Spatio-temporal Structure of the Ionospheric TEC Anomalies Immediately Before the Three Large Earthquakes in Chile

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Ionospheric electron enhancement was reported to have occurred ~40 minutes before the 2011 Tohoku-oki (M_w9.0) earthquake by observing total electron contents (TEC) with global navigation satellite system (GNSS) receivers [Heki, 2011]. This has been repeatedly criticized due mainly to the ambiguity in the derivation of the reference TEC curves from which anomalies are defined, and to the dominance of natural variability in TEC during times of high geomagnetic activities. A brief history of the debate can be found in the introduction of our latest paper [Heki and Enomoto, 2015]. There we proposed the AIC-based numerical approach to detect positive breaks (sudden increase of TEC) in the vertical TEC time series without using reference curves. We also demonstrated that the frequency of such breaks on days without earthquakes are low enough to rule out the possibility that these anomalies are all of space weather origin. We also found that such breaks detected 18-80 minutes before the 11 recent large earthquakes with moment magnitudes (M_w) 7.8-9.2, depend upon background TEC as well as M_w. The precursor times also showed clear M_w dependence.

Here we study three recent large earthquakes in Chile, i.e. the 2010 February Maule (M_w8.8), 2014 April Iquique (M_w8.2), and the 2015 September Illapel (M_w8.3) earthquakes. Fairly large numbers of continuous GNSS stations have been deployed in South America, especially in Chile and Argentine, which enables us to study spatial structure of the observed TEC anomalies. We analyzed raw GNSS data downloaded from data centers of UNAVCO, IGS, RAMSAC, etc., and found clear positive TEC breaks immediately before these earthquakes (see the attached figure). Here we compare the three-dimensional spatial structure of the TEC anomalies with those inferred by Kuo et al. [2014] as the ionospheric response to surface electric charges.

Precursor times (occurrences of TEC breaks) in these earthquakes were, 40 minutes, 25 minutes, and 22 minutes before earthquakes, respectively. Background VTEC reflects the difference in magnetic latitude (Iquique event occurred beneath the equatorial ionization anomaly) and in local time (Maule event occurred during midnight), and were below 5 TECU, ~60 TECU, and ~20 TECU, respectively, for the three cases. As a whole, the increases of the VTEC rates were consistent with absolute VTEC and M_w.

In all the three earthquakes, preseismic positive TEC anomalies appeared to the north of the epicenters (opposite in the northern hemisphere cases). The spatial extent of the positive anomalies also showed M_w dependence, and were ~500 km for 2010 Maule and ~300 km for 2014 Iquique and 2015 Illapel earthquakes (see the attached figure). Negative anomalies (TEC decrease) were found to have started together with positive anomalies (TEC increase) in areas farther from the epicenters. We studied the 3-D spatial structure of these anomalies before the 2015 Illapel event (which had the best station coverage), and found that the positive anomalies appear ~200 km above ground to the north of the epicenter, and that negative anomalies appear at height of ~400 km further to the north of the positive anomalies. These positive/negative anomalies align with the local geomagnetic field, and the inferred structure is consistent with the ionospheric response to surface positive charges by Kuo et al. [2014].

References

See the Japanese version

Figure caption: Distribution of TEC anomalies immediately before the three Chilean earthquakes,

i.e. 2010 Maule, 2014 Iquique, and 2015 Illapel events. The anomalies are shown with colors at ground projections of the intersection of the line-of-sight with a thin layer at 200 km altitude.

Keywords: GNSS-TEC, precursor, Chilean earthquake