ISSN 2250-3153

Monitoring the TEC variation using pattern matching method during earthquakes as determined from ground based TEC measurement and satellite data

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Abstract- Total electron content (TEC) data, obtained from GPS satellites can be used as a tool for extracting earthquake precursor. In this paper, a pattern matching technique is used for monitoring TEC variation during and prior to the earthquake. For the experiment two major earthquake events i.e. Bhutan earthquake on 21st September 2009 and Nepal earthquake on 25th April 2015 are considered for analysis. Work is based on TEC data collected from GPS at Gauhati (26º 10' N, 91º 45' E) and National Oceanic and Atmospheric Administration (NOAA) satellite data.

Index Terms- Total electron content, earthquake, pattern matching

I. INTRODUCTION

The ionosphere has a major role in the propagation of electromagnetic radio waves. Due to large variability of ionosphere these propagation are widely affected. Such variability occurs mostly under the influence of some geophysical phenomenan mainly the sunspot number, solar flares and magnetic storms. Many of the researchers have been reported that the ionosphere shows anomalous variations prior to large magnitude impending earthquake. The study of ionospheric variations during seismic activities becomes an interesting field of earthquake prediction. These studies are being carried out by analyzing different parameters such as foF2, foEs, TEC etc.

Total Electron Content (TEC) obtained from satellites has now been adopted as one of the tools for identifying earthquake induced characteristics to utilizing these as precursory parameters [Kalita et al 2012, Devi et al 2001]. However earthquake induced effects on the ionosphere are inherently complex in nature because even at normal times the ionosphere is influenced by solar geomagnetic ambience. In addition to this, in latitudes like Guwahati (26º 10' N, 91º 45' E) the effect of a special phenomenon known as Equatorial Anomaly make such analysis difficult.

In this paper, the two major earthquakes i.e. Bhutan earthquake on 21st September 2009 of magnitude 6.1 and Nepal earthquake on 25th April 2015 of magnitude 7.8 are considered for analyzing ionospheric TEC variation using dynamic time warping method during and prior to the earthquake.

II. DATA AND ANALYSIS

TEC data used in the research work are mainly collected from National Oceanic and Atmospheric Administration (NOAA) satellite data and the GPS receiver of Guwahati. The TEC measurement from GPS is based on Faraday Rotations, measured through two different L band frequencies. From the slant TEC data, matrix inversion and smoothing techniques are used for vertical TEC measurement. At Gauhati laboratory, a GPS receiving set up is used for collection of TEC data. The system consists of a GPS antenna with a low noise oven controlled crystal oscillator which can track up to 11 GPS signals at L1 frequency (1575.42 MHz) and L2 frequency (1227.6 MHz).

Earthquake induced features on TEC are often examined by taking the TEC peak value as an parameter (Devi et al. 2010b). But the TEC peak alone is not exclusive as it cannot offer electron content magnitudes especially at post sunset hours in situations when abnormally high TEC variation is detected. Such enhancements in election density, leading to changes in shape of the TEC profile, are often observed on pre-earthquake days (Depueva and Ruzhin 1993, Devi et al. 2004). Therefore, the TEC peak may not be a sufficient predictive parameter for an earthquake thus necessitating using the TEC profile shape in a technique that brings the entire TEC profile period to the ambit of earthquake prediction analysis. For this apporoach a dynamic programming technique known as Dynamic Time Warping (DTW) is used to identify dissimilarity between two time series and to determine the deviation between the two. Here, one of the time series is framed from quiet day average of TEC profiles while the second series is for any other day. The two series are compared by calculating the magnitude of 'like-to-like' matches. Based on this matching, a parameter called the 'certainty factor' is defined to identify earthquake cursors. However, before applying the DTW technique, it is essential to examine TEC variations due to seismic and other non seismic factors. The work is based on the previous research work of Kalita et al, 2012.

III. Result and Discussion

The 2009 Bhutan earthquake with M=6.1 magnitude occurred at 14:43 (82.5 EMT), on September 21, 2009 in the eastern region of Bhutan. The epicenter was at 180 kilometers (radius =445.85 km) east of the capital Thimphu and thus the receiving station at G.U. is within the earthquake preparatory zone. As DTW technique demands framing of the template from ten quiet days (Q-days) of this month for finding out "certainty" parameter, we present in figure 1a the Q-day TEC feature along with one of the pre- earthquake day to highlight the differences between the two. The modification in shape of TEC before the earthquake day (see figure 1b) is significant compared to that for Q-day one. And it is expected that the certainty factor should be low before this event. Thus from a number of quiet day TEC profiles a template for this particular month is created to measure distance of deviation between template and time series of other days of this month and the certainty factor is calculated .

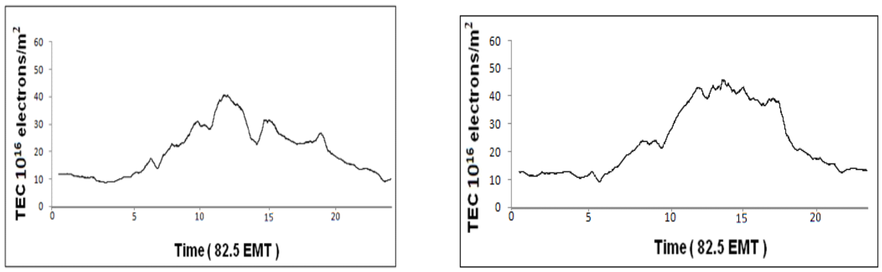


Fig 1: TEC profile for *(a)* Q-day and *(b)* pre earthquake day of 20.9 .2009

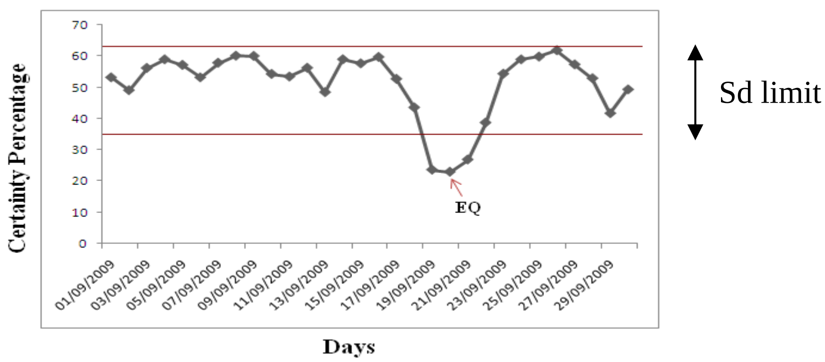


Fig 2: Certainty factor for the month of September 2009. Note the depletion of this factor during earthquake time; earthquake occurred on 21.9.2009.

The certainty percentage is plotted (figure 2) against day for the entire month and it is clearly observed that the magnitude of this parameter has gone down below the sd limits (shown by red lines) from 19th Sep 2009 i.e two days prior to the earthquake and the parameter revives to its original value from 22nd Sep 2009. This indicates that it is possible to identify an earthquake day by calculating the certainty factor using the method.

The above approach is now applied for identifying the recent earthquakes of 25 April 2015 Nepal earthquake which is also referred to as the Himalayan earthquake with M=7.8 magnitude occurred at 11.56 NST. The epicenter was approximately 34 km (21 mi) east-southeast of Lamjung, Nepal, and its hypocenter was at a depth of approximately 15 km (9.3 mi) and Guwahati lies well within the earthquake preparatory zone, offering a rare occasion to examine the reliability of the DTW technique for a case like this. The Q-day template has been made and the 'certainty factor' between the template and the other days of this month is calculated and presented in figure 3. Here too, a clear drop of this factor prior to the earthquake is seen. Low values of the 'certainty factor', even after the earthquake events, are interesting because such a factor may be associated with aftershocks.

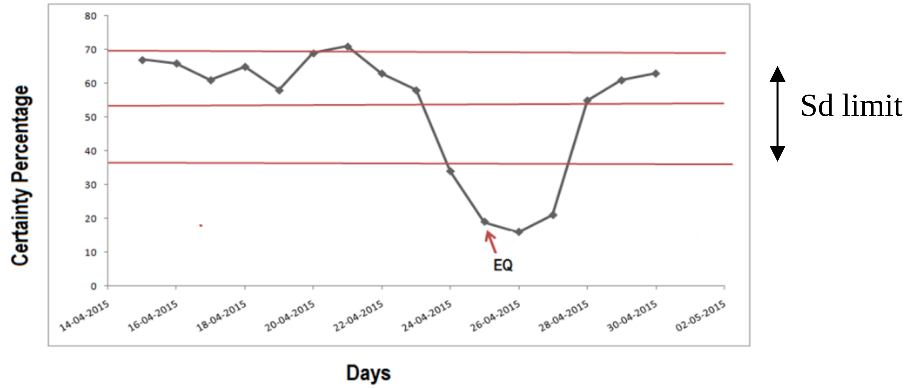
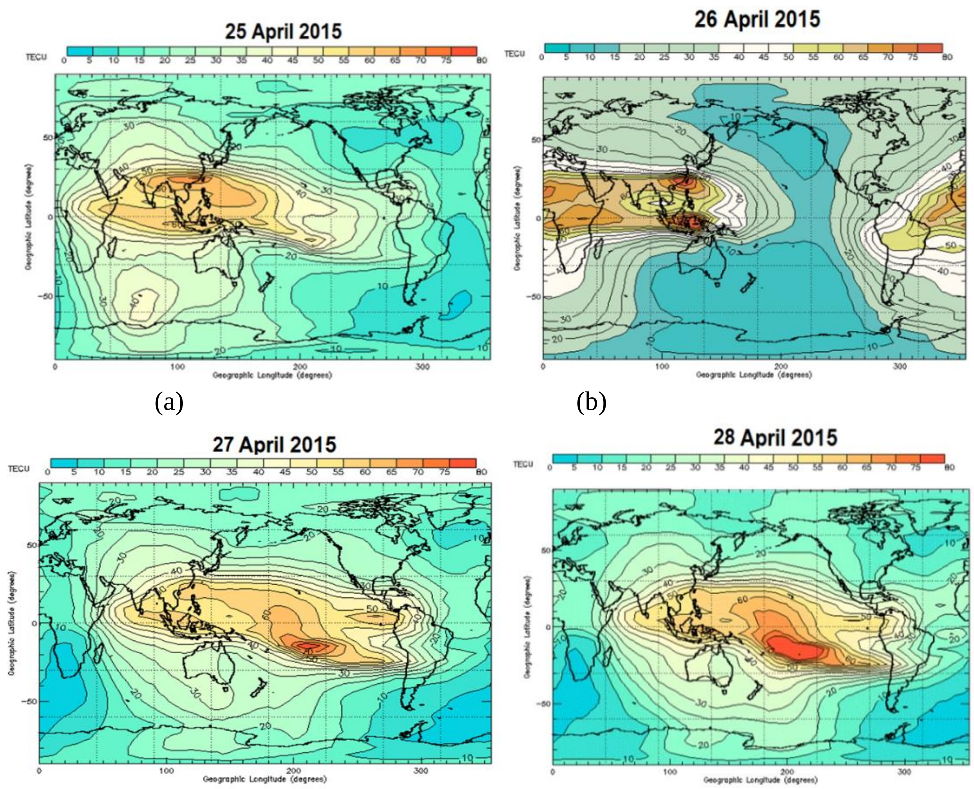


Fig 3: Certainty factor for the month of April 2015. Note the decrease in the certainty factor prior to the earthquake day, marked by arrow head in the figure.



(c) (d)

Fig 4: Displaying abnormal growth of TEC during April 25, 2014 and April 26, 2014 at 22°-30° Latitude and 80°-120° Longitude Zone.

By analyzing global TEC data (figure 4) during strong earthquake events of Nepal, it can be clearly observed that there is strong ionization density at off 22°-30° Latitude and 80°-120° Longitude on 25th April 2015 gets extended as reflected in the global TEC plot of Figure 3,which is a suggestive cursor to a very strong earthquake in this sector. Such abnormal behavior can be identified while comparing the normal day TEC map.

Past studies on the analysis of TEC features that appear prior to an impending earthquake have shown that precursors at low-latitudes manifest themselves as a kind of Appleton type ExB charge movement when the epicentre lies near to the equator (Depueva and Ruzhin 1995, Devi et al. 2001, Hayakawa 2004, Depueva et al. 2007), imparting a mark in the TEC value (Depueva and Rotanova 2001, Devi et al. 2004, 2010b). It is shown by Devi et al. (2010b) that low-latitude
earthquakes also force similar changes on profiles of electron density, though the modifications may extend to beyond the day peak. Thus, modifications to electron content imposed by an equatorial earthquake may not be similar to that of a low latitude one, when shifts of the anomaly crest may lead to either an increase or decrease of TEC, depending in a complex way on magnitude of the earthquake, proximity of the epicentre to the observing station and the simultaneous presence of an equatorial earthquake (Devi et al. 2010b).

IV. Conclusion

We have here adopted a new approach for monitoring TEC variation during and prior to the strong earthquake day profile from Q-day one by pattern reorganization. This is the first step for utilizing this approach for monitoring the behavior of TEC during and prior to an impending earthquake. However the limitation is that it cannot resolve fine structure (like changes in hours) because the enormous increase in size of the necessary matrix for computation such changes .However, there is an improvement on DTW algorithm (FDTW) for preparing large matrices and large number of distance calculation. Our next step will be to designing a model using kp, fof2 and other important data as a parameter for extraction of earthquake precursors and to adopt the new algorithm for identification of epicenter position through use of multiple features of TEC as discussed by Devi et al. (2010a).

Acknowledgment

The author S. Kalita has acknowledged with thanks the Assam Science Technology & Environment Council (ASTEC), Assam, India for suggestions received in preparation of the work and the financial support.

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