We_P05_15 Forecasting of Global Ionospheric Perturbation Maps Using GIM and ARIMA as a Precursor of Earthquake Introduction

Conference Paper · June 2019

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Forecasting of Global Ionospheric Perturbation Maps Using GIM and ARIMA as a Precursor of Earthquake

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Summary

The study of seismo-ionosphere interaction with respect to earthquake events using Total Electron Content (TEC) data deriving from receivers of global navigation satellite systems (GNSSs) are increasingly being used to detect pre-earthquake ionospheric anomalies. This is primarily because ionospheric anomaly variation has been considered to constitute one possible method to identify earthquake precursors. In this paper, we have reported significant evidence for pre-seismic ionospheric anomalies of TEC in the global ionosphere anomaly map (GIM) to visualize the perturbations before the 28 September 2018 Mw=7.5 Indonesia Tsunami. After distinguishing other anomalies related to the geomagnetic and solar activities, it is found to be of seismogenic origin. But the data availability has a delay of 3-5 days. To make it in real time we have used the statistical regression model (ARIMA) to forecast the real-time prediction model from the anomaly trend, which matches with the data derived from the GNSS with a promising accuracy and the predicted epicenters are also falling within 120 km of the real one. Statistical approach of forecasting worldwide TEC value prior to the earthquakes may provide some new and beneficial insights for the future study of ionospheric earthquake precursors.

Introduction:

Earthquake is one of the most destructive natural disasters, which causes huge loss of lives and properties. In spite of tremendous progress in the field of geo science in the recent few decades, it is still not possible to accurately predict the time of occurrence of earthquakes. However, several techniques have achieved success for scientifically forecasting earthquakes. The study of seismo-ionospheric anomaly variation before large earthquakes has attracted the attention of geophysicists for several years (since the great Alaskan earthquake in 1964). In the initial stage of precursor, ion cluster is formed in the near ground atmosphere within the earthquake preparation zone leading to the generation of an anomalously strong electric field (Pullinets et al., 2002). This field penetrates to the upper levels of the ionosphere without any decay, which gets manifested in the periodic oscillations of electron density, which is observed as largescale irregularities in Total Electron Concentration (TEC) in the F2 region of the ionosphere (Freund, 2013). While discussing the relationship between ionospheric anomaly and earthquake, the solar terrestrial environment must be taken into account to exclude anomalies that might have been caused by solar or magnetic field activities under the influence of electric field of seismo-genic origin the observed local negative anomaly is appeared few days prior to the earthquake. After distinguishing other anomalies related to the geomagnetic activities, we found a temporal precursor around the epicenter, few days prior to the earthquake, which can be seen in 2-D anomaly maps and its spatial variation along the nearest plate boundaries to determine the probable epicenters. But the GPS derived TEC in the CODG (or CORG) format, which has a delay of 3-5 days. This data gap may cause the unnoticed perturbation in proper time before earthquakes. To make it in real-time, we have statistically analyzed the regressive model of the consisting available data trend which shows very promising correlation with the spatial variations in latitude–longitude–time (LLT) maps prepared by the forecasted data using the ARIMA model.

Physics behind the TEC anomaly:

Numerous papers had proposed for the physical interpretation of this seismo ionospheric precursors.This phenomenon has strong arguments in favor of the theory given by Freund et al. (2018) for the pre earthquake phenomena which could be track back to ‘Peroxy defect theory’, the activation of electronic charges in rocks subjected to tectonic stress variations. Silicate is the most common constituents of earth crust, which has the anionic oxygen link with Si^{4+} and AL^{3+} (Freund, 2010). These minerals contain a typical peroxy bonds subjected to the stress variations, in which condition the anionic O^{2-} is replaced by the pair of O^- bonds. In this process during cooling over geological time along the regional geotherms, the solute hydroxyl ions (OH^-) undergo a redox conversion, in which the hydroxyl protons steal on electron from the parent hydroxyl oxygen forming H_2 (which is mobile and immediately diffuse away), that makes the conversion as irreversible thermodynamic equilibrium. Mechanical stresses variations prior to the major earthquakes cause the grains to slide relative to each other which results the breakup of the peroxy bonds and the electrons becomes trapped in the broken peroxy bond, which is equivalent to a defect electron on O^{2-} sub lattice. The number of p-hole (+ve charge) depends on the stress level and stress rate. Thus the potential difference occurs between the positively charged unstressed rock volumes to the electron dominant stressed rock volume leading to the significant electrical conductivity increase across the two volumes. The high electric fields at the free surface ionize the air molecules. Among which the O_2 is ionized easily (ionized to O_2^+) as it has lowest ionization potential. Massive proportion of air ionization leads to the upward migration of charged particles causing the vertical current flow which produces the electromagnetic anomalies by creating a downward pull of electrons located at the bottom of the ionosphere. This microscopic phenomenon caused by peroxy defect results the macroscopic impact in the ionospheric plasma perturbation.

Method of data processing:

Ionospheric TEC maps in agreement with the IONEX format containing GPS derived TEC values along the zenith direction, so-called Vertical TEC (VTEC), at points arranged in a globally distributed grid with a spatial resolution of 2.5º in latitude and 5º in longitude covering the whole globe consisting 5183 points each hour (having temporal resolution of 1 hour). To distinguish the anomaly we computed the running median (m) and standard deviation (σ) of the GPS TEC 30 days prior to the earthquake under the consideration of normal distribution. We constructed the upper bound (UB) as (m+1.34σ) and the lower bound (LB) as (m-1.34σ) respectively (having confidence level of about 82%). If the TEC value lies outside either of the bounds, it is treated as anomalous (Liu et al., 2004). Besides this we have also plotted the spatial variations in latitude–longitude–time (LLT) maps to predict the epicenter, which agrees well with the statistical approach.

We used an Auto Regressive Integrated Moving Average (ARIMA) model to forecast predicted points in the series (data forecasting). So far first time we have successfully predicted the ensuing TEC variation for the next couple of days for the entire globe, with a promising accuracy. We have also plotted both of the spatial variations in ARC-Map model, which matches well with the actual map prepared from the satellite derived TEC value.

Earthquake analysis:

On Sep 28, 2018, a 7.5 magnitude (Mw) earthquake having intensity IX, devastated Palu, Indonesia at 10:02:45 (UTC), which induced tsunami, occurred as a result of a strike-slip fault at shallow depths within the interior of the Molucca Sea microplate, part of the broader Sunda tectonic plate. TEC data of the nearest grid point for a period of one month prior to the events and one weeks after the events are extracted from global GIM file and analyzed using the median, upper and lower bound as explained before The graphical temporal plot of TEC shows anomalous (lower) TEC values (marked by black circle) on 9th, 14th, 17th, 20th and 21st September (Figure 1a) for Palu, Indonesia. Which are also checked against geomagnetic and Solar activity (Ap index <30 and F10.7 <84) (Figure 1c.) within that time interval. 2-D anomaly maps and its spatial variation along the nearest plate boundaries are plotted (Figure 2) to determine the probable epicenters. This shows very nice correlation with the spatial variations in latitude–longitude–time (LLT) maps prepared by the forecasted data using the ARIMA model (Figure 3). Both the maps show that the predicted epicenter is inside 120 km of radius of the real epicenter which lies within the earthquake preparation zone (EPZ). Earthquake preparation zone is given by Dobrovolsky's formula. Radius of Earthquake Preparation Zone = $10^{(0.43\times Mw)}$ Km (Dobrovolsky et al., 1979). Where Mw is the magnitude of the earthquake. In this case the earthquake preparation zone is coming around 1679 Km.

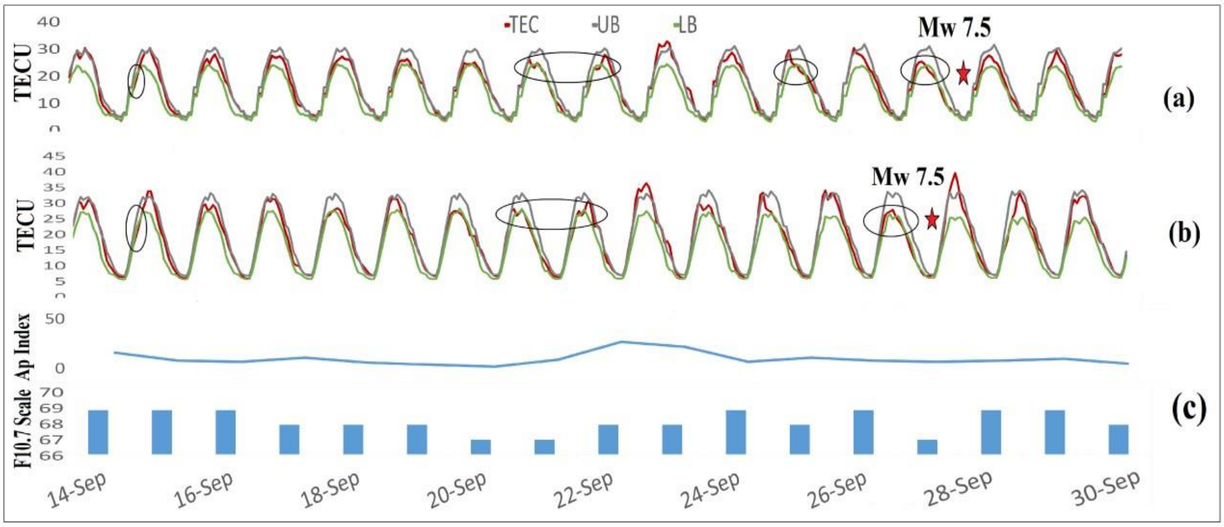

Figure 1 *(a) and (b) TEC variation as observed from GPS (IGS) derived data and as observed from forecasted value by ARIMA model respectively along with lower, upper bound and anomaly as observed during, before Indonesia Tsunami of 28th September 2018, (c) AP Index and F10.7 covering the event (14th September to 30 September).*

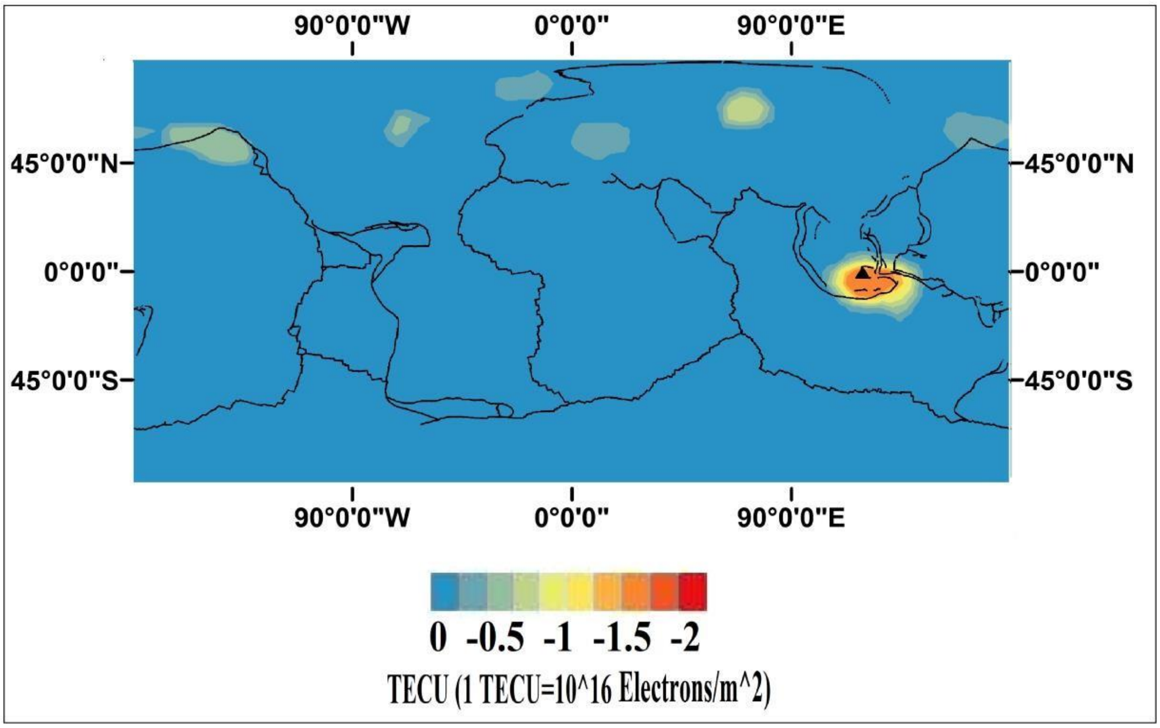

Figure 2: *Global ionospheric spatial TEC Anomaly maps (22 September at UTC 2:00) observed before Indonesia Tsunami from GPS (IGS). The epicentre is shown as black triangle (Units in TECU; 1TECU=10 ^{16} electron/m^{2}) (Resolution 2.5^{o}× 5^{o})*

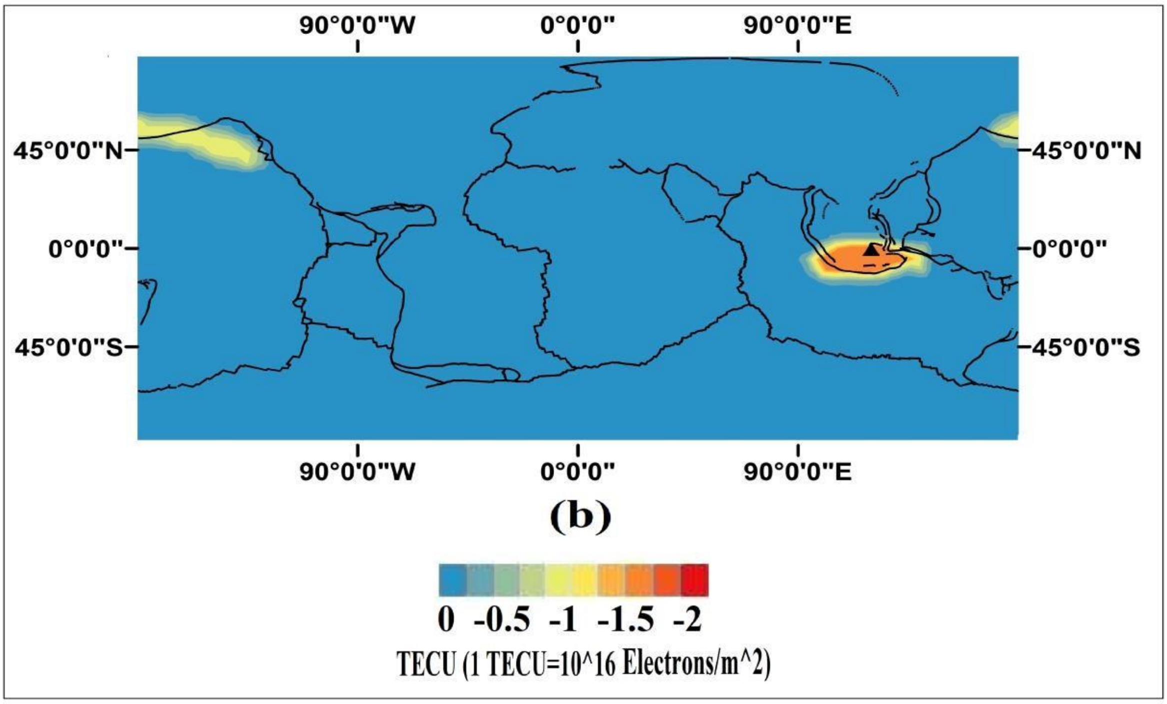

Figure 3: *Global ionospheric spatial TEC Anomaly maps (22 September at UTC 2:00) observed before Indonesia Tsunami from forecasted TEC anomaly by ARIMA model. The epicentre is shown as black triangle. (Units in TECU; 1TECU=10 ^{16} electron/m^{2}). (Resolution 2.5^{o}× 5^{o})*

Conclusion:

In this study, through statistical variations it confirms that the anomalous variation of TEC values prior to earthquake, which are independent of the geomagnetic or solar activities. In addition it is also possible to predict the earthquake epicenters with a limited accuracy with the help of the 2D TEC anomaly maps. But the data availability had a very crucial factor for the prediction of the epicenter. To overcome it, first time so far it is being reported with the statistical ARIMA model to ensure the backup of the data availability and this technique has proved very effective in monitoring the TEC anomaly. Without a single day of delay, it is possible to distinguish the ensuing seismo-ionosperic perturbations and the degree of its variation. This study can be used as the precursory measure of the earthquakes and forecasting its probable epicenters, which may somehow be able to save so many lives.

Acknowledgement:

Author is thankful to Geo Science Department (GSD), Indian Institute of Remote Sensing (IIRS, ISRO) Dehradun for giving us the opportunity to do the project on earthquake precursor analysis. Author would also like to acknowledge NASA, NOAA for giving the data. The author wish to thank the Director, IIT (ISM) and HOD, Department of Applied Geophysics, IIT (ISM) Dhanbad for their keen interest in this study.

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