Study of plasma depletions and UHF scintillations at the crest of the equatorial ionization anomaly using GPS receiver

Nirvikar Dashora [(1)], **R. Pandey** [(2)] **and B. M. Vyas** [(3)]

[(1)] *Department of Physics, M. L. S. University, Udaipur 313 001, India, nir_unc@yahoo.co.in*
[(2)] *"As (1) above, but Email": -- pandey_r@yahoo.com*
[(3)] *"As (1) above, but Email": -- bmvyas@yahoo.com*

ABSTRACT

A GSV 4004A GPS receiver has been operational at the crest of the equatorial anomaly at Udaipur, India for some time now. The receiver provides the total electron content and the amplitude scintillation index, S_4. This paper presents the first results on the nighttime TEC depletions associated with the equatorial spread F in the Indian zone. The TEC depletions have been found to be very well correlated with the increased S_4 index. A new feature of low latitude TEC is also reported. It is about the observation of isolated and localized TEC enhancements in the nighttime low latitude ionosphere. The TEC enhancements are not correlated with the S_4 index. The TEC enhancements have also been observed along with the TEC depletions. The TEC enhancements have been interpreted as the manifestation of the plasma density enhancements reported by Le et al (2003). The mechanism of Le et al (2003) has been invoked to explain the TEC enhancements.

INTRODUCTION

Equatorial spread F (ESF) has been a topic of extensive studies for over a very long time. With the advent of the GPS based navigation, there is a renewed interest in its studies. It is because the ESF not only degrades the received signal, the plasma density variations associated with the ESF, that manifest as variations in the total electron content (TEC), introduce large range errors.

Recent observations [1-3], using the GPS satellites in the equatorial and low latitude zone, have revealed the occurrence of the UHF scintillations and the fluctuations in the total electron content (TEC). Since the TEC values are known to be highest around $\pm 15^{o}$ magnetic latitude, the Appleton anomaly or the equatorial ionization anomaly region, the problem is more acute at these latitudes. Udaipur is situated (Geog Lat. 24.6^{o}N, Geog.Long. 73.7^{o} E, 15.6^{o} N MLAT) right at the crest of the Appleton anomaly, and therefore is the most suited place for the measurement of TEC and scintillations.

UHF Scintillations and TEC have been measured using the GSV 4004A GPS Ionospheric Scintillation and TEC Monitor (GISTM) of M/s GSV Silicon Valley, USA. The system (GISTM) provides true amplitude, single frequency carrier phase measurements and TEC measurements from up to 11 GPS satellites in view, simultaneously and provides outputs in 22 receiver channels. The real-time values of the amplitude scintillation index, $S_{4,}$ and the phase scintillation index, σ_φ, computed over periods of 1, 3, 10, 30, and 60 seconds, averaged over one minute are obtained. Additionally, the 4 pairs of TEC and TEC rate values computed every 15 seconds are also provided. Thus the equipment is ideally suited for the studies of the S_4 index, TEC and TEC rate etc., simultaneously. Of the various parameters, results pertaining to the S_4 and TEC only would be presented and discussed here.

OBSERVATIONS

The results presented here are for the months of October 2004 and February 2005 during quiet conditions. Results for different satellite passes, designated by a pseudorandom number (PRN), are shown in the following diagrams. Each of the figures has four panels. The horizontal axis of each panel corresponds to the universal time (UT) from which the local time can be obtained by adding 05 hours 30 minutes. The top panel of each figure gives the variation of the satellite elevation angle. The second panel gives the geomagnetic latitude and geographic longitude of the ionospheric pierce point (IPP), computed from the elevation and azimuth angles of the satellite at each instant of its pass, as seen from Udaipur. For IPP computations, a thin ionospheric shell at an altitude of 350 km has been assumed. In this panel, the solid line curve is for the MLAT, and the broken one is for the longitude of the IPP and their scales are given as the left and the right ordinate, respectively. The third panel gives the variation of the VTEC with the universal time. The S_4 index derived from the L1 signal is plotted in the fourth panel. Observations for elevation angles lower than 20^o shall not be considered as these may suffer from multipath reflections. A horizontal line in the top panel is drawn as a demarcation. Similarly, a demarcation line at S_4 value of 0.2 has been drawn to emphasize that the significant levels of scintillations are to be considered only when this limit is exceeded.

Depletions in TEC

Here we follow the definition of Valladares et al [3] for the identification of TEC depletion with the equatorial plasma bubble. Accordingly, TEC depletion is a sudden reduction of TEC followed by a recovery to a level near the TEC value preceding the depletion. Results for satellite PRN 9 on 5 October 2004 are given in fig.1. It can be seen from the second panel that for the entire pass of the satellite, the MLAT of the IPP varies from about 27^o N to 4^o N. But, its longitude is nearly constant, around 70^o E. The variation of the VTEC reveals a sudden reduction around 1630 UT. The reduction in TEC is a manifestation of a plasma depletion, wherein the TEC decreased by about 10 TEC units. The S_4 index is less than 0.2 prior to the appearance of the depletion. It shoots to a value of about 0.6, coinciding with the occurrence of the depletion. For the observed depletion, the MLAT of the IPP varies from about 12^o N to 10^o N. Thus the depletion is far away from the magnetic equator. Its longitude is, however, nearly constant, around 70^o E. The TEC values recover after the dip. A sudden drop in TEC to zero TEC, at the eastern end of the depletion is a case of the cycle slip. It implies a sudden loss of the phase lock of the signal, either due to increased scintillation activity (S_4 is about 0.8), or, due to non-ionospheric causes.

Results obtained for PRN 15 on 7 February 2005 are presented in fig. 2. Two consecutively located depletions in VTEC, wherein the TEC varied by about 10 TECU are seen between 1500 and 1600 UT. The S_4 index suddenly shoots up with the appearance of these depletions and is about 0.6. Yet another depletion of 10 TECU is seen around 1700 UT. For this depletion also, the S_4 is quite high, around 0.5. Between the two sets of depletions, the variation in TEC is smooth with no scintillations.

A series of depletions in VTEC were observed on October 28, 2004 for PRN 5 and 30. Results for these PRNs are given in figures 3 and 4, respectively. In fig. 3, the TEC variation shows a series of well-defined depletions. The fluctuations in VTEC are seen between two well-separated regions. The first region is occurring between 1545 and 1700 UT. This region is embedded with a number of well-separated depletions. The second region is between 1715 and 1800 UT. Although fluctuations in TEC are seen beyond 1800 UT, these are ignored as the satellite elevation is below 20^o. The S_4 index in each of these regions is seen to be very well correlated with the occurrence of depletions in TEC. The most striking feature of the scintillation index is the complete absence of scintillations between the two sets of depletions. This is also the region where the TEC variation is smooth.

Results for PRN 30 on 28 October 2004 are shown in Fig. 4. These results are very informative as the trajectories of PRN 30 and PRN 5 are nearly the same. PRN 30 appears about an hour after the PRN 5, and the maximum elevation for PRN 30 is about 10^o lower than for PRN 5. As is the case in fig. 3, a series of depletions appear in two well-separated regions. The first set is between 1530 UT and 1700 UT, and the second one between 1745 and 1815 UT. The VTEC variation in the region that separates the two regions of TEC depletions is smooth, although its time extent in fig. 4 is much larger than in fig. 3. These two regions are characterized by strong scintillations, co-occurring with the depletions in VTEC.

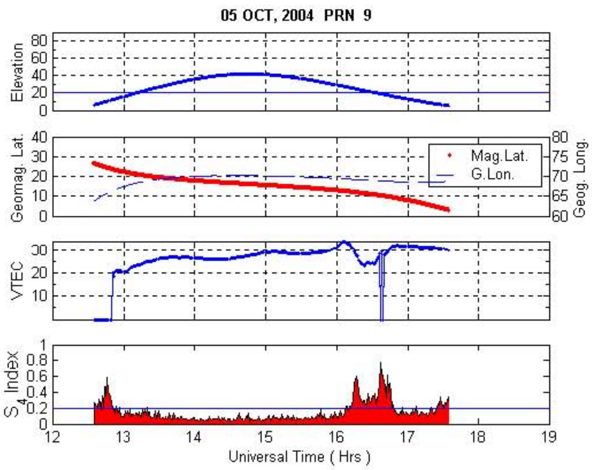
Enhancements in TEC

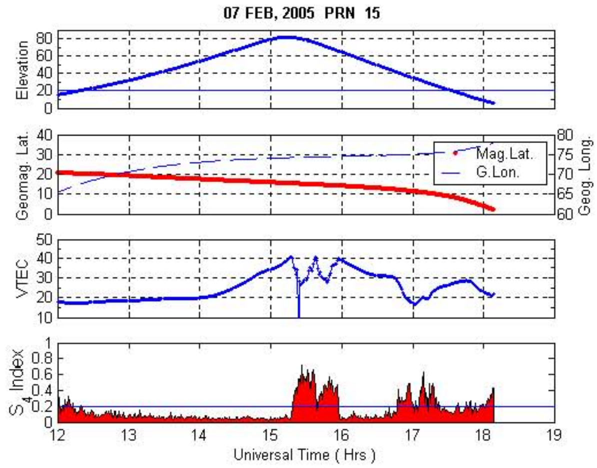
A very interesting case of the VTEC variations has been obtained on October 28, 2004 for PRN 6, as shown in figure 5. A sudden enhancement of about 5 TECU is seen around 2000 UT. The temporal width of the enhancement is about half an hour. The local time is past 0130 hrs. The MLAT of the IPP at this hour is about 12^{o} N. Thus the enhancement in TEC is located far away from the equator. The S_4 index around 2000 UT is well below 0.2. Thus unlike the depletions in VTEC, which had corresponding increase in the scintillation index, the enhancement is devoid of such an increase. This is probably the first reporting of an isolated and localized enhancement in TEC. The very fact that a TEC enhancement does not have associated scintillation suggests a different mechanism for its generation.

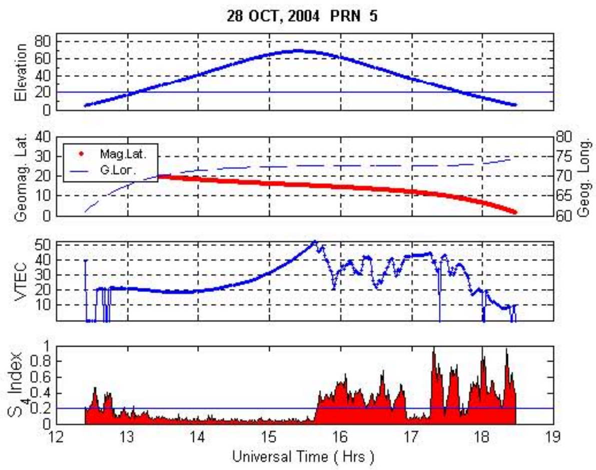
Co-located Enhancements and Depletions in TEC

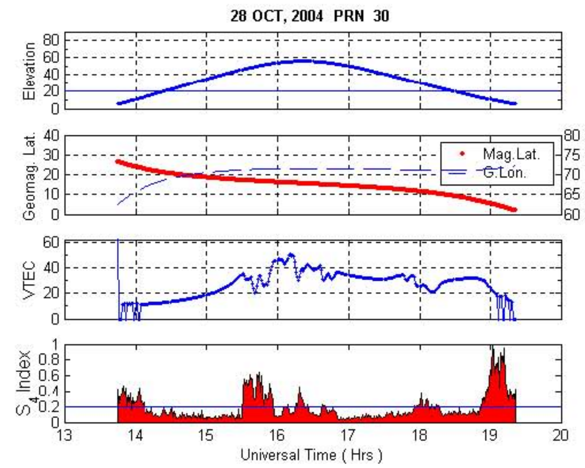
Co-occurring enhancement and depletions in TEC were observed on October 5, 2004 as shown in figure 6 for PRN 5. The figure shows consecutive depletions and enhancements around 1800 UT. The depletions as well as enhancements are of about 5 TECU. Again the depletions in the TEC seem to be correlated with the enhancement in the scintillation index whereas the enhancements in TEC are devoid of such a correlation. For these features, the longitude of the IPP was nearly same (73^{o} E) and the MLAT varied from 15^{o} N to 13^{o} N. A nearly constant longitude of the IPP implies that these features are field aligned.

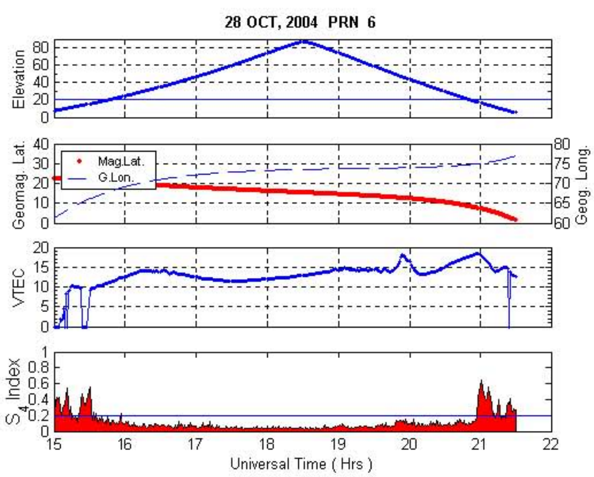
As the longitude of the various satellites is nearly constant, but MLAT varies suggests that the depletions are mainly field aligned. Since the depletions are seen well past the local sunset, these are likely to be of equatorial origin. The most striking finding of the present study is the observation of TEC enhancements in localized regions. We have











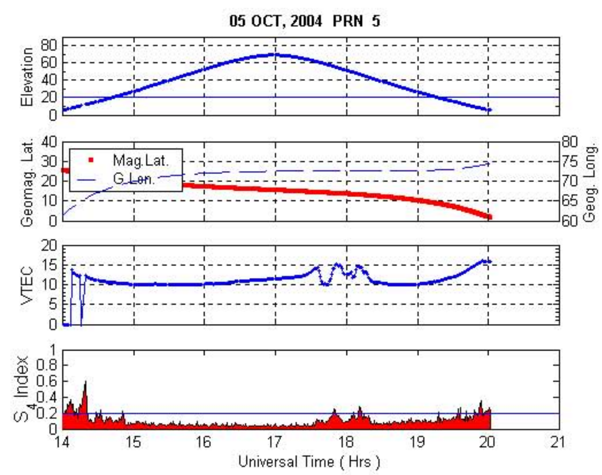


Fig. 1 (Top left): Variation of TEC and S_4 index on 5 October 2004 for PRN 9.

Fig. 2 (Top right): Variation of VTEC and S_4 index on 7 February 2005 for PRN 15

Fig. 3 (Left middle): Variation of VTEC and S_4 index on 28 October 2004 for PRN 5

Fig. 4 (Right middle): Variation of VTEC and S_4 index on 28 October 2004 for PRN 30

Fig. 5 (Left bottom): Variation of VTEC and S_4 index on 28 October 2004 for PRN 6

Fig. 6 (Right bottom): Variation of VTEC and S_4 index on 5 October 2004 for PRN 5 reported the first observation of an isolated TEC enhancement at the anomaly zone latitude (fig. 5). Most surprisingly, the enhancements were completely devoid of the associated increase in the S_4 index. This leads to the belief that the enhancements in TEC are a local phenomenon, not connected with the equatorial spread F. Observations of TEC enhancements in association with the depletions in TEC (fig. 6) have also been reported for the first time here. Weak scintillations were found to be associated more with the depletions in TEC than with the enhancements.

Le et al [4] have also reported enhancements in the ion density in the topside equatorial F region at 600 km and 850 km. These density enhancements have been found to be associated with or without depletions in the ion density. The cases of isolated enhancements of plasma density were observed only onboard DMSP satellite. They have proposed the mapping of the polarization electric fields associated with the depletions at the equator to be responsible for the generation of localized regions of plasma enhancements. According to this mechanism, the plasma density depletions are generated at the equator due to the Rayleigh-Taylor plasma instability. The polarization electric fields associated with these depletions lift them up at the equator. While the depletions have a limited latitudinal extent, the polarization field map to higher latitudes along the field lines. When the depletions rise to the topside F region at the equator, the flux tube associated with these depletions may be connecting the F peak in the anomaly zone latitudes. The mapped field in the anomaly zone thus moves the high-density plasma upward so that density increments occur just above the flux tube. They further point out that the density increments are additionally reinforced if the background ionosphere move downward. The same mechanism probably explains the observation of TEC enhancements.

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