Ionospheric TEC changes immediately before large earthquake: Magnetic declination changes observed before the 2011 Tohoku-Oki earthquake

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Shortly after the 2011 Tohoku-Oki Earthquake, Heki (2011) found that the ionospheric total electron content (TEC) started to change ~40 minutes before earthquake. Number of earthquakes showing similar immediate precursory TEC changes increased (e.g. He & Heki, 2017), but physical process behind the phenomenon has not been fully understood. Existence of such precursors suggest that the final size of an earthquake is largely prescribed when the fault rupture starts, which would be of sound seismological importance.

Why does the ionospheric TEC increase immediately before large earthquakes? We hypothesize that a certain process weakens the fault by sweeping the fault from one end to the other. It causes micro-scale cracks and dislocations, which cut peroxy bonds within rocks mobilizing positive holes. Electron movements let positive holes diffuse out of the rock and accumulate on the surface. They would make vertical electric fields (E) which may reach the ionosphere if the fault is large enough. High conductivity in ionosphere along geomagnetic fields (B) prohibits E along B. Thus, ionospheric electrons come down along B to cancel external E. This process would increase electron density at the bottom end of the geomagnetic field line and decrease electron density in higher regions. This hypothesis is supported by the 3-dimensional structure of the electron density anomalies just before the 2015 Illapel earthquake by He & Heki (2018).

In this study, we compare vertical TEC changes before and after the 18 earthquakes with Mw 7.3-9.2 that showed significant immediate preseismic TEC anomalies and explore scaling laws of various quantities. Then we derive the ‘standard curve’ of preseismic TEC changes by stacking the time series of individual cases after normalizing their horizontal and vertical axes. Comparing individual cases with the standard curve and highlighting their differences would help us characterize between-earthquake differences and get insight into their physical mechanisms. The current model suggests that the coseismic release of crustal stress would stop further generation of positive changes from faults and halt the TEC anomaly buildup. The derived standard curve suggested that the TEC does not show further increase after the earthquake occurrence time and remain almost constant until acoustic disturbances arrive. Also, the shapes of the pre-earthquake anomaly buildup curves may have regionality, reflecting e.g. the ocean-land proportion around the epicenter. Higher conductivity of the sea water will let electric charges diffuse rapidly and make the TEC anomaly reaches plateau earlier after its start. Comparison of the TEC change curves of individual earthquakes with the standard curve, however, showed that they are highly coincident in most cases with little significant differences in how the TEC anomaly builds up.

Also, we calculated geomagnetic fields changes from TEC anomalies immediately before the 2011 Tohoku-oki earthquake by Biot-Savart law. We compared it with magnetic declination changes observed immediately before the 2011 Tohoku-oki earthquake (Heki & Enomoto, 2013). It was a little smaller than the changes calculated from TEC anomalies.

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In addition, using the data from the Japanese geomagnetic observatories, we analyzed the magnetic field change before the earthquake in various parts of Japan. On March 11th, when the earthquake occurred, the geomagnetic disturbance caused by space weather was large. In order to consider the influence, the relative value with Kanoya (KNY) was taken at each station. At mid-latitudes such as Japan, auroral currents flowing in the polar regions cause magnetic field changes. Looking at the relative values of the magnetic field change in Kanoya (KNY) located to the south and various places, it is considered that the higher the latitude, the larger the relative value of the magnetic field change. In addition to this, it is considered that the magnetic field change is observed according to Biot-Savart law because the TEC has changed just before the earthquake. A comparison between the latitude dependence of the magnetic field disturbance just before the earthquake and the magnetic field disturbance considered to originate in space weather suggests that the magnetic field declination may have changed near the epicenter due to the TEC change immediately before the earthquake.

Keywords: TEC changes before large earthquake, Magnetic declination changes before earthquake

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