Study of Ionospheric Variability during the Storm of January, 2005 using GPS and DEMETER Satellite Measurements

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Abstract
The dual frequency Global Positioning System (GPS) receiver provides an opportunity to determine Total Electron Content (TEC) over the crest of equatorial ionization anomaly region Bhopal by taking advantage of the dispersive nature of the ionospheric medium. The TEC values observed for the geomagnetic storm of the January 2005 is used in this paper to discuss the behaviour of ionospheric total electron content (TEC) during geomagnetically disturbed period. Variation of TEC is studied in correlation with the geomagnetic index Dst and southward component of interplanetary magnetic field Bz. The TEC variability is found to vary between with the maximum negative excursion of Dst index during the geomagnetic storms days. Positive phase is observed. Maximum TEC variability is observed during the recovery phase of the storms. Electron and ion density measurements from the DEMETER satellite are compared with the TEC measurements. The study of storm time TEC behaviour is very important due to recent increase in satellite-based navigation applications.
Keywords: Ionosphere, geomagnetic storms, GPS, DEMETER, TEC

1. Introduction

During a geomagnetic storm, the solar wind energy deposited into the magnetospheric polar cap region will eventually be dissipated into the ionosphere and thermosphere. Meanwhile, various physical and energy transport processes within the ionosphere become extreme and more complicated (Mendillo, 1971; Fuller-Rowell et al., 1996; Buonsanto and Fuller-Rowell, 1997). Interactions of the various near Earth space plasma regions with the interplanetary magnetic field and solar wind has been known for decades. Various aspects of this process continue to attract intensive research even today. In particular, one of the major indications of the magnetosphere-ionosphere coupling is the significant variation of electron density during a storm (Buonsanto, 1999; Danilov, 2001). A number of instruments have been used to investigate the electron density variation during such events. Several investigators have shown that the observations of total electron content (TEC) by GPS can contribute to understanding of the characteristics of ionospheric variations during geomagnetic storms (Jakowski, 1996, Lu et al., 1998). Drastic changes in low latitude and equatorial ionospheric TEC can be produced by intense disturbance electric fields (Fejer and Scherliess, 1997). There are several studies on low latitudinal ionosphere responses during magnetic storms events (Pavlov et al. 2004; Lynn et al., 2004 and Lima et al., 2004). A number of studies by Indian workers have been conducted on low latitudinal ionospheric responses during magnetic storm periods that have significantly advanced our knowledge on this subject Dabas and Jain, 1985; Lakshmi et al., 1997). The study in this paper is related to the TEC changes during eight magnetic storms at the crest of equatorial ionization anomaly (EIA) region. The ionization in this region is known to be high compared to relatively moderate levels of electron content in mid latitude ionosphere. The purpose of this work is to examine the TEC and electron density variations in EIA crest region during geomagnetically disturbed period.

2. Data and Method of Analysis

TEC derived from GPS signals is a powerful method of studying the ionospheric response to geomagnetic storms, Total Electron Content (TEC) data obtained from dual frequency GPS receiver is used to study the ionospheric variability during the geomagnetic storm of January, 2005. For the present study GPS data has been obtained from GPS receiver GSV 4004A stationed at Bhopal (23.2º N, 77.4º E, Dip lat. 18.4 º N) a station at the equatorial ionization anomaly crest. The TEC data are corrected for receiver and satellite (instrumental) biases. The variability of the ionosphere can be estimated by different ways (Forbes et al., 2000; Rishbeth and Mendillo, 2001) but the changes in the ionosphere are more evident in TEC deviation from the monthly average. The disturbance degree was estimated by the deviation from the monthly average:
$\delta TEC = (TEC_{obs} - TEC_{avg}) \times 100 / TEC_{avg}$. %
where TECobs is the observed value of the total electron content and TECavg is the average value.
Slant TEC measurement at one minute interval from the GPS receiver are converted into VTEC from elevation angle greater than 35° using the formula given in Rama Rao et al. (2006). The purpose of our work is to examine the behavioral change in Z component of interplanetary magnetic field (IMF), Bz, and TEC data for several sudden commencements that occurred in the low latitude region. In addition to the TEC measurements we also

used electron and ion density measurements from the DEMETER satellite. The DEMETER satellite was launched in June, 2004 and carries a Langmuir Probe and Plasma Analyzer for in-situ electron and ion density measurements respectively.

According to Gonzalez et al. (1994) "the geomagnetic storm is an interval of time when a sufficiently intense and long lasting interplanetary convection electric field leads, through a substantial energization in the magnetosphere-ionosphere system, to an intensified ring current sufficiently strong to exceed some threshold of the quantifying storm time Dst index". This index is a quantative measure of the ring current forming around the earth during the geomagnetic storm. It is commonly agreed that the magnetic storm can develop when Dst index exceeds the threshold –50 nT (which corresponds to the interplanetary magnetic field Bz component –5 nT) and stays over this threshold at least 2 hours (Gonzalez et al., 1994). Minimum values of Dst, which are indicators of geomagnetic storm, can be used to classify the magnetic storms: weak (-30nT≥Dst≥-50nT), moderate (-50nT≥ Dst≥-100nT), intense (-100nT≥Dst≥-200nT) and very intense (Dst≤-200nT).

3. Results

Ionospheric variability during the magnetic storms of January 17-22, 2005 is studied in this paper. Two intense storms were observed in the month of January 2005. Hourly TEC deviations from January 15 to 24 are plotted alongwith Bz component and Dst index in Fig. 1. The intense storm of January 17 started with SSC at 07:48 UT (15:18 LT). with Bz turning southward and maximum value in the negative direction ~ –13.54 nT observed at 06:00 hrs UT (11:30 LT) on January 18. Two hours later at 08:00 hrs UT (13:30 LT) maximum negative excursion of Dst ~ –121 nT is noted and the storm lasted until January 19 which was followed by the recovery phase on January 20. δTEC values started increasing in the positive direction from 07:00 UT i.e. one hour before the maximum negative excursion of value of Dst and reached its maximum variation of 63.78% at 10:00 UT (15:30 LT) on 18 January. During the recovery phase of the storm TEC showed positive deviations (~ 40% to 47.85%) on January 19 and 20. One day later on another storm started with SSC at 17:11 UT (22:41 LT) on January 21 and the maximum value of Bz component in the negative direction is –7.70 nT at 18:00 UT (23:30 LT) on January 21. The Dst value reached a maximum negative value of –105 nT at 06:00 UT (11:30 LT) on January 22. The percentage variation in the TEC values from its average values reached maximum at 45.69% at 05:00 UT on January 22.

4. Discussion and Conclusions

The ionospheric variability during the storm of January 2005 using both GPS TEC measurements and DEMETER measurements is discussed in this paper. Increase in the total electron content from the average values that is the background VTEC values is being observed for the storm, which represents positive storm effect. The response of the ionosphere to these storms can be summarized as follows.

An additional source of ionization arises from equatorial latitudes: the enhancement of the zonal electric field during perturbed periods increases the upward drift and the subsequent drainage from equatorial region followed by the ambipolar diffusion down the magnetic field lines toward low latitudes. This effect could be also responsible for the delay and the maintenance of positive effects at the crests (Mansilla, 1999). Delayed positive ionospheric storms have been attributed to changes in neutral gas composition (Chandra and Stubbe, 1971; Rishbeth, 1991). The storm-induced circulation transports air rich in atomic oxygen from higher latitudes toward lower latitudes. The enhanced oxygen density (as seen from DEMETER data) will affect the ionization production, thus producing the positive effects.

The study of storm time behavior of TEC at EIA region is very important for Satellite Based Navigation System (SBAS) using Wide Area Differential GPS (WADGPS) technique over Indian Airspace, which is popularly known as GAGAN (GPS And Geo Augumented Navigation). Change of ionospheric range delay, which is directly proportional to change of total electron content during geomagnetic storms, is a potential limitation in precise positioning using radio waves from Global Positioning System (GPS). The positive deviations in TEC during intense and severe storms can lead to range corrections at L1 frequency in crest of EIA region can vary from 4m to 18m for navigational applications. This feature is of interest for Satellite-Based Augmentation System (SBAS) developers. Without knowledge of this feature's existence the GAGAN broadcast error bounds might not be wide enough to protect against such features.

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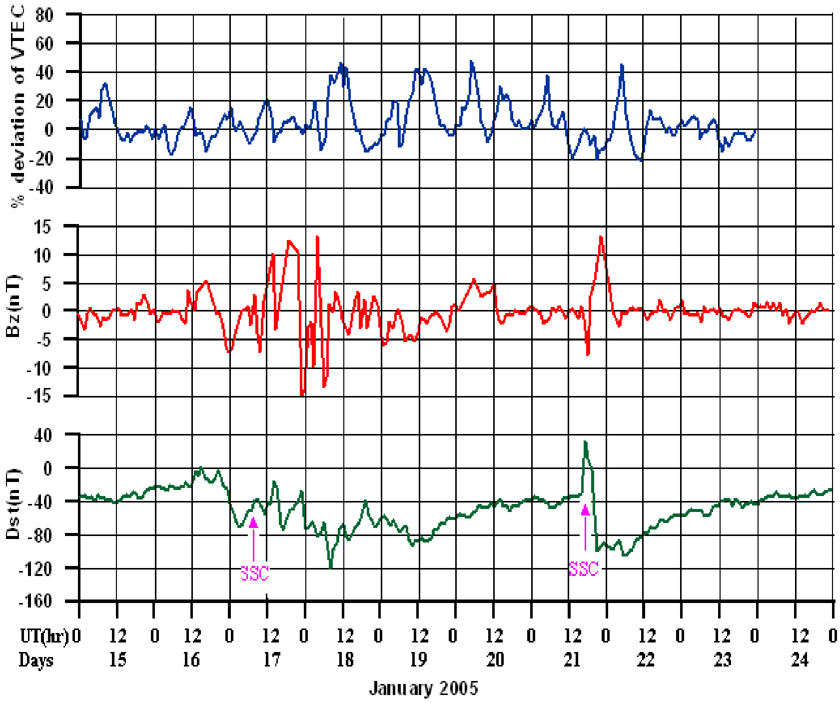

Figure 1. Hourly variation of TEC (in percentage) in top panel, IMF Bz component (middle panel) and Dst geomagnetic index (bottom panel) during the storm period from 15-24 January 2005.

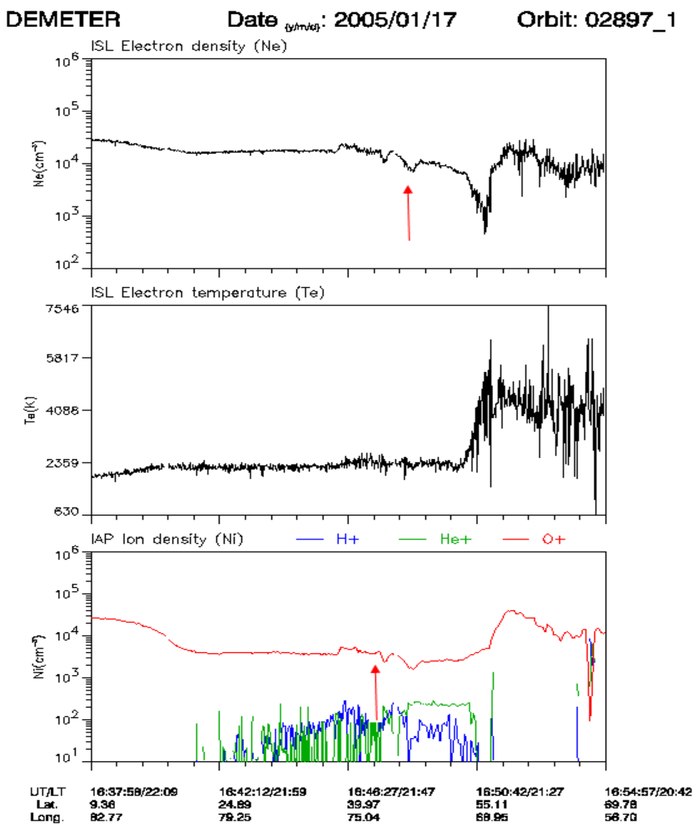

Figure 2. Data recorded by DEMETER along the orbit 2897_1. The top panel shows the electron density, the middle panel shows the density of O+ ion. At the bottom, UT, LT, geographic latitude and longitude values are indicated.