The effect of geomagnetic storm on GPS derived Total Electron Content (TEC) at Varanasi, India

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Abstract. In this paper we studied the effect of geomagnetic storm on Global Positioning System (GPS) derived total electron content (TEC) at low latitude Varanasi (Geomagnetic lat 14°, 55°N, geomagnetic long 154°E) during the period of May 2007 to April 2008. During this period 2 storms were found, which were occurred on 20 November 2007 and 9 March 2008. In this study vertical total electron content (VTEC) of single Pseudorandom Noise (PRN) and average of VTEC of same PRN before 10 days of storm, which is called background TEC, were used to see the effect of these storms on the variation of TEC. From this study this is found that during the storm of March 2008 the TEC increases in main phase of storm while in the case of November 2007 storm, TEC decreases during the main phase of storm but increases in the recovery phase (next day) of storm.

1. Introduction
The southward turning of z-component of the inter-planetary magnetic field (IMF Bz) has dramatic effects on the topology of the ionospheric plasma. It is one of the key parameters that characterize the onset of geomagnetic storm. Studies of storm time ionospheric electrodynamics have revealed the occurrence of large electric fields and currents during and after geomagnetically disturbed periods [1]. The disturbance electric fields at the low latitudes have been identified as prompt penetration zonal electric fields and disturbance dynamo electric fields. The prompt penetration fields are produced both during the southward turning of the IMF [2-4] and also during the terminating phase of the substorm when IMF Bz turns northward [5-7]. The disturbance dynamo fields are produced due to the increases corpuscular radiation and consequent Joule heating of the high latitude plasma. This additional heating may launch equator-ward winds, which in turn generate disturbance dynamo fields [8-9]. In addition, Fuller-Rowell et al. [10] have shown that the mid latitude storm time winds, which may be forced in the very early stages of the storm, may drive an F-region dynamo. The resultant electric fields leak immediately to the equator. The mechanism for the generation of the field given by Fuller-Rowell et al. [10] is different from that of Blanc and Richmond [8]. The prompt penetrations fields are transmitted to the low latitudes on the time scales associated with transmission of the disturbance...
dynamo fields are much longer [9]. The delayed effects of solar disturbances on the ionospheric plasma density are manifested by on time scales of several hours to days.

Pandey and Dashora [11] made study of effect of geomagnetic storm of Nov. 2004 and May 2005 on variation of GPS derived TEC at Udaipur, India. Their results showed that during the geomagnetic storm of Nov 2004 the VTEC values decreases where as for the storm of May 2005, it increases during the main phase of storm. Recently, the GPS measurements were used to study the effect of geomagnetic storms on TEC [12-14]. These studies over equatorial ionization anomaly (EIA) regions are very important because the equatorial plasma fountain is highly sensitive to the disturbance electric fields. In this paper we have studied the effect of geomagnetic storms on GPS derived TEC at Varanasi (Geomagnetic lat 14°, 55' N, geomagnetic long 154° E), near the equatorial ionization anomaly (EIA) crest region.

2. Experimental Observation:

The GPS navigation system comprises of three distinct ‘segments’ [15-16]. The global positioning system consists of 24 satellites, called ‘space segment’, distributed in six orbital planes, around the globe at an altitude of 20,200 Km and orbital period of 12 hours. Each satellite transmits signals on two frequencies \( f_1 = 1575.42 \text{ MHz} \) and \( f_2 = 1227.60 \text{ MHz} \) with two different codes P1 (or C/A) and P2 and two different carrier phases, L1 and L2 both being derived from a 10.23 MHz common oscillator. The second is the ‘control segment’, which includes ground stations, used for monitoring satellites and sending signals upward for the engineering control of each satellite and its transmitted codes and waveforms. The ‘third segment’ is the user segment, which includes GPS receiver, who is making use of the transmitted signals by satellites. The ionosphere has a refractive index at radio frequencies, which is different from unity and can affect GPS signals in a number of ways as they pass from satellite to ground receiver [17-18]. One of the significant effects is that the GPS signals traversing the ionosphere undergoes an additional delay proportional to the total electron content (TEC), which is defined as total number of free electrons in column of 1 m\(^2\) cross-sectional area along the ray path from the satellite to receiver. The GPS data provides an efficient way to estimate TEC values with greater spatial and temporal coverage [19-21]. Since the frequencies that are used in the GPS system are sufficiently high, the signals are minimally affected by the ionospheric absorption and Earth’s magnetic field, both in the short-term, as well as in the long-term changes in the ionospheric structure.

In the present study the slant total electron content (STEC) derived from GPS data recorded at our low latitude station Varanasi is converted into vertical total electron content (VTEC) according to [21]

\[
VTEC = STEC - b_R + b_S \left( \frac{S}{E_i} \right)
\]  

(1)

where, \( b_R \) and \( b_S \) are receiver and satellite biases respectively, \( E_i \) is the elevation angle of the satellite in degrees, \( S \) (\( E_i \)) is the obliquity factor with zenith angle \( \chi \) at the ionospheric pierce point (IPP) and VTEC is the vertical TEC at the IPP. The obliquity factor \( S \) (\( E_i \)) (or mapping function) is defined as [22-23].

\[
S \left( E_i \right) = \frac{1}{\cos \left( \frac{\chi}{E_i} \right)} = \left\{ 1 - \left( \frac{R_e \cos \left( E_i \right)}{R_e + h} \right)^2 \right\}^{-1/2}
\]  

(2)

Where \( R_e \) is the mean Earth’s radius in Km, \( h \) is the ionospheric effective height above the Earth’s surface \( \chi \) is the zenith angle and \( E_i \) is the elevation angle of satellite in degree.

In this paper VTECs derived from a GPS receiver (Trimble 5700) installed at Varanasi, are used to study effect of geomagnetic storm on TEC.
3. Effect of Geomagnetic storm on TEC
To study the effect of geomagnetic storm, we have chosen two most intense storms observed during our data analysis period. The first occurred on 20 Nov 2007 and other was on 9 March 2008 with minimum Dst-index -71nT and -72nT respectively. Details about these two storms are given in the following section.

3.1 Geomagnetic storm of 20 Nov 2007
A sudden storm commencement was recorded at 06:00 UT, on 20 Nov, 2007. To see the effect of this storm on GPS derived TEC we have plotted the TEC observed by single PRN (No 17) and average TEC for 10 days before the commencement of storm of the same PRN (denoted as background TEC) in Figure 1. To study in more details the effect of this storm we have also plotted in this figure, the interplanetary magnetic field, IMF Bz (Second panel), Dst-index (third panel), and Kp-index (last panel) for the whole storm period 20-24 Nov 2007. It is clear from the Figure 1 that the main phase of storm started at about 11:00 UT, on 20 Nov, when Dst dropped from 21 to -71 nT at 21:00 UT. After that, storm started to recover slowly up to 22 Nov at about 15:00 UT (Dst = -15 nT) and again started decreasing and reached the value -44 nT and reached its quite time value on 30 Nov. At the time of commencement IMF Bz was 8.3 nT and Kp-index was 2. During the main phase of storm the value of IMF Bz and Kp-index were -11.3 nT and 5.5 respectively. During the recovery phase of storm the value of maximum Kp and minimum IMF Bz were 3.75 and -5.8 nT respectively. It is clearly seen from the Figure 1 that there is a decrease in TEC during main phase of storm and an increase in TEC (~Maximum 17 TECU) was observed in compared to background TEC during recovery phase (21 November) of main storm. This enhancement in TEC is because of southward movement of interplanetary magnetic field, which produces loading of the interplanetary particles in the magnetosphere-ionosphere. The net result is the enhancement of TEC. There was again enhancement in TEC (~Maximum 8 TECU) after the southward turning of interplanetary magnetic field on 22 Nov, which is due to the same reason.

3.2 Geomagnetic storm of 9 March 2008
The commencement of this storm was occurred on 7 March 2008 at 21:00 UT. To study effect of this storm on variation of TEC, we have plotted VTEC of a single PRN (PRN No 29), IMF Bz, Dst –index and Kp-index in Figure 2 in same manner as Figure 1. The main phase of storm started at 02:00 UT on 9 March. During the main phase the Dst was dropped to -72nT (06:00 UT) and then started to recover slowly and reached to its quite time value on 12 March. During the main phase of storm the value of IMF Bz and Kp-index were -12 nT and 5.75 respectively. It is seen from the Figure 2 that an increase in TEC (~Maximum 19 TECU) was observed compared to background TEC in the main phase of the storm.

From both of the above storms we observed that the value of TEC increases in the case of storm of March, 2008 in the main phase (i.e. on the same day of storm) while same happens in the recovery phase (i.e. on next day of storm) in case of storm of Nov, 2007.

4. Discussion
To study the geomagnetic storm activity in more details and to study the short-term effects of geomagnetic storms on variation of TEC, we have chosen two most intense magnetic storms during our period of analysis. It is clear from Figure 1 that during the main phase of geomagnetic storm of Nov 2007 the TEC value decreases and increases in recovery phase (21 November) while Figure 2 shows that during the main phase of geomagnetic storm of March 2008 the TEC value increases. In case of geomagnetic storm of November 2007 the occurrence of the storm sudden commencement
4

Figure 1. Variation of VTEC, IMF Bz, Dst-index and Kp-indices against UT during storm of Nov 20-24, 2007.

(SSC) and southward turning of IMF Bz was during the local evening time and remains southward up to local pre midnight time (i.e. downward $E \times B$ plasma drift) where as for the geomagnetic storm of March 2008 the same happened during the local daytime hours (i.e. upward $E \times B$ plasma drift). The prompt penetration electric field of magnetospheric origin characterized by southward turning of IMF Bz produces a dawn dusk electric field which is eastward during the day side and westward during the night sides in the equatorial ionosphere [2,4]. These prompt penetration fields produce remarkable effects in the equatorial ionosphere as $E \times B$ plasma drift is severely affected. Thus such electric field will make the equatorial F-region plasma drift upward in the daytime and downward in the nighttime. The normal zonal field in the equatorial F-region is eastward during the daytime and westward during the nighttime. Similar result was also explained by Pandey and Dashora [11, 14] and their result shows that during the geomagnetic storm of November 2004, the TEC value at Udaipur, India decreases during the main phase and increases during the recovery phase (next day of storm) whereas for the storm of May 2005 the TEC increases during the main phase (same day of storm) of storm.

5. Conclusion
We have studied the effect of storms on variation of TEC at low latitude station Varanasi, which is near the equatorial anomaly region. The effect of magnetic storm of 20 November 2007 on TEC is to decrease the TEC slightly during the main phase of the storm and to increase (~ 17 TECu) it significantly in recovery phase of the storm. Whereas the effect of storm of 9 March 2008 is to
increase the TEC (19 TECu) in main phase of storm. This effect can be explained on the basis of local time of southward turning of IMF Bz in the particular storm.

Figure 2. Variation of VTEC, IMF Bz, Dst index and Kp indices Against UT during storm of March 9, 2008.

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