Space weather studies at the crest of the equatorial ionization anomaly using GPS receiver

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ABSTRACT

Space weather studies using the GSV 4004A GPS Ionospheric Scintillation and TEC Monitor of M/S GSV Silicon Valley, USA are underway at the crest of the equatorial ionization anomaly (EIA), at Udaipur (MLAT 15.3° N), India. These studies are probably, the first of its kind in the Indian zone, at the crest of the EIA. Although the current solar cycle is going through its minimum phase, yet on a number of occasions, the disturbed sun conditions characterized by solar flares of X and M class have occurred. These flares were some times associated with the geomagnetic storms. The effects of geomagnetic storms on the TEC have been studied. The effect of the disturbed sun is not as pronounced as it is at the high and polar latitudes, yet the variations in TEC are very well associated with the storm. Results for two storms events are being presented in this paper. The first geomagnetic storm occurred during November 2004 and the second one during May 2005. These storms were quite severe as inferred from the IMF Bz and Dst index. Drastic variations in the TEC have been observed during these storms. The variations in the TEC have been interpreted in terms of the penetration electric field arising due to storm-induced currents. During the May storm, the prompt penetration of electric field has been suggested, whereas, during the November storm disturbance dynamo fields have been invoked to explain the variations in the TEC. Surprisingly, the storm time variation in TEC were devoid of associated ionospheric scintillations.

INTRODUCTION

Disturbances on the sun produce two categories of electric fields, viz., prompt penetration fields and disturbance dynamo fields. Both the types arise due to the magnetosphere-ionosphere interaction and often observed in the equatorial latitude [1-4]. These disturbance electric fields may lead to redistribution of ionospheric plasma. In the recent years, a number of workers have used GPS based systems to assess the impact of geomagnetic storm on the TEC [5-10]. Drastic changes in low latitude ionospheric vertical TEC can be produced by intense disturbance electric fields [11,12]. The effects of storm related fields are more important in the equatorial ionization anomaly (EIA) zone, because the equatorial plasma fountain is highly sensitive to such disturbance electric fields. Udaipur (in India) is situated (MLAT 15.3^{o}), right at the crest of the EIA, and therefore is a very appropriate location for the space weather studies.
The GSV 4004A Ionospheric Scintillation and TEC monitor was installed at Udaipur during August 2004. There have been two instances of significant solar and geomagnetic activities between September 2004 and May 2005. Results pertaining to these activity periods are presented in this paper.

STORM 1: NOVEMBER 7 to 11, 2004

The period November 7 to 11, 2004 was a very disturbed period. Fig. 1 shows the variation of the IMF Bz, Dst and Kp indices for the period November 7 to 11. The top panel in fig. 1 gives the variation of Bz. The variations in Bz were bizarre during Nov. 7. The IMF Bz turned southward for a very short duration around 1400 UT and recovered thereafter to become northward by about 1500 UT. It remained northward, attaining a peak value of about +40 nT just before 1800 UT. It fluctuated violently between north and south directions, from about 1800 UT. Although it remained southward after 1800 UT, except for a very short duration, its value was very low. The interplanetary shock that reduced the IMF Bz suddenly around 2200 UT, is clearly visible. It remained southward with an average value of about –40 nT up to about 0400 UT on Nov 8. Thereafter it recovered gradually. By 1200 UT on Nov 8 its value was around 0 nT. On Nov 9 it became southward for a short while from about 1800UT to 2000UT onsetting a substorm. On Nov 10 at 0100 UT, the Bz component again became southward for sometime. It again became northward for a short duration before going southward. It remained southward until 1800 UT on Nov 10. Variation of Dst index is shown panel 2. The SSC occurred just after 1800 UT on Nov. 7, and the Dst index dropped to a value of –373 nT at 0700 UT on November 8. The Dst index recovered thereafter, to a value of –126 nT by 2400 UT on November 8. A number of sub storms followed on November 9 and 10. By the end of November 11, the recovery phase was almost over. The second largest substorm occurred on Nov. 10, where the Dst index was –289 nT at 1100 UT. The corresponding variations in Kp index are also shown in the same figure in panel 3. The Kp index increased progressively from 0800 UT on November 07 from a value of 1 and attained a value as high as 9 between 0300UT and 0600UT on November 08. The Kp index reduced to 2 by 2000 UT on November 08. It again increased thereafter to a high of 9 around 2100 UT on November 9 during a substorm. On November 10, occurrence of yet another substorm resulted in a high Kp value (>=8) from 0300 UT to 1200 UT. Both Kp and Dst indices were low thereafter.

The vertical TEC calculated for all visible PRNs for the period November 07 to November 11 is plotted against the Universal Time in the fourth panel from the top in fig. 1. For the VTEC calculations, a thin ionospheric shell at an altitude of 350 km has been assumed. It is quite obvious from the figure that on November 08 and Nov. 10, when Dst index was the lowest, the VTEC values were also much lower than those on the adjoining days. The break in data for about 4 hours around 1000UT on Nov 10 is due to power supply failure. Large variability of VTEC, discernible for any day, is due to the fact that different PRNs cover different range of latitude and longitude wherein the TEC varies drastically. As a matter of fact, the variation in MLAT for different satellite passes could be from about 20^o N to 0^o. Similarly the longitude variation could be from about 65^o E to 75^o E. Notwithstanding VTEC variation on any given day, the plot clearly reveals very low VTEC values on Nov 8 and Nov 10. On these very days, the Dst index was also the lowest.

Variation of VTEC with magnetic latitude (MLAT) for the period Nov 7 to 11 is given in the bottom panel of fig. 1. Again the VTEC values obtained for all visible PRNs on a given date are plotted. Indeed, the time information is lost from such a plot. The plot of Nov 7 reveals an anomaly peak around 12^o N. It disappears completely on Nov 8 and Nov 10, whereas, on Nov 9 and 11 the anomaly peak is again visible around the same MLAT. Variations in VTEC in this panel are complementary to those in the panel above it, as in the former the time information is lost, whereas in the later the MLAT information is lost.

STORM 2: MAY 13 to 17, 2005

Fig.2 gives the variation of IMF Bz, Dst and Kp index and VTEC for the period May 13 to 17, 2005. Details of fig. 2 are the same as that of fig. 1. This period is also characterized by a severe magnetic storm. The IMF Bz fluctuated violently from about 0200 UT on Nov 15 before turning southward around 0600 UT. The fluctuations in IMF Bz prior to the shock are not associated with storm but are due to some disturbances in the magnetosphere. The shock resulted in a southward IMF Bz with the lowest value of -40 nT for a short duration around 0600 UT. The IMF Bz remained southward until about 0900 UT. It is worth noting that the SSC and southward turning of IMF Bz occurred during the local daytime hours on this date. It became northward around 0900 UT and remained so until a little after 1800 UT. The SSC occurred around 0200 UT on May 15 and Dst value was the lowest (-256nT) at 0900 UT. Thereafter, the recovery phase started. The most striking feature of this storm is the short duration of the main phase, with no associated substorms. Thus it represents a clean event. The Kp index suddenly reached a value of 5 during the SSC and maximized at a value of 9, coinciding with the period of the lowest Dst value.

The VTEC calculated for all visible PRNs for the period May 13 to 17 is plotted against the Universal Time in the fourth panel from top in fig. 2. The VTEC values reveal a day-to-day variability. The peak VTEC values on May 14, 17 and 18 are much lower than on other the days. The peak VTEC values on May 13 and 16 are comparable but higher than on May 14, 17 and 18. Compared to all other days, the VTEC values on May 15 are the highest, with a peak value of about 100 TECU. This is the day when the geomagnetic storm occurred.

Variation of VTEC with magnetic latitude for the period May 13 to 17, 2005 is given in the bottom panel of fig. 2. The anomaly peak is visible on May 13, 16 and 17. There is a complete absence of anomaly peak on May 14 and the VTEC values are the lowest compared to other days. A very well pronounced though disturbed anomaly peak pattern is discernible for May 15 in fig. 2. The VTEC values are very high for the majority of the PRNs. The poleward shift in the anomaly peak on May 15 is also apparent.

DISCUSSION

While during the geomagnetic storm of November 2004, the VTEC values decreased, the values increased during the May 2005 storm. These apparently conflicting observations can be explained if the direction of the penetration electric field in relation to the ambient electric field is properly assigned. As has been noted earlier, in case of the November storm, the occurrence of the SSC and the southward turning of IMF Bz was during the local night hours. Whereas for the May storm the same happened during the local daytime hours. The prompt penetration electric field of magnetospheric origin, characterized by southward turning of IMF Bz produces a dawn-dusk electric filed which is eastward during the daysides and westward in the night sides in the equatorial ionosphere [13,14]. These prompt penetration fields produce remarkable effects in the equatorial ionosphere as the **E**x**B** plasma drift is severely affected. Thus such electric fields 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 is westward during the nighttime. The penetration electric fields associated with the southward turning of the IMF Bz are therefore so

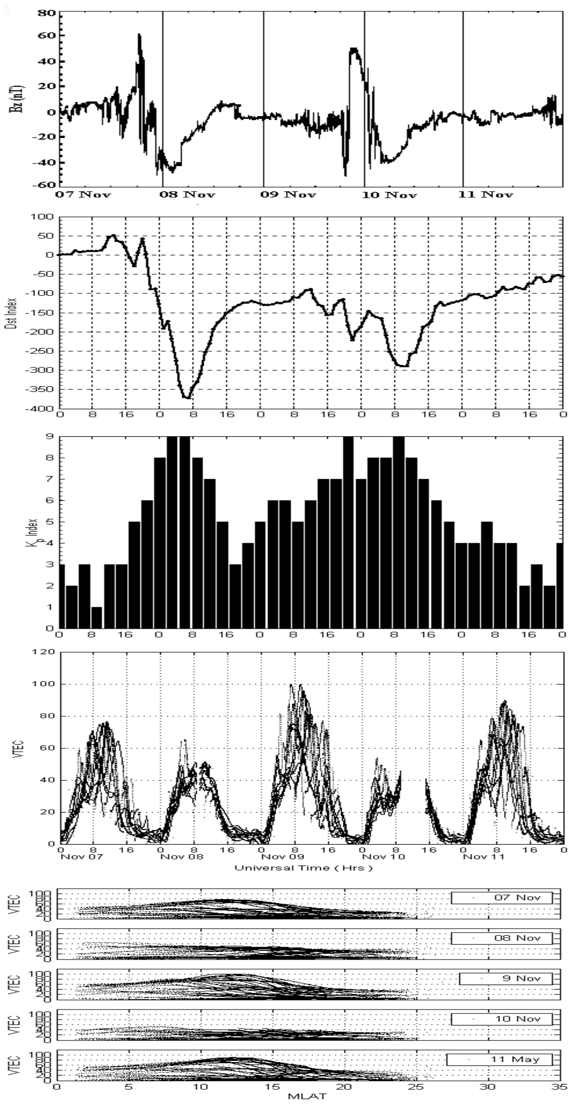

Fig. 1. Variation of IMF Bz, Dst and Kp indices during Nov 7 to 11, 2004. The IMF Bz, Dst and Kp are given in panel 1,2 and 3 from the top. Variation in VTEC against UT and MLAT for different days is given in panel 4 and 5 from the top.

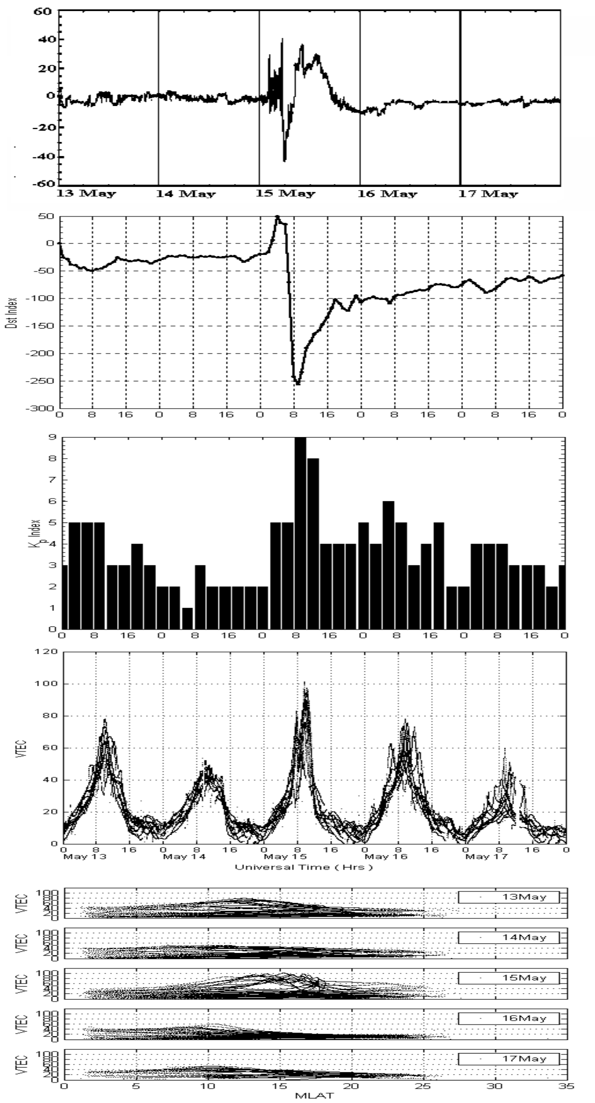

Fig. 2. Variation of IMF Bz, Dst and Kp indices during May 13 to 17, 2005. The IMF Bz, Dst and Kp are given in panel 1, 2 and 3 from the top. Variation in VTEC against UT and MLAT for different days is given in panel 4 and 5 from the top.

directed as to enhance the effective electric fields and associated drifts at the equator.

On May 15, the shock was observed a little before 0600 UT. The corresponding local time is 1130 hrs. Thus the southward turning of the Bz occurred during the daytime. The penetration fields are so directed as to enhance the vertical drift of the plasma in the low and equatorial latitudes. The enhanced drifts lead to increased TEC a couple of hours after the shock and the enhancement persists for about a few hours [11]. The variations in VTEC on May 15 are consistent with this explanation wherein abnormally high VTEC values are observed. The duration of enhancement is however short, as can be inferred from the width of the VTEC peak on May 15 in panel 4 of fig.2. It must be emphasized here that the southward turning of IMF Bz was for about 3 hours, followed by northward turning that persisted over 12 hours on May 15. Hence the drifts were enhanced only for about 3 hours, followed by effective reduction in the vertical drifts thereafter.

Such a cause and effect relationship between southward turning of IMF Bz and the TEC could not be established for the November observations. This is probably due to the fact that the excursions of IMF Bz to south and north were frequent on Nov 7. Thus the observation of reduced TEC on Nov 8 cannot be attributed to prompt penetration electric field. It is possible that the reduced TEC are due to the disturbance dynamo fields, which should be opposite in direction to the ambient fields in the F-region. The TEC observations on November 10, although have a break of about four hours, do reveal reduced TEC levels compared to the other days. The IMF Bz variations on Nov 9 and 10 are a near replica of the variations on Nov 7 and 8. Hence the arguments that would be applicable for TEC variations on Nov 8, would also be valid for Nov 10. Zhao et al [12] have recently reported the responses of the equatorial anomaly to the super storms of October-November 2003. In agreement with Fejer et al [13], they also emphasize that prompt penetration electric fields reach the equatorial region only when Bz is stable southward. The variations of IMF Bz on Nov 7, so also its variations on Nov 9 and 10, probably forbid the prompt penetrations fields to reach the equator. Hence disturbance dynamo fields, which are oppositely directed to the ambient electric fields, are possibly responsible for reduced TEC during November storm.

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