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Influence of Major Geomagnetic Storms Occurred in the Year 2011 On *TEC* Over Bangalore Station In India

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Abstract

To improve the positional accuracy of Global Positioning System (GPS) and for wide coverage, a satellite Based Augmentation System (SBAS) is being developed in India popularly known as GAGAN. The positional accuracy of GPS is predominantly affected by the ionospheric time delay, which is a function of Total Electron content (*TEC*). The ionosphere above the Indian subcontinent, which is located near the equatorial region, is highly volatile with large horizontal gradients. Further, major magnetic storms originated from solar bursts can cause strong disturbances in the geo space environment which ultimately affects the performance of Global Navigation Satellite Systems (GNSS). The *TEC* values at a low latitude station Bangalore (77.51^{0}E, 13.03^{0}N) India for three major geomagnetic storm events occurred in the year 2011 were presented in this paper and compared with the *TEC* values obtained from International Reference Ionosphere (IRI) 2007 empirical model. Strong *TEC* enhancements were observed during the storm days. The results presented in this paper are useful in developing the region specific ionospheric prediction models.
Key words: GNSS, GPS, GAGAN, IRI, GEOMAGNETIC STORM, *TEC*

1. Introduction

Satellite based navigation systems such as the Global Positioning System (GPS) are being implemented now days all over the world due to their global coverage and operational ease [1]. In India, Indian Space Research Organization (ISRO) and Air port Authority of India (AAI) are jointly developing a navigation system popularly known as GAGAN (GPS Aided GEO Augmented Navigation) over the Indian Air Space and is expected to become operational by 2014 [2]. The positional accuracy of GPS is predominantly affected by the ionospheric time delay, which is a function of

Total Electron content (*TEC*). Major magnetic storms originated from solar bursts can cause strong disturbances in the geo space environment. These storms are usually associated with increased electron densities in the lower ionosphere and result in simultaneous increase in absorption of radio waves[3-5]. High resolution applications of GPS technology require better space weather support to compensate the ionosphere – induced errors. Hence, there is a clear necessity to thoroughly understand and model the effects of the ionospheric time delay on radio systems during geomagnetic storm periods. The Solar cycle 24 began on 8^{th} January 2008. During this solar cycle, three major geomagnetic storm events (dst < -100 nT) occurred in the year 2011. In this paper, the *TEC* values estimated for a low latitude station, Bangalore (77.51^{0}E, 13.03^{0}N) India during these three major geomagnetic storms are presented and compared with International Reference Ionosphere (IRI) 2007 empirical model[6] results.

2. Effects of Geo Magnetic Storms on the Ionosphere

Areas of instability in the sun release high speed plasma with huge amount of matter and energy, called as the coronal mass ejections (CME's). Eventually these solar CME's reach the earth's magnetosphere, causing great disturbances in the earth's magnetic field which translates into perturbations of the charged particles of the ionosphere [7], denominated as geomagnetic storms, observed by ground magnetic observatories. The CME's take around 20 hours to travel from sun to reach earth. The severity of geomagnetic storms is usually explained with the help of Dst (Disturbance storm time) index as well as Kp index (weighted average of K-indices from a network of geomagnetic observatories i.e. Planetary K indices). The Dst index is a measure of geomagnetic activity used to assess the severity of magnetic storms. It is expressed in nano teslas and is based on the average value of the horizontal component of the earth's magnetic field measured hourly at four near equatorial geo magnetic observatories. These geomagnetic storms can be classified according to different Dst index levels: weak; -50 nT ≤ Dst ≤ -30 nT; moderate; 100 nT ≤ Dst ≤ -50 nT and intense Dst<-100 nT. The kp index, a quasi-logarithmic index, is computed on a three-hour basis and represents the overall level of planetary geomagnetic field disturbance. It is derived from ground based magnetic field measurements and ranges from 0-9, with each scale step being ten times more disturbed than the previous step at the higher end of the scale. A typical quiet day will have Kp values of 0-2. According to the NOAA scale (http://www.swpc.noaa.gov/NOAAscales), storms are classified into strong (G3: kp = 7), severe (G4: kp = 8) and extreme (G5: kp = 9).

The dispersive ionosphere introduces a time delay in the GPS signals. The relative ionospheric delay of the signals is proportional to the total electron content (*TEC*) along the signal path and the frequency of the propagated signals. Generally ionospheric delay is of the order of 0.5 meters to 15 meters, but can reach over 150 meters under extreme solar activities, at mid day, and near the horizon [8]. Solar and geomagnetic storms cause severe variations in the ionosphere that result in extremely large values of *TEC*, which ultimately affect the performance of the navigation systems in use.

In this paper the *TEC* values observed for three major geomagnetic storms in the year 2011 is used to discuss the behavior of ionospheric total electron content (*TEC*) during geomagnetically disturbed periods at a low-latitude station, Bangalore (77.51^0E, 13.03^0N) India. The variation of *TEC* was discussed with reference to the geomagnetic index Dst and sunspot number. The criterion in selection of the major geomagnetic storm was -100nT or lower in the Dst index[9].

3. Estimation of *TEC* from GPS data

The *TEC* of the ionosphere, which is an integral of the total electron content in a column of 1 m^2 from the observation point to the satellite, is given by

$$\int_{path} N_e \, dl \ (electrons/m^2) \quad \text{----- (1)}$$

The Ionospheric time delay is a function of the total electron content (*TEC*) along the signal path and the frequency of the propagated signals. A first order expression for the ionospheric time delay ' τ' is

$$\tau = \left\{\frac{40.3 \times TEC}{c \times f^2}\right\} \quad \text{----- (2)}$$

where, c is the velocity of light in m/sec, f is the frequency in Hz .

Since the ionosphere is a dispersive medium it allows correction of the first order ionospheric time delay errors. Ionospheric time delay can be estimated using a single frequency approach, but it can remove only 60% of the error. A dual frequency GPS receiver can minimize Ionospheric time delay through a linear combination of L_1 (f_1=1575.42 MHz) and L_2 (f_2=1227.60 MHz) observables. If range measurements ($P_1$and P_2) are available on two separate frequencies (f_1 and f_2), then the *TEC* can be estimated using the following formula.

$$TEC = \frac{1}{40.3} \times \left\{\frac{f_1^2 f_2^2}{(f_1^2 - f_2^2)}\right\} \times (P_2 - P_1) \quad \text{----- (3)}$$

Where, P_1 and P_2 are pseudo range observables on L_1 and L_2 signals respectively.

Since the *TEC* between the satellite and receiver depends on the satellite elevation angle, this measurement is called as slant *TEC* (*STEC*). As slant *TEC* is a quantity which is dependent on the ray path geometry through the ionosphere, it is desirable to calculate an equivalent vertical value of *TEC* (*VTEC*) which is independent of the elevation of the ray path. The slant *TEC* can be converted into *VTEC* using the following formula.

$$VTEC = STEC \times \sqrt{\left[1 - \left\{\frac{R_e \cos\theta}{(R_e + h_i)}\right\}^2\right]} \quad \text{----- (4)}$$

Where, R_e is radius of earth (6378 Km), θ is the elevation angle and h_i is the height of the ionosphere shell (350 Km).

TEC can also be easily converted to ionospheric range delay for the L_1 and L_2 frequencies. One TECU is equal to 0.16 meters range delay on L_1 frequency and 0.27 meters on L_2 frequency.

The *TEC* values are obtained from observation data files of SOPAC data in Receiver Independent Exchange (RINEX) data format [10]. As per the Dst index three major geomagnetic storms are recorded in the year 2011

4. Results and Discussion

Three major geomagnetic storm events (defined by minimum $Dst \leq -100$ nT) occurred in the year 2011 were selected to study the ionospheric *TEC* variations over a low latitude station Bangalore (77.51^{0}E, 13.03^{0}N) India. The *TEC* values are obtained from observation data files of SOPAC data in Receiver Independent Exchange (RINEX) data format. Further, the *TEC* values obtained for each storm day are compared with the *TEC* values obtained from IRI-07 empirical model results.

August 06, 2011: A strong geomagnetic storm was commenced on 6th August 2011 with a peak Dst value of -131 nT at 04.00 IST with Kp index of 8. The sun spot number (SSN) on that day is 61. From the figure, it was observed that the maximum *TEC* is 79.16 TECU at 22.00 IST. The enhancement in *TEC* was recorded in retarding phase of the storm. The *TEC* maximum from IRI-07 results is 46.1 TECU at 17.00 IST.

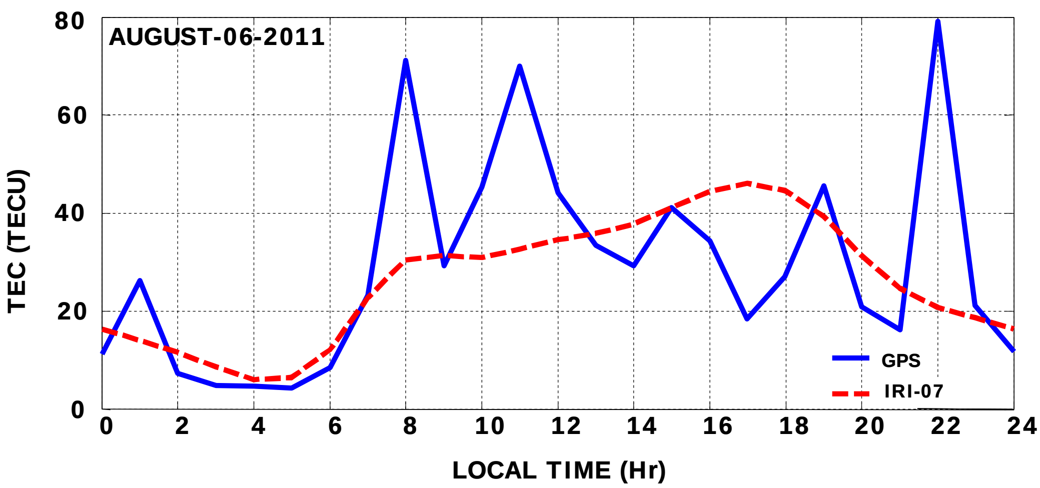

Fig.1. Storm time variations of *TEC* on 06th August, 2011
(*TEC* from GPS____, *TEC* from IRI07 ----)

September 26, 2011: Another strong geomagnetic storm was commenced on 26th September 2011 with a DST index peak value of -103nT at 24.00 IST. The Kp index is 8.0 and the SSN is 73. The TEC value reached to 72.9 TECU at 08:00 IST and then decreased. Further, *TEC* value reached to its maximum value of 77.01 TECU at 23:00 IST in the positive phase of the storm. The *TEC* maximum from IRI-07 results is 50 TECU at 16.00 IST.

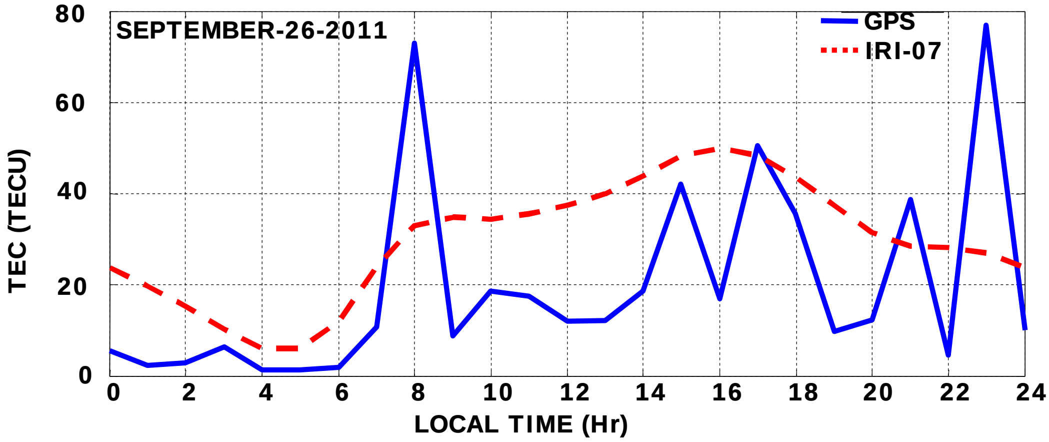

Fig.2. Storm time variations of *TEC* on 26th September, 2011
(*TEC* from GPS____, *TEC* from IRI07 ----)

October 25, 2011: Another major geomagnetic storm was commenced on 25th October 2011 with Dst peak of -123 nT at 06.00 IST. On this storm day the Kp index is 7 and SSN is 77. The maximum observed *TEC* was 66.61 TECU at 08.00 IST in the recovery phase of the storm. The *TEC* maximum from IRI-07 results is 57.2 TECU at 16.00 IST.

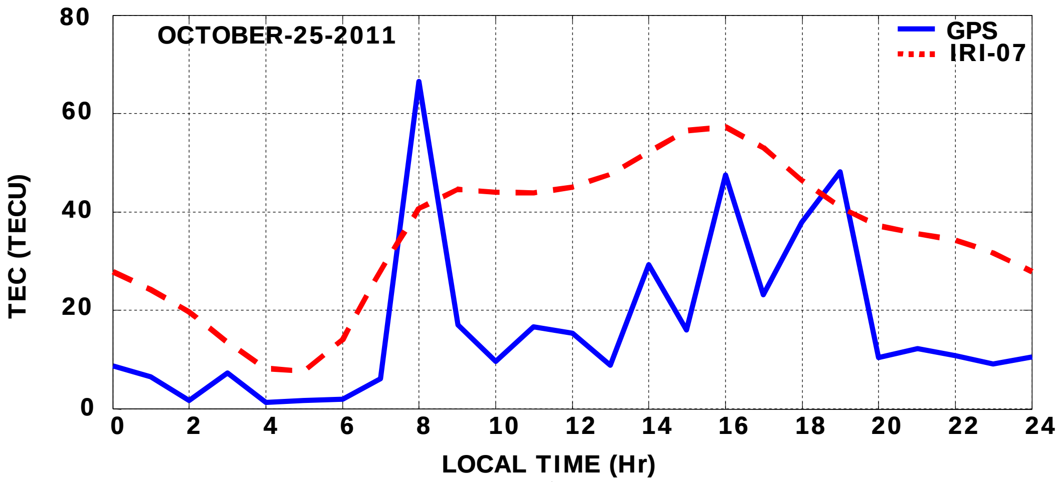

Fig.3. Storm time variations of *TEC* on 25th October, 2011
(*TEC* from GPS____, *TEC* from IRI07 ----)

5. Conclusions

The ionospheric *TEC* variations over a low latitude station Bangalore, India during three different major geomagnetic storm events occurred in the year 2011 are presented in this paper. The *TEC* fluctuations are different for different geomagnetic storms. It was observed that the *TEC* fluctuations are dependent on SSN value, peak Dst value and its occurrence time and Kp value of the storm day. Further, it is clearly evident from the results that the IRI estimations on any storm day are almost consistent and it could not catch any variability in the *TEC* values due to major storms. During the storm days the maximum *TEC* obtained from IRI-07 model is around 50 TECU and the occurrence time is around 16.00 IST. The results presented in this chapter are useful to develop a region specific ionospheric prediction model for GAGAN.

Acknowledgements

The data used in this analysis is obtained from SOPAC data archives of the IGS network.

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