IONOSPHERIC CHARACTERISTICS OF LOW LATITUDE ANOMALY ZONE OVER INDIAN REGION BY GROUND BASED GPS, RADIO OCCULTATION AND SPIM MODEL PREDICTIONS

Sampad Kumar Panda, Shirish S. Gedam

Indian Institute of Technology Bombay
Centre of Studies in Resources Engineering
Mumbai-400076, India

Girija Rajaram (Retd.)

Indian Institute of Geomagnetism Bombay
C/o CSRE, IIT Bombay
Mumbai-400076, India

ABSTRACT

The present paper deals with investigation of ionospheric electron density over low latitude Indian region from seven ground based dual frequency global positioning system (GPS) stations across Indian region. The electron density in terms of total electron content (TEC) is estimated from the parameters of GPS observation at different locations and compared with international GNSS service global ionosphere map (GIM) as well as standard international reference ionosphere (IRI) and standard plasmasphere-ionosphere model (SPIM) predictions for both geomagnetic quiet and disturbed periods.

Index Terms— Ionosphere over India, interplanetary parameters, global positioning system, total electron content, radio occultation

1. INTRODUCTION

The equatorial ionosphere over the Indian region covers a large span of latitude and longitude with the magnetic equator passing through the southern most tip of the country and the equatorial ionization anomaly (EIA) crest approximately lying in the center straddling the line joining Kolkata and Ahmedabad [1]. The EIA is characterized by a trough in the ionization density at magnetic equator and a crest at around 15° on each side.The electron density, ion composition and their spatiotemporal variation in the equatorial and polar regions is known to be higher than mid-latitude region [2]. The ionosphere over low latitudes is characterised by equatorial electrodynamics associated with plasma fountain, equatorial ionization anomaly (EIA) and equatorial electrojet etc. The ground and space-based global positioning systems (GPS) are utilized nowadays in measuring electron density of ionosphere in terms of TEC from the amplitude and phase of received signals due to continuous operation of GPS satellites around the globe [3]. The ionospheric TEC is important for precise positioning, navigation and measurement of electric wave field [4]. The present paper illustrates the regular variations and disturbances in the ionospheric electrons above the Indian region from ground based GPS observations as well as space based GPS radio occultations [5]. The measured TEC is correlated with solar activity and geomagnetic indices and compared with international GNSS services global ionosphere map. Finally, TEC predictions from standard international reference ionosphere (IRI) model [6] and international standard plasmasphere-ionosphere model (SPIM) [7] are also discussed in this study.

2. DATA AND METHODOLOGY

The observation data from seven permanent GPS stations across Indian region for the duration November 2011-October 2012 are processed to estimate TEC at different latitudes [8], the geographic and geomagnetic co-ordinates of the stations are given in table 1. The distribution of GPS stations is shown in fig. 1. To avoid the effect of geomagnetic disturbances due to earth and solar events, the days with geomagnetic Ap indices below 20 nanotesla ($Ap < 20nT$) are considered.For the dual frequency (L1, L2) observation, TEC in the slant direction can be calculated from the pseudorange (P) and phase observations (Φ) as;

$$TEC = \frac{1}{40.3}\left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\right)(P2 - P1) \tag{1}$$

$$TEC = \frac{1}{40.3}\left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\right)(\Phi1 - \Phi2) \tag{2}$$

Here, $\Phi1$ and $\Phi2$ are phases and $P1$ and $P2$ are pseudoranges of carriers $L1$ and $L2$ respectively. To reduce the effect of pseudorange noise on TEC data, GPS pseudoranges are smoothed by carrier phase leveling. The slant TEC (sTEC) is converted into vertical values (vTEC) using a single layer ionosphere model (SLIM) associated with an ionospheric piercing point (IPP) height of 350km [9]. To avoid the multipath, change in satellite geometry and other atmospheric effects, an elevation angle of 30° is chosen for all the stations.

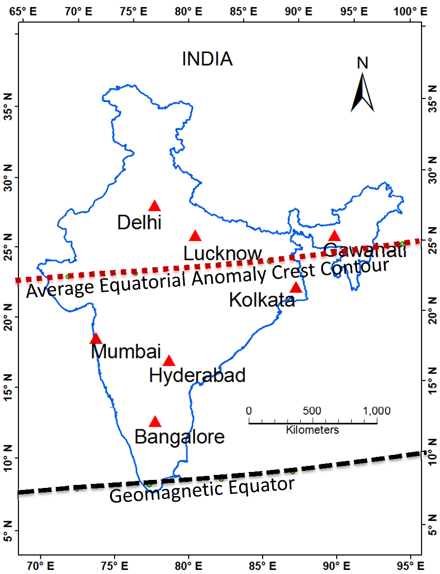

Fig. 1. Permanent GPS stations across Indian region, Geomagnetic equator and average equatorial ionisation anomaly (EIA) crest contour during 2011 to 2012.

Table 1. The geographic and geomagnetic co-ordinates of GPS stations across Indian region.

GPS Station	Geo.Lat.(N)	Geo.Lon.(E)	Mag.Lat.(N)
Delhi	28.59	77.22	20.0
Lucknow	26.91	80.96	18.0
Guwahati	26.10	91.59	16.6
Kolkata	22.54	88.33	13.2
Mumbai	18.89	72.81	10.7
Hyderabad	17.42	78.55	8.7
Bangalore	13.02	77.57	4.4

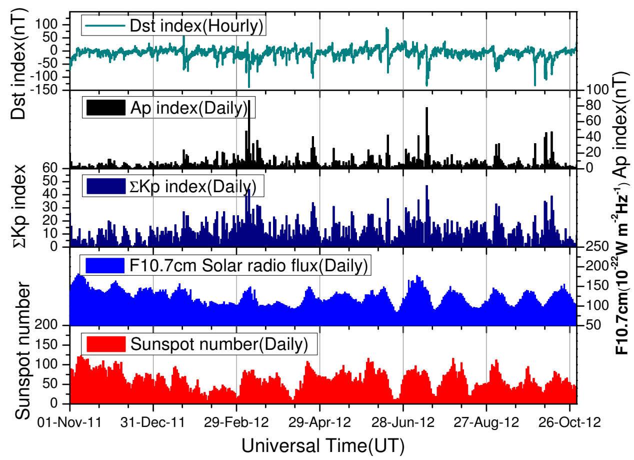

Fig. 2. Variations of Sunspot number, Solar radio flux, geomagnetic Kp, Ap and Dst indices during November 2011 to October 2012.

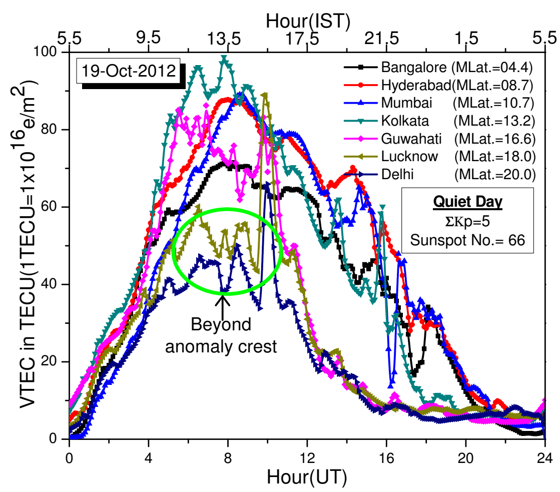

Fig. 3. Diurnal variation of TEC over different GPS stations across Indian region.

3. RESULTS AND DISCUSSION

The fig. 2 shows variations of geomagnetic Kp, Ap and disturbance storm (Dst) indices along with international sunspot number and solar radio flux. It shows very good correlation between the parameters throughout the period. The diurnal variation of TEC at different stations for a quiet day (19 October 2012, $\Sigma Kp = 5$) is shown in fig. 3. It can be observed from the figure that the TEC gradually increases with sunrise, attains a peak at around 10:00 UT (IST = UT+5:30) and then minimum value after midnight. The daily maximum value of TEC remains for a longer duration towards equator (Bangalore), while the longer nighttime minima is observed over stations beyond anomaly crest region (Delhi).

The latitudinal variation of TEC (fig. 4) for the month of October 2012 shows that during daytime the TEC increases from equator towards anomaly crest region and then decrease to minimum value towards mid-latitude region. Ths is due to electro-dynamic $(E \times B)$ drift of fountain effect lifting the ionospheric plasma upward to develop an electrojet and subsequent diffusion along magnetic field lines to approximately 15° north and south of geomagnetic equator to form anomaly crest. Similarly, latitudinal variation of TEC for each month from November 2011- October 2012 at all stations were studied to observe monthly ionospheric changes. The higher value of daily maxima of TEC are observed during months of March, April, May, September, October and November while the months of January, June and July are depicting lower values of TEC at all stations. To investigate the seasonal variations in TEC, the seasons are categorized as December solstice, March equinox, June solstice.The TEC at all the stations are plotted along with standard deviation errors (not depicted). Maximum value of TEC was observed during the equinoxes, and the September equinox shows slightly higher value than the March equinox at all stations.

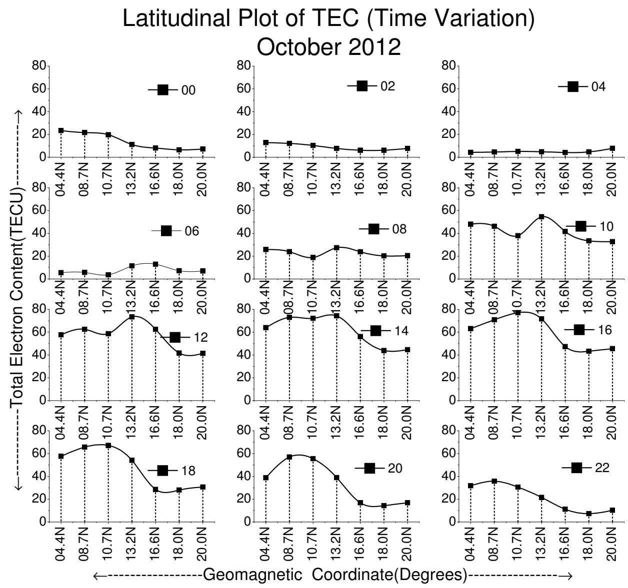

Fig. 4. Mean Latitudinal plot (2 hourly variation) of TEC over Indian region during October 2012.

To study the anomalous variation of ionospheric TEC during geomagnetically disturbed condition, the event of 9^{th} March 2012 was chosen. The maximum excursion of disturbance storm index Dst was $-129\ nT$. In general, the effect of a geomagnetic storm on the ionosphere is severe over the auroral zone but the equatorial region is more prone to the electro-dynamic fountain effect. The geomagnetic storm starts with initial phase followed by a large decrease in magnetic strength (main phase) which then recovers in the subsequent recovery phase. During the recovery, TEC shows significant enhancement [10]. It is observed that the diurnal maximum value of TEC at all stations was enhanced due to this strong geomagnetic storm. The enhancement in TEC is seen to be severe at Lucknow, followed by Hyderabad and Bangalore, and this enhancement is more on the storm day than on the previous and succeeding quiet days.

The best complement to global ground GPS measurements is provided by radio occultation (RO) from GPS receivers of LEO satellites. The RO yields vertical electron density profile at the occultation latitude. Here the second level FORMOSAT- 3/COSMIC RO "*ionprf*" files are taken from CDACC to observe the F layer peak positions (hmF2) and corresponding electron density (foF2). The electron density profiles of two RO at 09:08 UT and 10:57 UT on 22 October 2012 at two different positions over Indian region are shown in fig. 6 with the critical frequencies $(foF2)$ and their corresponding altitudes $(hmF2)$.

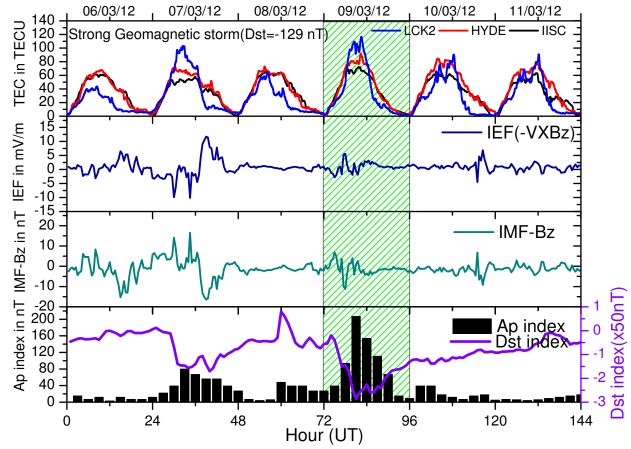

Fig. 5. Variations of geomagnetic Ap and Dst indices, IMF-Bz and TEC over Bangalore, Mumbai and Lucknow during minor to strong geomagnetic storm 06-11 Mar 2012.

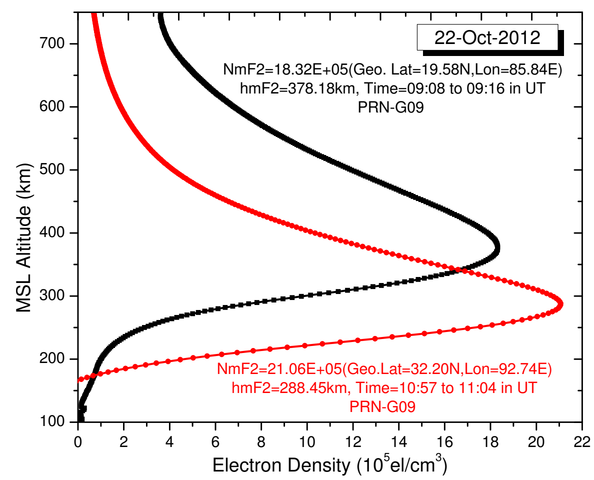

Fig. 6. Electron density profiles of two COSMIC occultations over Indian region at different latitudes on 22 October 2012.

The international reference ionosphere (IRI) is an analytical model providing ionospheric informations in the altitude range 50 km to 2000 km, but the predictions are most accurate in northern mid-latitude regions due to dense network of monitoring stations. The international standard plasmasphere-ionosphere model (SPIM) is developed under international standardization organization (ISO) by merging IRI below 1000 km and the plasmasphere region of the Russian standard model of ionosphere (SMI) up to 20,000 km. The measured TEC is compared with global ionosphere map published by IGS and IRI-2012 and SPIM predictions for both quiet and disturbed days. The comparision plots during quiet period 19-21 October 2012 is shown in fig. 7. It shows that the measured TEC (black curves) agree with the global ionosphere map (red curves). The IRI-2012 predictions (blue curves) underestimated the TEC at equatorial stations but are similar at mid-latitude stations. The SPIM model predictions (dark cyan curves) show much higher values at all stations than that of local measurements and IRI outputs though the second maxima is prominently visible torawds the equatorial station. Hence further improvement is needed for TEC predictions over equatorial region.

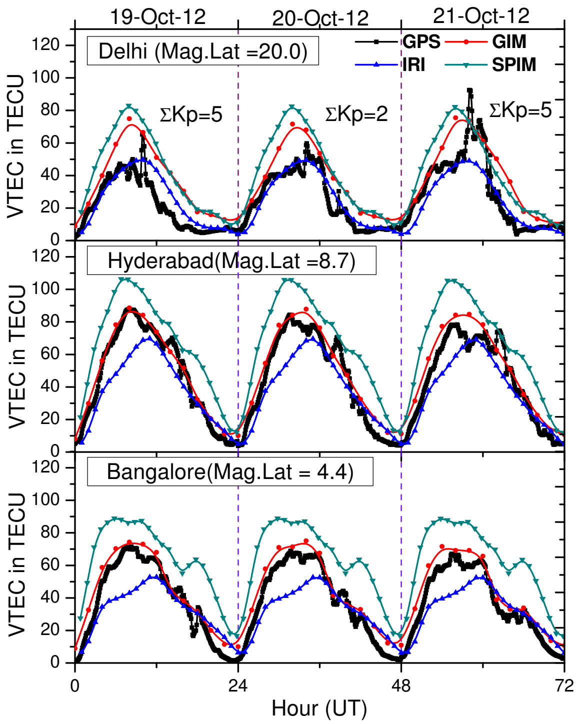

Fig. 7. Comparision of GPS derived TEC with Global Ionosphere Map, IRI-2012 and SPIM model predictions during quiet period (19-21 October 2012).

4. CONCLUSION

Most part of the Indian region is covered by low latitude equatorial ionization anomaly. Hence the electrodynamics of equatorial region has a great impact on ionospheric distribution with latitude. The ground-based GPS observations along with space-based GPS radio occultation, ionosondes can be combined with other geophysical measurements such as disturbance storm index (Dst), interplanetary magnetic field (IMF), interplanetary electric field (IEF) to better understand the ionosphere over the low latitude Indian region. As the International standard models are still lacking reliable results over equatorial anomaly region further studies are needed for developing a suitable model.

5. ACKNOWLEDGEMENT

The authors acknowledge SOPAC and IMD Delhi for providing GPS data, CODE for differential code biases,the CDDIS for BRDC files, WDC Kyoto for geomagnetic indices, and GSFC/SPDF OMNI website for the IMF as well as IEF parameters. Also sincere thanks to Dr. Gopi K. Seemala of Kyoto University, Japan for providing TEC analysis software.

6. REFERENCES

[1] A. DasGupta, A. Paul, and A. Das, "Ionospheric total electron content (TEC) studies with GPS in the equatorial region," *Indian Journal of Radio and Space Physics*, vol. 36, pp. 278–292, August 1997.

[2] K. Davies and G. K. Hartmann, "Studying the ionosphere with the Global Positioning System," *Radio Science*, vol. 32, no. 4, pp. 1695–1703, 1997.

[3] A. Komjathy, *Global Ionospheric Total Electron Content Mapping Using the Global Positioning System*, Ph.D. thesis, Dept. of Geodesy and Geomatics Engineering, University of New Brunswick, September 1997.

[4] C. Cai, "Monitoring seasonal variations of ionospheric TEC using GPS measurements," *Geo-spatial Information Science*, vol. 10, no. 2, pp. 96–99, 2007.

[5] M. M. Alizadeh, H. Schuh, S. Todorova, and M. Schmidt, "Global Ionosphere Maps of VTEC from GNSS, satellite altimetry, and formosat-3/COSMIC data," *Journal of Geodesy*, vol. 85, no. 12, pp. 975–987, 2011.

[6] D. Bilitza, "35 years of International Reference Ionosphere Karl Rawers legacy," *Advances in Radio Science*, vol. 2, pp. 283–287, 2004.

[7] T. L. Gulyaeva, "International Standard Model of the Earth's Ionosphere and Plasmasphere," *Astronomical and Astrophysical Transactions*, vol. 22, no. 4-5, pp. 639–643, 2003.

[8] G. K. Seemala and C. E. Valladares, "Statistics of total electron content depletions observed over the South American continent for the year 2008," *Radio Science*, vol. 46, pp. 5019, October 2011.

[9] S. Schaer, *Mapping and predicting the Earth's ionosphere using the Global Positioning System*, vol. 59, Institut für Geodäsie und Photogrammetrie, Eidg. Technische Hochschule Zürich, 1999.

[10] S. K. Panda and S. S. Gedam, "GPS derived spatial ionospheric total electron content variation over South-Indian latitudes during intense geomagnetic storms," *Proc. SPIE 8535, Optics in Atmospheric Propagation and Adaptive Systems XV*, pp. 85350B–85350B–10, November 2012.