to the east of a trench-parallel boundary ~20–30 km landward from the trench axis, along which little vertical movement occurs, and subsidence to the west; the uplift or subsidence becomes larger as it goes away from the boundary. Except for Site G06 off Sanriku, to be described later, the fastest uplift 3.2 cm/year was observed at Site G01, located on the Pacific plate and ~70 km away from the trench axis. The fastest subsidence was 3.5 cm/year at Site G14 located ~100 km landward from the trench axis.

The observed movement was compared with a model of postseismic deformation of the 2011 Tohoku earthquake by Agata et al. (2019). The model incorporates power-law viscoelastic flow, and the plate interface is considered as a frictional interface on which afterslip or backslip (fault locking) occurs according to frictional conditions. The calculation period of the model is 2.8 year after the earthquake and thus much shorter than the period of our observations (1.5–9.3 year after the earthquake). Nevertheless, the model surface movements become rather steady 2 years after the earthquake, and therefore, the model displacements during the period of 2.0–2.8 year were used to calculate the displacement rate to be compared with our observation. The overall pattern of resulting vertical movement was in excellent agreement with the observed one; uplift in the seaward and subsidence in the landward across a trench-parallel zero line located a little landward of the trench axis. However, the model magnitude of uplift or subsidence was generally two to three times as large as the observed one. Because the vertical movement is mainly caused by viscoelastic relaxation, the result would suggest that the model viscoelastic structure leave room for further adjustment.

Remarkable uplift was observed at the three adjacent sites off Sanriku: Site G04 (located at 39°34'N, 2.6 cm/year), Site G06 (39°18'N, 3.4 cm/year), and Site G07 (38°57'N, 1.9 cm/year). Such significant uplift in this area cannot be explained by viscoelastic relaxation. The local uplift seems to exactly occur in the mid-slope terrace, a flat area ~4,500–5,000 m deep elongated parallel to the trench axis. Active slow earthquakes have been observed in the downdip of these sites (e.g., Nishikawa et al., 2019), and a slow slip event occurred in the early 2015 (Uchida et al., 2018; Honsho et al., 2019). Uplift of the seafloor can be qualitatively explained by fault slip only in the downdip side of these sites, or backslip only in the updip side, or both. Our observations are not frequent enough to determine whether the uplift is episodic or steady movement. However, our result suggests that fault slip in the downdip side, including the slow slip event in 2015, does not reach the trench axis but stops around these sites located ~20–30 km from the trench axis.

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