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Study of ionospheric variations before the great Tohoku earthquake in search of precursors of catastrophic earthquakes

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Purpose of this work is to study seismic-ionospheric connections and find out possible precursors of earthquakes. We concentrated on anomalous variations of total electron content (TEC) observed in different layers of the ionosphere before the catastrophic Tohoku earthquake, which occurred on March 11, 2011 near the east coast of Japan.

Signals of global navigation satellite systems (GNSS) received by stations of GEONET network were used to measure ionospheric delay of GNSS signals and valuate TEC over the area of interest. We used TEC maps calculated based on GNSS signals over Japan, provided by Nagoya University (NU), Japan, featuring resolution of 30 seconds and 0.5 by 0.5 degrees by geographic latitude and longitude. For comparison, we used TEC maps calculated using UPC model based on the spherical harmonic functions, provided by Technical University of Catalonia.

Measurements of F2 critical frequency (foF2) provided by vertical ionosphere sounding stations in Japan were used as independent source of information on ionosphere disturbances. Indexes of SME and F10.7 cm were used to account for solar and geomagnetic activity. Instead of plain TEC, we used integral values of TEC (iTEC) over the region, influenced by the earthquake, 26-46 degrees North Latitude and 128-148 degrees East Longitude, which covers whole territory of Japan, including the epicenter of the earthquake. In a time scale, we used moving average method with 7 days period to distinguish anomalous variations of TEC from daily variations due to solar activity.

During the period from March 3 to March 15, 2011 inclusive, anomalous iTEC values were observed, which clearly correlate with increased solar activity. However, approximately 27 hours before the foreshock of March 9, 2011, abnormal increase in iTEC (about three times the average and about 9 hours long) was observed. There was also a less pronounced increase in iTEC for about one hour before the foreshock, when SME index, reflecting the disturbance of the Earth's magnetic field, remained minimal. One day before the main shock of March 11, 2011, moderate increase in iTEC (about 1.5 times the average and about 5 hours long) was observed. There were no solar flares on March 10 and 11, and Solar activity index was minimal. Approximately 1-2 hours before the main shock, abnormal increase in iTEC (up to 130%) was observed in absence of any significant increase in model iTEC values at minimal SME and F10.7.

Moderate increases in foF2 were observed one day before the main shock at Kokubunji station, located close to the epicenter. Significant increase in foF2 was observed 1-2 hours before the foreshock and several hours before the main shock.

Considering the above, coordinated analysis of iTEC variations over the earthquake area shows the presence of two types of anomalies: (a) day-long anomalies (20-25 hours before the foreshock and the main shock), and (b) hour-long anomalies (1-2 hours before the foreshock and the main shock).

The most prominent increase in foF2 was observed one day before the shock at the Okinawa station, located far away from the epicenter of the earthquake. Moderate increase in foF2 was observed hours before the shock at Kokubunji station, closest to the epicenter. It is possible that anomalous phenomena in the ionosphere "pull together" from the periphery towards the epicenter, following increase in stress of the earth's crust.

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