Detection of offshore vertical displacements after the 2011 Tohoku-oki Earthquake from GPS-A observations

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Postseismic displacements following the 2011 Tohoku-oki Earthquake (Tohoku Eq.) have been detected by on- and off-shore geodetic observations. Especially offshore GPS/Acoustic (GPS/A) observations showing an extensive postseismic displacement pattern [Watanabe et al., 2014, GRL; Tomita et al., 2016, AGU], which have strong constraints on modeling postsesimic deformation processes [e.g., Sun et al., 2014, Nature]. However, these GPS/A studies have basically detected only in horizontal components. Potseismic vertical motions are sensitive to the postseismic processes because they show different spatial pattern from horizontal motions; therefore, detecting vertical motions is quite important. Although Watanabe et al. [2014] detected vertical motions after the Tohoku Eq., an extensive pattern of the postseismic vertical motions has not still been obtained.
It has been a difficult work to detect vertical motions by GPS/A observations because a parameter of calculating vertical motions has the trade-off nature with a parameter of the sound speed in the seawater (SSS). Sato et al. [2013, J. Geod.] showed acoustic ranging data obtained from numerous and extensive sea-surface ranging points could constrain the parameters; Watanabe et al. [2014] similarly estimated the postseismic vertical motions. In contrast to their data collections, we have collected acoustic ranging data from a fixed ranging point just above the center of a seafloor transponder array (point survey data) based on the strategy of Kido et al. [2006, EPS]. In this strategy, we can obtain a horizontal seafloor motion precisely by each ping, but it is difficult to constrain vertical motions. However, we have also collected less but extensive acoustic ranging data (moving survey data) occasionally to initially configure the seafloor transponder array. In this study, we challenge to calculate extensive vertical motions after the Tohoku Eq. using moving survey data obtained from Seq. 2012 to Nov. 2016 at the 20 GPS/A sites in the Tohoku-oki region.
In our strategy, we initially calculated relative positions of seafloor transponders at each site; then we simultaneously calculated positions of arrayed transponders (array positions) in both horizontal and vertical components for each cruise and temporal changes of SSS. In order to accurately calculate vertical motions, we also have to estimate an offset between a GPS antenna and an acoustic transducer mounted on each research vessel. Since we have employed a different vessel for each cruise, the transducer offset values may cause critical biases in the calculated vertical motions. Thus, we iteratively estimated the transducer offset values and the initial relative positions of seafloor transponders and the array positions. Then, postseismic displacement rates were calculated from the obtained vertical motions.
The obtained vertical displacement rates show spatially charaterized pattern: subsidence above the coseismic rupture area and uplift near the trench, but they have 3-15 cm/yr errors in 1 σ that are much larger than the errors in the horizontal components. The worse errors in the vertical component are probably caused by the trade-off nature with SSS and the shortage of the moving survey data. Some sites show small errors with ~3cm/yr, but we cannot figure that the accurate results are actually obtained because the larger errors are obtained in the other sites by the same method. Due to the errors, it is difficult to quantitatively discuss the postseismic deformation processes at the moment. However, this study successfully showed the potential capability of our data for detecting vertical motions. In order to quantitatively discuss the vertical motions, further moving survey data in the future and detailed evaluation of the errors are required.

Keywords: Seafloor geodesy, The 2011 Tohoku-oki Earthquake, GPS/Acoustic observation, Postseismic deformation, Vertical motions