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Study of night time TEC depletion over Indian region

S S Rao*, Shweta Sharma & R Pandey
Department of Physics, MLS University, Udaipur 313 001, India

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Observations of night time total electron content depletions recorded over the Indian stations, Udaipur and Bengaluru, are presented. Udaipur is located near the crest of the equatorial ionization anomaly and Bengaluru is the near equatorial station. New features like location of plasma bubble over equator, north-west drift of the plasma bubble and time duration of sustainability of plasma bubble that produced depletion over low latitudes are being reported.

Keywords: Low latitude, TEC depletion, Plasma bubble

1 Introduction

Equatorial spread F (ESF) has been a topic of great interest and has been studied using ground based as well as satellite based experiments in the past. ESF is a night-time phenomenon that may occur in latitude belt 30-40° wide, centered on the magnetic equator. It is now known to be produced due to the plasma instabilities and neutral wind driven processes in the Earth's equatorial ionosphere[1-8]. The scale sizes of plasma density irregularities so produced may range from more than 1000 km down to less than 10 cm. The altitude range covered by spread-F could extend from the valley between the E and F region up to altitude, at times, exceeding 1000 km. Satellite based experiments have revealed that, the ESF manifests itself as large scale depletions of plasma density[9]. With the advent of Global Positioning System (GPS) based navigation a renewed interest in the study of the night-time plasma density irregularities has arisen. This is because the GPS based range measurements are very sensitive to the changes in the total electron content (TEC) of the ionosphere through which the satellite signals have to travel before reception at the ground stations. The most important aspect of studies of GPS-TEC depletions is the introduction of an error in the estimated range due to the group delay of the signal traversing the ionosphere. The range errors so caused are detrimental to navigation and ground positioning because of the fact that even a change of 1 TECU (1 x 10^{16} electrons per cubic meter) may introduce a range error of about 0.16 m. Valladares *et al*.[10] in the South American region and Dashora and Pandey[11] in the Indian region have presented observations of night-time TEC depletions which are believed to be associated with the equatorial spread F. Their study shows that the TEC depletions are very well correlated with the increased S4 index. Galav *et al.*[12] have also presented observations of TEC depletions over Indian low latitude zone. The results of their study show that the amplitude of TEC depletions due to the ESF may vary with time and locations of the observations.

In the past, many researchers[11-16] have reviewed the study of plasma depletions from GPS observations confined mostly to the equatorial and low latitude regions. Present study aims to give the location of plasma depletion over equator, its drift and approximate life time.

2 Data Set

For the study of night-time TEC depletions, the TEC data have been investigated for the low latitude station, UDPR, Udaipur (Geog. Lat. 24.60° N, Geog. Long. 73.70° E, Geomag. Lat. 16.16° N) located near the northern crest of EIA and for the near equatorial station, IISC, Bengaluru (Geog. Lat. 13.02° N, Geog. Long. 77.57° E, Geomag. Lat. 4.36° N). TEC data for station Udaipur were obtained from a dual-frequency state-of-the-art GPS receiver GSV 4004 A. Whereas the Bengaluru is an International GNSS Service (IGS) station and the data thereof have been downloaded from the website (ftp:://garner.ucsd.edu). Data of the IGS stations are in RINEX (Receiver Independent Exchange) format and indigenously developed codes

*Corresponding author (E-mail: ssraophy116@gmail.com)

developed by Sharma *et al.*[17] have been utilized to retrieve the TEC. The GPS derived TEC is an integrated parameter giving the total number of electrons over the entire path from the satellite to the receiver along the line of sight and is termed slant TEC, STEC, whose unit is TECU.

3 Results and Discussion

Depletion in TEC is identified as sudden reduction of TEC, for a period of a few tens of minutes over its normal course and its recovery to almost same initial level. Results concerning the equatorial and low latitude TEC depletion observations along with the trajectory of satellites over each station are presented in Figs 1-6. Each satellite is designated by a pseudo random noise, PRN. Each figure showing TEC depletion gives the variation of slant TEC (STEC) with time for a particular PRN. The abscissa of each figure shows time in UT and ordinate shows the value of STEC in TECU. For the figures showing trajectory of the satellite over each station, the coordinates of the sub-satellite point at each instant of time are plotted as geographic longitude and geographic latitude. Hence, the curves represent the variation of ionospheric pierce points. Time in UT hours is marked over each trajectory. A common color code is followed to identify the satellite trajectory and TEC variations for a particular station.

3.1 Observations of 31 March 2012

To show the TEC variation on 31 March 2012, the trajectory of satellites whose PRN is 8 (in magenta) and 17 (in blue) are shown in Fig. 1. It can also be seen from Fig. 1 that the trajectory of PRN 8 as seen from UDPR covers wide range of longitudes (68° E to 74° E) from about 1300 UT to 1600 UT, thereafter, it passes along nearly same longitude (75° E) tracing the wide range of latitudes (26° N to 20° N). The trajectory of the same satellite with PRN 8 as seen from IISC covers 74° E to 78° E longitude band from 1400 UT to 1600 UT and thereafter, it moves along nearly same longitude (79° E) crossing a wide range of latitudes (15° N to 8° N).

Compared to PRN 8, PRN 17 (in blue) as seen from UDPR crosses wide range of latitudes (20° N to 26° N) from 1500 UT to 1800 UT and thereafter, it moves along the nearly same latitude (24° N). The trajectory of PRN 17 as seen from IISC covers 10° N to 15° N latitude band and 1800 UT onwards, it passes along nearly same latitude (14° N). Thus, the overall pass of satellites, PRN 8 and PRN 17, is opposite to each other; PRN 8 is moving from west to south while PRN 17 is moving from south-west to east.

Variation of TEC on 31 March 2012 observed by satellite whose PRN is 8 is shown in Fig. 2 Two depletions, each having a depth of 5 TECU over UDPR, are seen (upper panel, Fig. 2). The first depletion in TEC is observed at around 1610 UT and second one around 1720 UT. The same PRN 8 when seen over IISC also reveals depletions in TEC at around 1500 UT, 1545 UT and 1700 UT. Depth of the first two depletions was more than 15 TECU while the third one that occurred at around 1700 UT, had a depth of about 8 TECU. During the period when the depletions are observed, the trajectory of PRN 8 over UDPR covers a latitude band of 2°, from about 25° N to 23° N whereas, it covers 15° N to 12° N over IISC.

Since, depletions observed from the two stations are widely separated in space and time, similarity of

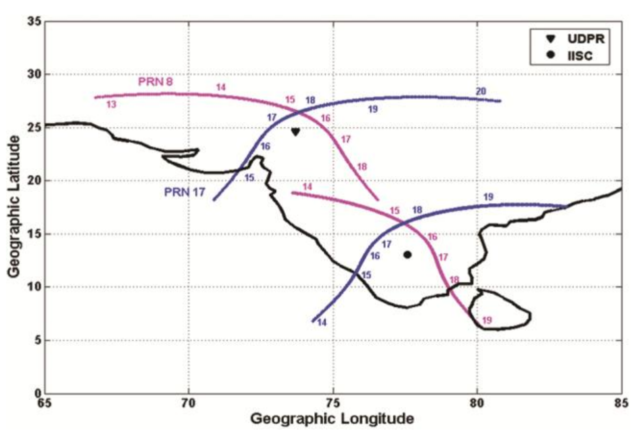

Fig. 1 — Trajectories of satellites designated by PRN 8 (in magenta) and PRN 17 (in blue) as seen from Udaipur and Bengaluru on 31 March 2012 are shown.

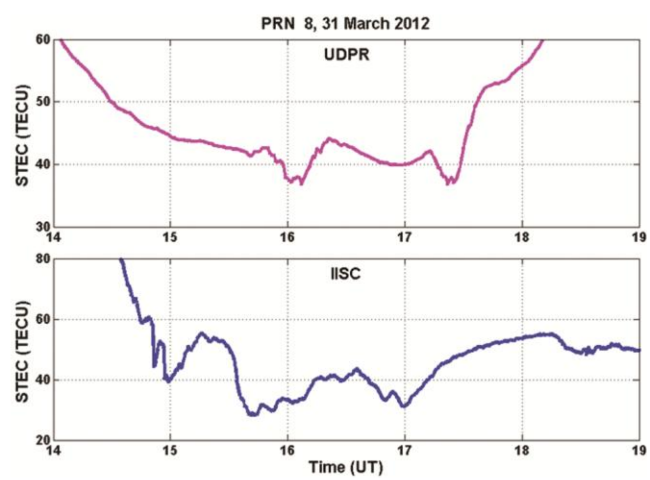

Fig. 2 — Variation of TEC for PRN 8 on 31 March 2012 at Udaipur (top panel) and IISC (bottom panel) is shown.

the shape of the depletions observed from the two locations may be incidental. However, the most important aspect of these observations is the location where these are seen. While the magnetic latitude of Udaipur in the year 2012 was about 16.16° N, the depletion observed around 1600 UT from Udaipur occurred at around 17° N, magnetic latitude. It is very rare to observe depletions north of Udaipur. Observance of depletion north of Udaipur suggests that the plasma bubble this produced this depletion and must have risen to a very high height over the equator, so that the connecting field line had a foot in the ionospheric region which was much above the geographic location of Udaipur.

The TEC depletions detected by PRN 17 are shown in Fig. 3. The depletion over UDPR can be seen around 1515 UT for PRN 17. The loss of lock due to the cycle slip can also be seen just before and after the time when depletion occurred. PRN 17 has also recorded TEC depletions over IISC at around 1500 UT and 1630 UT respectively. Since the shape of the depletion seen around 1500 UT over IISC is nearly similar to that observed after 1500 UT over Udaipur suggests that one may be observing the same depletion, first from IISC and later from UDPR. Further, the longitudinal separation between the two stations may also be used to infer the north-west drift of the bubble that produced this depletion.

3.2 Observations of 10 March 2013

The trajectory of satellites designated by PRN 7 (magenta) and PRN 8 (blue) is shown in Fig. 4. It can be seen from Fig. 4 that the both PRN 7 and 8 traces almost same path as seen from the UDPR. They are coming from west and moving towards the south-east covering a wide range of longitudes. During the time period in which depletions in TEC were observed over UDPR, both the PRNs covered nearly same latitude band (of 2°), from about 24° N to 22° N.

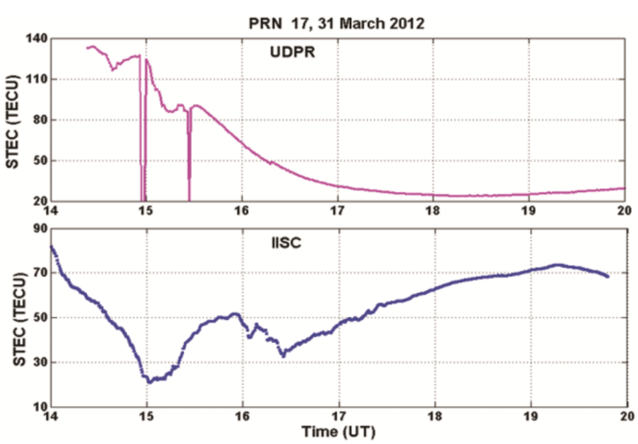

Fig. 3 — Variation of TEC for PRN 17 on 31 March 2012 at Udaipur (top panel) and IISC (bottom panel) is presented.

For this date TEC depletions observed from Udaipur by PRN 7 (in magenta) and 8 (in blue) are shown in Fig. 5 & 6, respectively. For PRN 7, the two depletions are seen around 1630 UT and 1650 UT, the ones observed by PRN 8 are seen around 1730 UT and 1750 UT respectively. During the time period in which depletions in TEC were observed over UDPR, both the PRNs covered nearly same latitude band (of 2°), from about 24° N to 22° N.

While the time difference in observation of depletions for the two PRNs is about 1, it is interesting to note that the latitudinal location of both the depletions seen by each PRN is nearly same. This

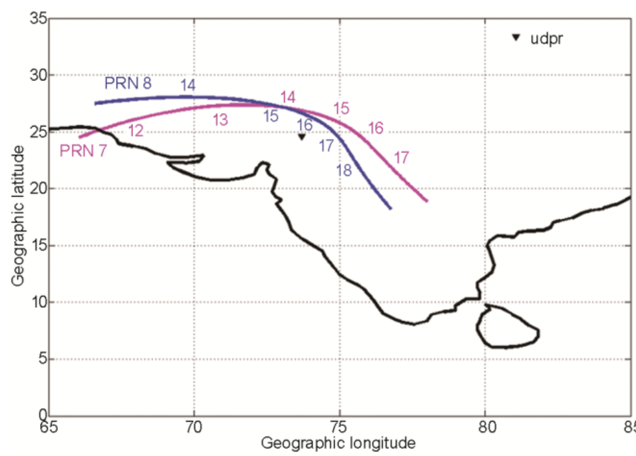

Fig. 4 — Trajectories of satellites designated by PRN 7 (in magenta) and PRN 8 (in blue) as seen from Udaipur on 10 March 2013 are shown.

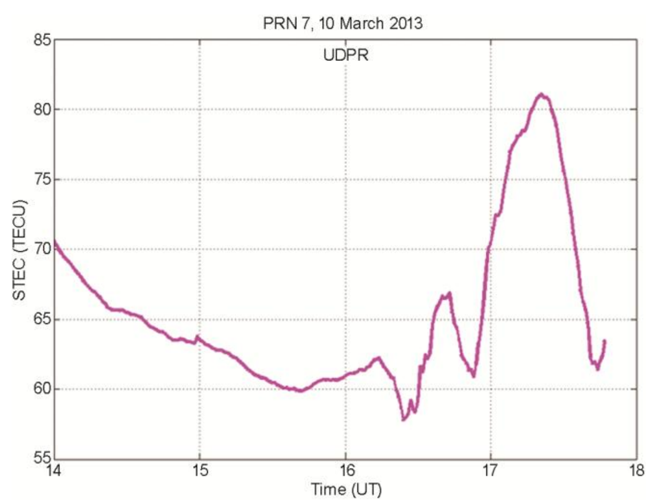

Fig. 5 — Variation of TEC for PRN 7 on 10 March 2013 as seen from Udaipur is shown.

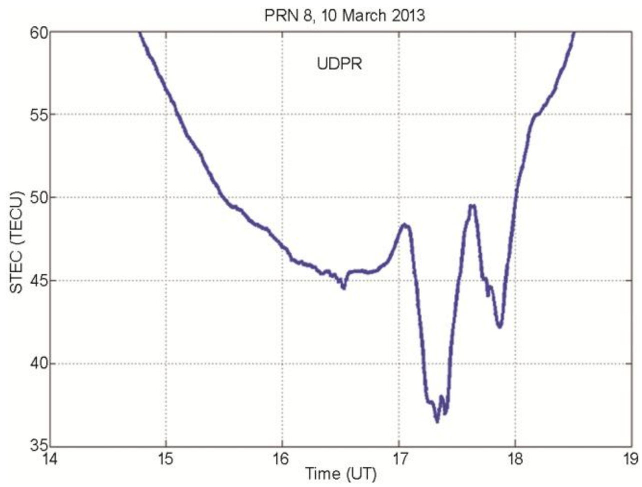

Fig. 6 — Variation of TEC for PRN 8 on 10 March 2013 as seen from Udaipur is shown.

implies that the plasma bubble that produced these depletions may have sustained for at least an hour, wherein it drifted from west to east, in same latitude. Such a case is being reported for the first time. If more such observations were available, it would have been possible to deduce the drift speed of the plasma bubbles that gave rise to TEC depletions.

4 Conclusions

(i) Observance of TEC depletion north of Udaipur (beyond 15° N, Geomagnetic Latitude) on 31 March 2012 suggests that the plasma bubble that produced this depletion must have risen to a very high height over the equator so that the connecting field line had a foot in the ionospheric region which was much above the geographic location of Udaipur,

(ii) Observation of PRN 17 on 31 March 2012 suggests that one may be observing the same depletion, first from IISC and later from Udaipur. Further, the longitudinal separation between the two stations may also be used to infer the north-west drift of the bubble that produced this depletion And

(iii) Observation of TEC variation on 10 March 2013 implies that the plasma bubble that produced these depletions may have sustained for at least an hour, wherein it drifted from west to east, in same latitude. Such a case is being reported for the first time.

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