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# A study of ionospheric precursors associated with the major earthquakes occurred in Pakistan region

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**ABSTRACT**

The GPS-TEC measurements have been in progress at Agra station (27.2º N, 78º E), India since 01 April 2006. In the present paper, we analyze the GPS-TEC data for two months of April and September, 2013 in which two major earthquakes (M > 7) occurred in the adjoining region of Pakistan. We use the quartile based statistical technique for the analysis of data and identify the significant precursors associated with the earthquakes. These precursors occurred on different days in the interval of 2-10 days prior to the earthquakes. We also examine the effect of geomagnetic storms on the total electron content (TEC) data and find that the precursors are not influenced by the storms. The cause of the precursors is E × B drift with the electric field generated over seismic regions and penetrated the ionosphere.

## INTRODUCTION

As per reports available in recent years, many scientists have presented interesting results on GPS-TEC variations related to earthquakes (Liu et al., 2001, 2004a, b, 2006, 2009; Pulinets et al., 2007; Kon et al., 2011, Akhoondzadeh, 2012a). Although, many techniques have been employed for the prediction of earthquakes the ionospheirc precursors identified from GPS-TEC measurements have drawn considerable attention due to their relatively more convincing characteristics. For example, Liu et al. (2001) have examined the effect of a major earthquake of magnitude M = 7.7 on the total electron content (hereafter TEC) data and found the precursors 1-5 days prior to the earthquake. Liu et al. (2004a) have performed a statistical analysis on TEC data related to 20 earthquakes (M ≤ 6.0) that occurred in the Taiwan region and found that 80% of pre-earthquake ionospheric anomalies occurred 1–5 days before the earthquakes. In a similar manner, Liu et al. (2008) also examined the TEC data obtained using 8 GPS (Global positioning Satellite) receivers over Taiwan before the 2006 Pingtung earthquakes and found a reduction of about 7 TECU (TEC unit) within a duration of 4.5 h. Akhoondzadeh et al. (2010) have studied the variations of electron and ion densities statistically in the light of four large earthquakes and found a very good agreement between the different parameters estimated by DEMETER (Detection of Electromagnetic emissions transmitted from Earthquake regions) satellite and GPS data in the detection of pre-seismic anomalies. Recently, Le et al. (2011) have studied the pre-earthquake ionospheric anomaly statistically by TEC data from the global ionosphere map (GIM) corresponding to 736 earthquakes (M < 6.0) that occurred during 2002 – 2010 and their results indicated anomalous variations in TEC data a few days before the earthquakes. Liu et al. (2011) have reported that there is a successive long time enhancement in GPS-TEC one day before M = 7.0 Haiti earthquake occurred on 12 January, 2010, and the TEC enhancement anomaly appears specifically in a small region over northern epicenter area. Akhoondzadeh (2012) have studied the GPS-TEC variation associated with the powerful Tohoku earthquake of 11 March 2011, and reported convincing precursors 1-3 days prior to occurrence of earthquake. More recently Pundhir et al. (2014) have examined the effect of a major earthquake on GPS-TEC data and found the precursors 1-9 days prior to the earthquake. In spite of publication of a large number of excellent papers in reputed journals suggesting earthquake precursors in the ionospheric region, the scientific communities at large entertain doubts about the integrity of the conclusions, in the absence of a well-proven and tested theory regarding the transfer of energy from the crust to the ionosphere. This is further abetted by the well-known day-to-day variability in the ionospheric parameters not connected to any solar or geophysical event, known as the geophysical noise, which incidentally is more severe in the tropics. However, researchers should continue to explore the possibility of using atmospheric signatures as precursors for earthquakes because earthquakes and the consequent tsunamis constitute the worst natural disasters. It is accepted by internationally reputed seismologists that earthquake precursors study alone could help in narrowing down the non-uniqueness associated with short term prediction. As such, earthquake precursors in the ionosphere need to be studied in detail, to help in finding apt signatures before an earthquake.

In the present paper, we select two cases of major earthquakes which occurred in Pakistan region, one of which was of magnitude M = 7.8 occurred on 16 April 2013 at Pakistan – Iran border region (28.0°N, 62.1°E) and the other of magnitude M = 7.4 occurred on 24 September 2013 in Pakistan (27.0°N, 65.7°E).These were very devastating earthquakes as they affected not only Pakistan but also adjoining countries; Iran, Afghanistan, India and China etc. We examine the spatial and temporal variations of GPS-TEC observed at Agra station prior to these major earthquakes during a span of $\pm$15 days from the occurrence of these earthquakes and look for associated anomalies. The effect of geomagnetic storms that occurred during the respective months are also examined.

## EXPERIMENTAL SETUP AND METHOD OF ANALYSIS:

The experimental set up for TEC measurements at Agra station is similar to that used by our group earlier (Singh et al., 2009). In brief, it consists of a GPS antenna (Novatel's Model GPS 702), a GPS receiver (Novatel's Euro Pak 3-M), connecting cables and relevant software (novatel.com) imported from Silicon Valley, USA. The experimental set up is placed in the Seismo-Electromagnetic and Space Research Laboratory (SESRL) in the Faculty of Engineering building at Bichpuri Campus of our college and round the clock observations are taken. The local electrical and electromagnetic disturbances are extremely low at Bichpuri due to its location in rural area about 12 km west of Agra city. We use quartile based statistical analysis as was initially used by Liu et al. (2009) to identify the abnormal signal properly. For this, we compute the median of GPS-TEC values for the previous 10 quiet days, and determine the corresponding lower and upper quartiles LQ and UQ respectively. Then, we calculate lower bound (LB) and upper bound (UB) as LB = M – 1.5 (M - LQ) and UB = M + 1.5 (UQ - M) respectively and find significant precursors in relation to these earthquakes.

## RESULTS AND DISCUSSION:

Fig. 1 shows the map of Asia which includes the locations of these two earthquakes (solid stars) and observing station

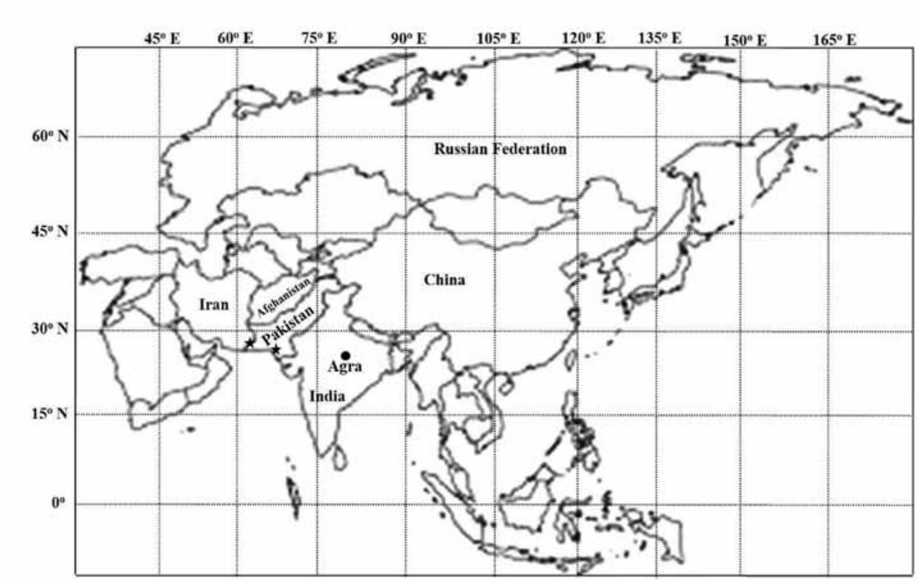


**Figure 1.** The map of Asia indicating the epicenters of earthquake (solid stars) and the location of TEC observing station Agra in India (solid circle).

**Table 1.** Details of Major Earthquakes in Pakistan Region.

| Date of Earthquake | Time (UT) | Lat. (deg.) | Long. (deg.) | Depth (km) | Magnitude | Region | Distance from Agra (km) | Radius of influence zone (km) |
|---|---|---|---|---|---|---|---|---|
| 16/04/2013 | 10:44:11 | 28.0°N | 62.1°E | 46 | 7.8 | Pakistan-Iran Border Region | 1568 | 2259.4 |
| 24/09/2013 | 11:29:48 | 27.0°N | 65.7°E | 10 | 7.4 | Pakistan | 1217 | 1520.5 |

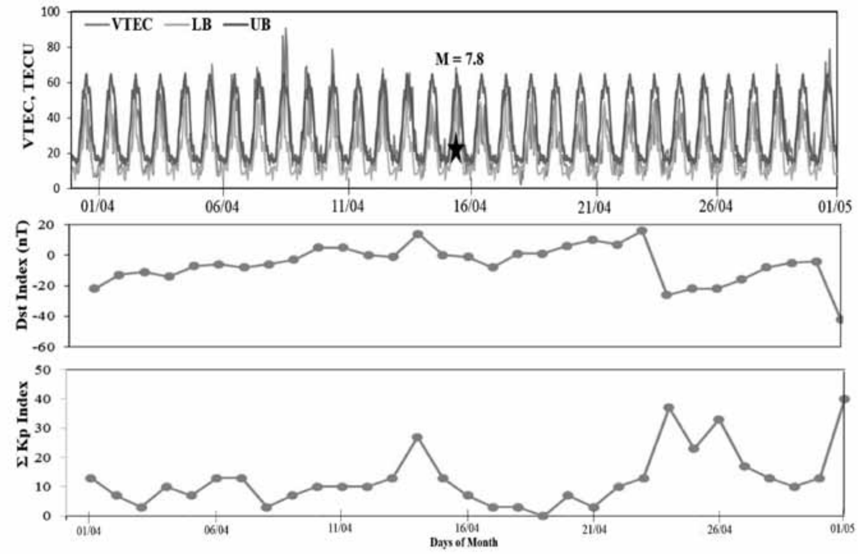


**Figure 2.** (Top panel) The variation of GPS-TEC for the period of 1 April – 1 May 2013 with lower (LB) and upper bound (UB) in blue, red, and green colours respectively. The black star shows the day of earthquake of magnitude M = 7.8. The variation of Dst and Σ Kp Indices are shown in the lower two panels.

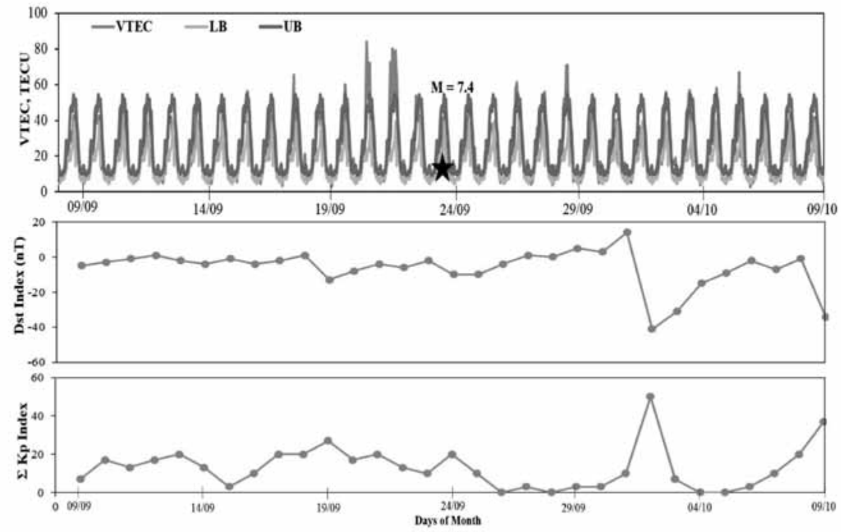


**Figure 3.** Similar as Fig. 2 but for the period of 9 September- 9 October 2013 in which an earthquake of magnitude M = 7.4 occurred.

Agra (solid circle). The details of these earthquakes such as date, time of occurrence in local time (LT), locations (latitudes and longitudes), magnitudes, depths (km), regions, distance from Agra (km) and radius of influence zones (km) are mentioned in table 1.

The radius of influence zone is calculated by the expression $R = 10^{0.43M}$ where $M$ is the magnitude of the earthquake (Dobrovolsky et al., 1979). Although these earthquakes have occurred at large distances (> 1000 km), far away from the observing station Agra, they are well covered by the radius of the influence zone (observing station inside the earthquake preparation zone, see table 1). The details of the earthquake data have been taken from United States Geological Survey (USGS) website www.earthquake.usgs.gov.in. We also examine the effect of geomagnetic storms for which Dst and $\sum$ Kp data have been taken from the website http://omniweb.gsfc.nasa.gov/form/dx1.html. We have used an earthquake selection criterion in which magnitude of earthquake must be greater than 7, occurred at shallow depths (≤ 20 km), and observing station must be inside the influence zone. Here, both the earthquakes satisfy all these criteria except that the earthquake of magnitude (M = 7.8) occurred at depth of 46 km, which is larger than the defined shallow depth. However, we cannot ignore this earthquake because it is of a very high magnitude (M = 7.8).

While examining the TEC variation carefully we find that although anomalies in the form of enhancements occurred on many days between 6 and 14 April, a major anomaly showing largest enhancement occurred on 9 April, 7 days before the main shock. These anomalies cannot be attributed to magnetic storms because there was no storm in this period as may be seen from the bottom two panels. A major anomaly on 01 May can be attributed to the isolated magnetic storm (∑Kp = 40) on 24 April. Such storms have delayed effects in the low latitude ionosphere (Jain and Singh, 1977; Lakshmi et al., 1983).

Fig. 3 (upper panel) shows the variation of GPS-TEC from 15 days before to 15 days after (9 September- 9 October 2013). The earthquake of magnitude M = 7.4 is shown by a solid star and other descriptions of this figure are similar as in Fig. 2. As the figure shows, while significant anomalies in the form of enhancements occurred on different days between 18 and 22 September, 2 to 6 days before the main shock, a major anomaly occurred on 22 September, 2 days before the main shock. It may further be seen from this figure that anomalies occurred on two days more but after the earthquake, one on 29 September and the other on 6 October. Since the whole month was magnetically quiet except an isolate storm (∑Kp = 40) on 2 October, the anomaly on 6 October may be attributed to this magnetic storm. However, the anomaly on 29 September may possibly be due to after effect of the main shock of 24 September.

In order to provide a better description of our results, we plot a graph between anomalous TEC enhancements (in percentage) by histograms and days of the month. The occurrence day of the earthquake is shown by downward arrow. The upper panel of Fig. 4 shows the TEC enhancements corresponding to the earthquake of magnitude (M = 7.8) and highest enhancement was found on 9 April (38% above the upper bound). The lower panel corresponds to the earthquake of magnitude M = 7.4. Here, the maximum value of the TEC enhancement was found on 22 September (56 % above the upper bound). The anomaly period was variant, viz, longer (2-10 days) for the largest earthquake of magnitude M = 7.8 and smaller (2-6 days) for the relatively smaller magnitude earthquake (M = 7.4). It may be concluded here that as the magnitude of the earthquake increases, the number of precursory days also increases.

The history identifying atmospheric precursors to earthquakes dates back to the Good Friday earthquake in Alaska on March 27, 1964. However, it was the large Tashkent earthquake of 1966 that provided the first opportunity for a systematic study of the ionospheric precursors by the Soviet scientists. The first attempt to explain the ionospheric precursors of earthquakes was considered in terms of direct penetration of electric fields generated at shallow depths in the crustal region during the preparatory phase of the earthquakes. Thus, these electric fields in the presence of local magnetic field (B) in the ionosphere cause upward or downward movements of ionisation depending on the relative direction of Electric and magnetic fields (Depueva and Ruzin, 1993). The dynamics of earthquake preparation is now understood to

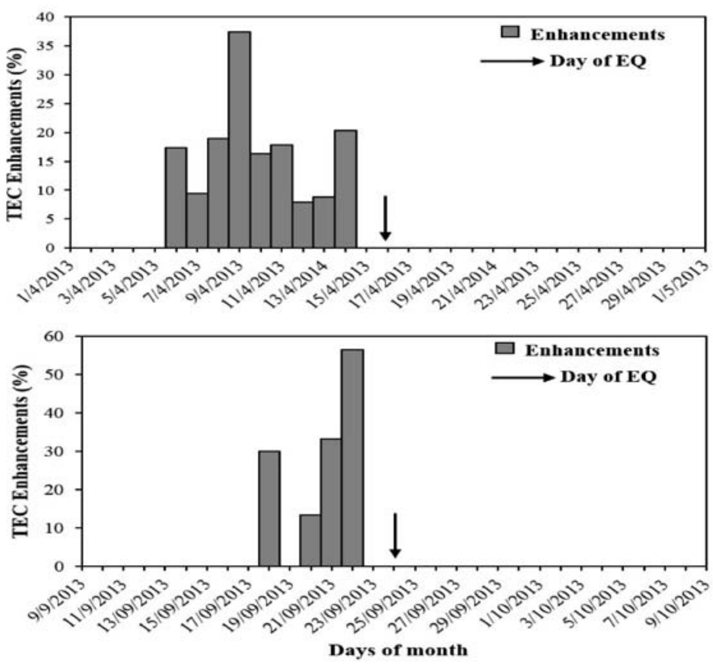


**Figure 4.** (Upper panel) Histograms showing the enhanced values of TEC (in %) in the month of April, 2013 prior to the occurrence of al large magnitude (M = 7.8) earthquake (shown by a downward arrow). (Lower panel) The same as the upper panel but for the month of September, 2013 corresponding to another large magnitude (M = 7.4) earthquake.

be a strictional stick-slip instability resulting in sliding of the crust along the faults. The simplest charge production mechanism is a piego-electric material subjected to high frequency oscillatory micro-fracturing processes.

The first step is the ionization near ground level by the copious amounts of radons emanating from the earthquake region (Pulinets, 2004). The next step is the formation of water cluster ions, both positive and negative. These ions joint together, aided by the Coulomb forces, but without recombining. This is followed by abundant release of gases, mainly carbon-di-oxide as the earthquake progresses. Large air motions of ordered laminar flow are generated, splitting the quasi-neutral ion clusters, resulting in ion densities of about $10^5$ to $10^6$ $cm^{-3}$.

The charge separation process generates an anomalously strong vertical electric field ($\approx$ 1 $KVm^{-1}$) in comparison with the fair weather electric field ($\approx$ 100 $Vm^{-1}$). Pulinets (2009) has also provided the explanation of the existence of a vertical atmospheric electric field and coupling between the ground and ionosphere using the concept of Global Electric Circuit (GEC), which may cause the perturbations in the ionosphere.

A more convincing mechanism for the electric field generation has been suggested by Oyama et al. (2011). They found an anomalous trough (precursor ionization anomaly, PIA) in the variations of atomic oxygen ion ($O^+$) and molecular ion observed by DE-2 satellite over the preparation zone of a major earthquake (M = 7.5). They suggested that it was due to lifting of plasma upward by eastward electric field, which was possibly generated as a result of disturbing the dynamo wind by internal gravity waves in the E-region of the ionosphere. Sun et al. (2011) have also suggested the same mechanism and studied a relation between the heights of profile of neutral temperature (Tn) and critical frequency of F-region ($foF_2$) for two major earthquakes of magnitude M = 6.9 and 7.9 respectively.

## CONCLUSION

Employing a dual frequency GPS receiver, TEC measurements have been in progress at Agra since 01 April 2006. In this paper, we have analyzed the data for the months of April and September 2013 in which two major earthquakes of Magnitude (M > 7) occurred in the neighbouring country Pakistan. We have analyzed the TEC data statistically using quartile based technique. The results show that precursory enhancements occurred in the TEC data 2-10 days before the earthquake of magnitude M = 7.8 with peak enhancement on 9 April 2013, 7 days before the shock. Similarly, we find precursory enhancements 2-6 days prior to the occurrence of the earthquake of magnitude M = 7.4 with peak enhancements on 22 September, 2 days before the occurrence of the earthquake. These ionospheirc precursors are not caused by geomagnetic storms because they occurred much prior to the occurrence of isolated storms, which occurred after the days of the main shocks of the earthquakes. The precursory enhancements are interpreted in terms of E × B drift where E is the electric field of the seismogenic origin and B is the local magnetic field in the ionosphere. The generation and penetration of seismogenic electric fields in the ionosphere are discussed in the light of suggestions made by earlier workers.

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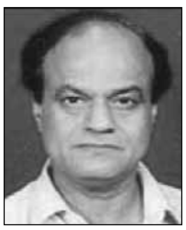

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