# 3D-Tomography of the Ionospheric Anomalies Immediately Before and After the 2011 Tohoku-oki ($M_w$9.0) Earthquake

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A dense network of ground Global Navigation Satellite System (GNSS) receivers detected ionospheric total electron content (TEC) increase immediately before the 2011 Tohoku-oki ($M_w$ 9.0) earthquake around the ruptured fault. It is also known that coseismic vertical crustal movements trigger acoustic wave propagating upward, reaching the F-layer of the ionosphere after 8-10 minutes. The wave front makes an N-shaped impulsive signature in TEC time series, often followed by electron depletion lasting for tens of minutes. This postseismic TEC drop has been sometimes thought to have caused artificial TEC increase before the earthquake. Our study robustly estimates three-dimensional (3D) distribution of both pre- and postseismic ionospheric anomalies of the 2011 event by performing tomography of electron density anomalies. We set up > 6,000 blocks over the region covering the Japanese Islands, the Japan Sea, and the Korean Peninsula, as large as 1.0° (east-west) x 0.9° (north-south) x 60 km (vertical) up to 840 km altitude. By using TEC residuals of pairs of ~1,200 stations and 8 satellites from reference curves, we estimated 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 around zero. The reliability of the solution has been confirmed in various ways including the checkerboard test. Our results showed that the estimated pre- and postseismic electron density anomalies do not overlap each other, i.e. the former occurred above land and the latter occurred above ocean (Figure 1). The preseismic anomalies are composed of a pair of positive (~300 km height) and negative (~600 km height) electron density anomalies along the geomagnetic field. The positive and negative anomalies are well balanced suggesting that the anomalies are caused by electron transportation. They occurred above the land of Northeast Japan without extending offshore, suggesting that the electric field due to surface electric charges are responsible for the preseismic anomaly. Electric field made by the surface charges would have penetrated the ionosphere and have caused downward electron transportation to cancel electric field along the geomagnetic field. On the other hand, the postseismic electron depletion occurred over the sea where coseismic vertical crustal movements were the largest. This supports its origin by vertical movements of the sea surface above the submarine fault. These results demonstrate that the pre- and postseismic ionospheric anomalies are independent not only temporarily but also spatially and certainly in underlying physical mechanisms.

Keywords: Pre-seismic Ionospheric Anomalies, Post-seismic, GPS-TEC, 3D-tomography