3D-Tomography of the Ionospheric Anomalies Preceding the 2011 Tohoku-Oki (M_w9.0) Earthquake

*Ihsan Naufal Muafiry[1,2], Kosuke Heki[1]

1. Hokkaido University, Japan, 2. Universitas Esa Unggul, Indonesia

The vertical deformation of solid earth could trigger direct acoustic wave propagating upward and will reach the F-layer of the ionosphere ~10 minutes after earthquakes (Cahyadi & Heki, 2015). Such an acoustic disturbance may also make long-lasting electron depletion (Shinagawa et al., 2013). These phenomena can be studied through Total Electron Content (TEC) data using Global Navigation Satellite System (GNSS) receivers. The GNSS phase difference can be converted to slant TEC (STEC) integrated along its line-of-sight (LoS), which are further converted to absolute vertical TEC (VTEC) by removing inter-frequency biases and multiplying with the cosine of the incidence angle of LoS to the ionosphere.

Shortly after the 2011 Tohoku-Oki M_w9.0 earthquake, Heki (2011) reported a significant positive anomaly in TEC starting ~40 minutes before the earthquake above the focal area, and He & Heki (2017) found similar TEC enhancements before 18 earthquakes with M_w 7.3-9.2. He & Heki (2016; 2018) investigated the spatial structure of the electron density anomalies before the 2015 Illapel earthquake, Chile (M_w8.3) using three-dimensional (3D) tomography technique. The result showed that positive electron density anomaly at ~200 km and negative anomalies at high altitudes line up along the geomagnetic field. This suggests their origin by electron redistribution caused by electric field made by surface positive electric charge (e.g. Freund, 2011).

Here, we report the 3D structure of the ionospheric electron density anomalies immediately before the 2011 Tohoku-Oki Earthquake using data from GEONET, a dense GNSS arrays in Japan, and the dense network in South Korea, with the 3D tomography technique similar to He & Heki (2018) and Muafiry et al. (2018). We set up more than 1500 blocks over the region covering the whole Japanese Islands, the Japan Sea, and the Korean Peninsula, with the size of 1.0° (E-W) x 0.9° (N-S) x 60 km (U-D) up to 900 km altitude. By using STEC residuals of pairs of thousand stations and 8 GPS satellites from reference curves, carefully determined by the L-curve method, as the input, we estimated the number of electron density anomalies within individual blocks. To stabilize and regularize the solution, we applied two types of constraints, i.e. continuity constraint and altitude-dependent absolute value constraint assuming the Chapman distribution. Before using the real data, we performed various tests to confirm the reliability of the solution including the checkerboard test, the test assuming realistic preseismic anomaly pattern, and comparing observed STEC anomalies of 10 % of the observation data with those calculated using the electron density anomalies estimated from the remaining 90% of data. These tests showed that our tomography results are robust with its difference is below 0.5 total electron content unit (TECU).

The attached figure shows the map view of our result at a height of 350 km with longitudinal and latitudinal profiles at three different epochs. The results show that positive electron density anomalies occurred at ~300 km altitude. They become large without spatial drifts as the main-shock approaches. Negative anomalies surround this compact and strong positive anomaly. The anomaly is situated just above to the focal area, suggesting its origin as the concentration of ionospheric electrons in response to surface positive electric charges appearing immediately before the 2011 Tohoku-Oki earthquake.

Keywords: Ionosphere-Anomalies, Earthquake Precursor, GPS-TEC, 3D-tomography