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].

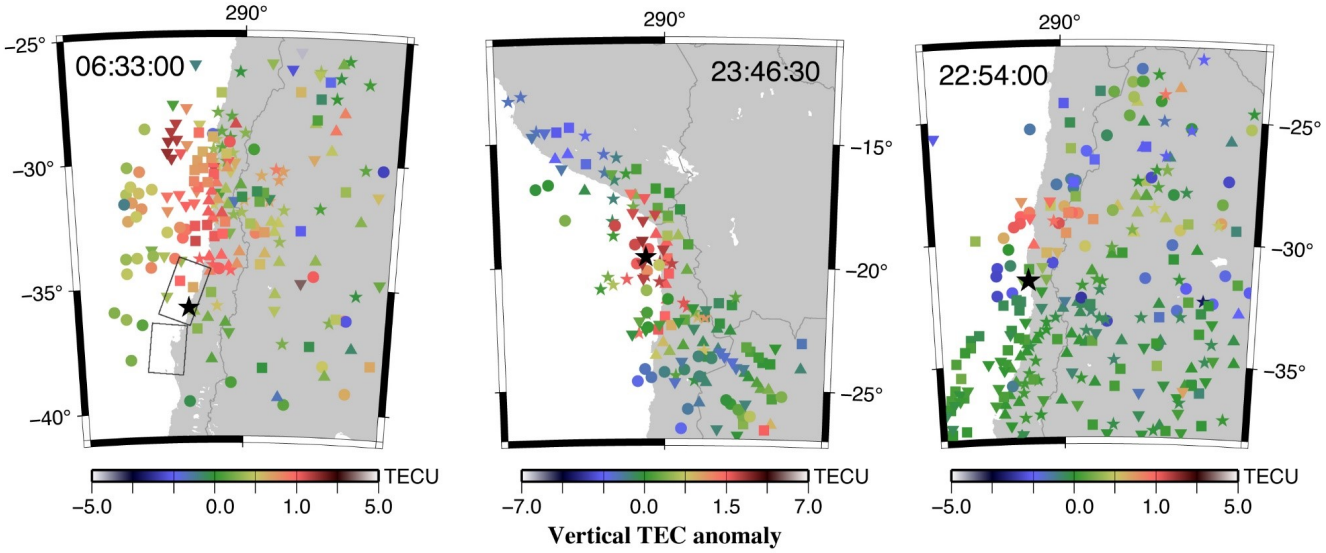
References

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



Statistical Analysis and assessment of Ionospheric TEC anomaly prior to large earthquake

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The detection of electromagnetic perturbations prior to large earthquakes has been proposed as a useful way to monitor the crustal activities. One of the most promising candidates is the measurement of Total Electron Content (TEC). There have been many reports on TEC anomaly associated with large earthquakes from different parts of the world. To verify the relation between TEC anomalies and seismicity around Japan, statistical studies by superposed epoch analysis have been carried out. The results have indicated that before a M>6 earthquake there are clearly higher probabilities of positive TEC anomalies in Japan. These results indicate the correlation between TEC anomalies and sizeable earthquakes. Furthermore, by making use of long-term TEC data over Japan during 2000-2013 and applying Molchan’s error diagram, we can evaluate the optimal parameter for earthquake forecasting. The results show that the TEC data contain potentially useful information on earthquake forecasts.

Keywords: Statistical Analysis, Ionospheric TEC anomaly

Ionospheric disturbance in D region possibly related to pre-earthquake activities observed by the DEMETER

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A decrease of electric field at the 1.7 kHz, i.e., VLF electromagnetic waves, within 4 hours before neighboring earthquake (EQ) with the magnitude of more than 4.8 was statistically shown through the data set of in-situ satellite measurement according to French groups. We found that the intensity originating from the whistler waves in the frequency of more than cutoff decreased in the orbit near the epicenter. The interpretation of the intensity decrease is due to the electron density increase in D region over the epicenter.

Keywords: Earthquake, Ionosphere, DEMETER

Statistical study on the Relationship between Major Earthquakes and Lower Ionospheric Perturbations based on the Focal Mechanism and Nighttime Fluctuation Method

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In this paper, we carried out the statistical study to investigate the relationship between major earthquakes over Japan and corresponding ionospheric perturbations before earthquakes based on the long-term data analysis. We categorized earthquakes into three different types, namely reverse fault, normal fault, and strike slip fault using focal mechanism. Ionospheric perturbations were identified by the nighttime fluctuation method applied to the daily nighttime amplitude data from UEC's VLF/LF observation network data between 2007 and 2012 (6 year-long). As a result, the lower ionospheric perturbations tend to occur much frequently for reverse fault type earthquakes, which is statistically significant. Furthermore, we calculated the optimal threshold for anomaly detecting for the prediction by using Molchan's error diagram, and 3 σ(standard deviation) below the mean value is found to be the best threshold for the optimal anomalous prediction.

Keywords: Earthquake, Ionospheric perturbation, Focal mechanism, VLF/LF transmitter, Earthquake prediction, Molchan's error diagram

Correlation between earthquake occurrence and the VHF propagation anomaly indicated by objectively produced prediction maps

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Radio waves intensity in the VHF frequency band, used by FM broadcast stations beyond the line of sight, sometimes increases shortly before earthquakes (Moriya et al., 2010). Hokkaido University monitors this anomalous VHF-band radio-wave propagation at 12 locations in Hokkaido. In this study, we used data at Erimo station for 2006 to 2015 to make Earthquake prediction maps. If 6 min-average sampled data exceeds a threshold in 2 consecutive samples, we labeled that time as anomaly (Morita and Mogi, 2015, IUGG). After anomaly, we turn ON the alarm for a certain period of time L, and this divide all time into “Alarm ON”, “Alarm OFF”, and “Undecided (due to missing data)” periods.
After excluding the Undecided period, we measured “r” the fraction of the period of alarm ON and “s” the fraction of earthquakes that occurred during periods of Alarm ON. The gain of the map is calculated as G = s/r. We found G>1 for most prediction maps. We further calculated “p-value”. Our best p-value of 0.036 was obtained for the prediction map with L = 4days when it was evaluated against the occurrence of M>5 earthquakes. G in this case was 2.1.
The present result is not strong enough, but by refining the extraction criteria of anomaly, we think there’s a good chance to firmly establish that some of beyond the line of sight VHF propagation are earthquake precursors.

Keywords: Earthquake prediction map, objective algorithm

Observation of DC Electric Field Radiated prior to Large Earthquakes

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According to results of increase of ionosphere electrons density which was formed prior to large earthquakes, it has become that the density increase might be caused by DC electric field generated prior to the earthquake. On the other hand, we found, in the laboratory simulation experiment on electromagnetic radiation from earth's crust, that a fluctuation of DC electric field was detected prior to strong impact by fracture of a glass ball, after loading heavy stress to the glass ball between two granite pillars. In order to confirm the DC electric field detected prior to large earthquakes, I began to observe DC electric field in a mountain side of Kyoto where electromagnetic environment is extremely quiet.
I used linear dipole antennas as a sensor system of DC electric field. For cancelling out the background electric field formed against the ground and for shortcutting AC electric components of electromagnetic noise, a new electric circuit composed of a resistance and a capacitance connected in parallel was connected between two dipole antenna elements. Since electric voltages at two connecting points between the electric circuit and each antenna element were led to a differential amplifier, the common mode of the background electric noise around the observation system can be cancelled out, and many AC electric components of electromagnetic noise can be shortcut. Then DC electric field only can be detected. Two sets of dipole antenna of 5 m tip-to-tip were installed in east-west and north-south directions at 4 m height, by which polarizations of horizontal electric field can be obtained. Output voltage from pre-amplifiers (700 times of input voltage) are captured as digital data by a personal computer via AD converter with a sampling frequency of 1 Hz. Since one data set is consist of 4096 points, we can see a time variation of DC electric field of 68 min duration.
The observation of DC electric field was started on Feb 5, 2016. Daily variation of DC electric field is as follows: electric field in nighttime was very quiet although there appeared large electric fluctuations in daytime. Therefore, the nighttime is suitable for the present observation of DC electric field.
At 08:28:30.9 Feb 9, 2016, we had an earthquake of M2.1 at 12 km depth of 18.5 km west of our electromagnetic observation site. A long time fluctuation of 25 min period of DC electric field was detected 35 min prior to the earthquake. Large amplitude electric noise of the shorter fluctuation (~8 second period) were also superposed on the large fluctuation. The long time fluctuation showed a similar form obtained in the laboratory experiment. Since the noise components of shorter fluctuation showed elliptic polarizations, they might be radiated out of the ground surface.
Hereafter, for clarifying the validity of generation of DC electric field prior to large earthquakes, we need to obtain a quantitative result of these DC electric fluctuations.

Keywords: DC Electric Field related to Earthquakes, Observation of Electric Field

