TEC anomalies preceding large earthquakes: Review and perspective

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An increasing number of Global Navigation Satellite System (GNSS) receivers continuously operating worldwide, makes it possible to observe changes in the ionospheric total electron content (TEC) associated with large earthquakes, e.g. coseismic ionospheric disturbances ~10 minutes after earthquakes by acoustic disturbances (Cahyadi & Heki, 2015). Heki (2011) also found TEC enhancement starting ~40 min before the 2011 Mw9.0 Tohoku-oki earthquake. He also confirmed similar TEC enhancements occurred before all the earthquakes in this century with Mw 8.5 or more (Cahyadi & Heki, 2013; Heki & Enomoto, 2015).
Several papers critical to Heki (2011) have been published during 2013-2015. They claim that (1) the preseismic increase is an artifact popped up by defining the reference curves using the data after earthquakes, and (2) the anomalies originate from geomagnetic activities rather than earthquakes. In our rebuttals papers (Heki & Enomoto, 2013; 2014; 2015), we demonstrated statistical significance of the preseismic increases of vertical TEC rates. We also counted the occurrences of similar changes in TEC caused by space weather during times of no earthquakes and demonstrated it statistically unrealistic to attribute all the observed preseismic anomalies to space weather.
Recently, He and Heki (2016) analyzed the spatial distribution of preseismic ionospheric anomalies of 3 large earthquakes in Chile, i.e. the 2010 Maule, the 2014 Iquique, and the 2015 Illapel earthquakes. There, both positive and negative anomalies started simultaneously at altitudes of ~200 km and ~400 km, respectively, with 3-D structure similar to Kuo et al. (2014) predicted as the ionospheric response to positive electric charges on the ground.
We found three different kinds of Mw dependence of the anomalies so far. At first, Heki and Enomoto (2015) found that the amount of the preseismic VTEC rate changes depend on Mw and background VTEC, i.e. larger precursors occur before larger earthquakes under similar background VTEC. Secondly, Heki and Enomoto (2015) found that earthquakes with larger Mw tend to have longer precursor times (i.e. tend to start earlier). Third, He and Heki (2016) showed that the anomalies of larger earthquakes have larger spatial dimensions. In the latest work, He and Heki (submitted) studied 32 earthquakes with Mw7.0-8.0 in this century, and found that 8 earthquakes showed possible preseismic changes starting 20-10 minutes before earthquakes. We could observe them before Mw7.0-8.0 earthquakes when background VTEC are large, say over 50 TECU.

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