Performance Analysis of Artificial Neural Network based TEC Models at Different Longitudes in the Low Latitude Region

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Abstract

The highest Total Electron Content (TEC) values in the world normally occur at Equatorial Ionization Anomaly (EIA) region resulting in largest ionospheric range delay values observed for any potential Satellite Based Augmentation System (SBAS). For any Satellite Based Augmentation System (SBAS), reliable forecasting of ionospheric Total Electron Content (TEC) is very essential. Three Neural Network based TEC models have been developed along 77°E, 88°E and 120°E in the low latitude region to characterize the sharp latitudinal variation of TEC and also to study any longitudinal variation of the equatorial ionization characteristics. The effects of the neutral wind over TEC variation have also been observed.

1. Introduction

The equatorial ionosphere can be characterized by prominent features like (i) sharp latitudinal gradients of TEC during 8-11 LT existing in the horizontal and vertical directions, (ii) steep temporal increase of TEC following plasma influx from magnetic equator to off-equatorial locations, and (iii) post-sunset secondary enhancement of TEC, often suggested as a precursor to occurrence of scintillations. It has been found that these characteristics are not properly addressed by standard models like International Reference Ionosphere (IRI) and Parameterized Ionospheric Model (PIM) and they showed severe limitations in the prediction capability over the low latitude Indian longitude sector. [1, 2]

Artificial Neural network techniques have been widely employed as an alternative to classical methods for ionospheric prediction problems in recent times [3, 4]. Neural network has the ability to deal with nonlinear behavior thereby establishing and modeling the nonlinear dynamical processes present in the equatorial ionosphere. Three Neural Network based TEC models have been developed along 77°E, 88°E and 120°E in the low latitude region named IRPE-TEC-77E, IRPE-TEC-88E and IRPE-TEC-120E respectively. These models are designed to characterize the variation of TEC in diurnal, latitudinal and longitudinal basis. These models have also been compared with IRI and PIM to establish their applicability to low latitudinal regions. The comparison of diurnal and latitudinal variation of TEC predicted by IRPE-TEC-88E with that of PIM and IRI has been already reported in literature [5].

2. Development and Performance Analysis of IRPE-TEC-77E

A neural network based TEC model named IRPE-TEC-77E has been designed based on real time GAGAN TEC data over 77°E longitude and a Subionospheric latitude span of 8°N - 31°N. This region extends from the geomagnetic equator through the northern crest of the Equatorial Ionization Anomaly (EIA) to locations beyond the northern crest of the EIA. The TEC data used for designing the model were obtained from GPS-TEC measurements from the stations at Trivandrum (8.47°N, 76.91°E geographic; magnetic dip 0.9°N), Bangalore (12.95°N, 77.68°E geographic; magnetic dip 11.69°N), Hyderabad (17.44°N, 78.47°E geographic; magnetic dip 21.9°N), Bhopal (23.28°N, 77.34°E geographic; magnetic dip 33.95°N), Delhi (28.58°N, 77.21°E geographic; magnetic dip 43.5°N), and Simla (31.09°N, 77.07°E geographic; magnetic dip 47.43°N) for the period of January 2004 to March 2005. The inputs of the model are (i) day of year, (ii) time of day in UT, (iii) 350 km subionospheric latitude and longitude and (iv) daily sunspot Number. In order to exclude scintillations under geomagnetically disturbed conditions, days with Dst >= -50nT are selected for model development. The model produces Vertical TEC at one minute interval at its output. The model has been validated during the period of April 2005 and the results have been compared with predictions obtained from PIM and IRI.

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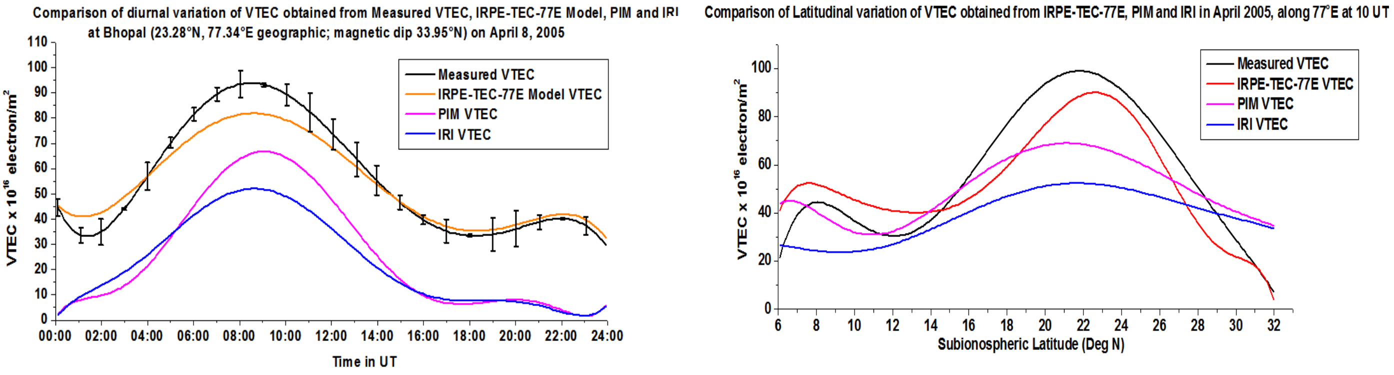
Comparison of the diurnal TEC and latitudinal variation have been shown in Figure 1(a) and (b) respectively. The predicted TEC from the model shows good correspondence compared to PIM and IRI in the diurnal as well as latitudinal variation of the measured TEC throughout a large latitudinal swath of 6°N to 32°N.

3. Development and Performance Analysis of IRPE-TEC-120E

It has already been established that the occurrence of equatorial ionospheric irregularities varies with the distinct variation of longitude for a given season [6]. The variation of TEC with longitudes has been already reported [7, 8]. The reasons for this variation can be attributed to the change of geomagnetic declination and the change of zonal wind. A neural network based model has been designed with the real time GNSS data from selected IGS (International GNSS Service) stations over 120°E for the year of 2011-2012 a moderate to high solar activity period. TEC data used from (i) Hsinchu (24.80°N, 120.99°E geographic, magnetic dip 35.52°N), (ii) Taoyuan (24.95°N, 121.16°E geographic, magnetic dip 35.76°N), (iii) Quezon City (14.64°N, 121.08°E geographic, magnetic dip 15.50°N) for the duration January 2011 to March 2012. This model has been validated with other standard models like IRI and PIM during April 2012 to understand the applicability of the model to the low latitude region. The diurnal TEC variation comparison for a geomagnetically quiet representative day has been shown in Figure 2. The diurnal response from IRPE-TEC-120E shows good correspondence with the diurnal variation of the measured VTEC for a major part of the day.



(a) (b)

Fig.1 Diurnal TEC variation and latitudinal TEC variation comparison for IRPE-TEC-77E model with IRI and PIM

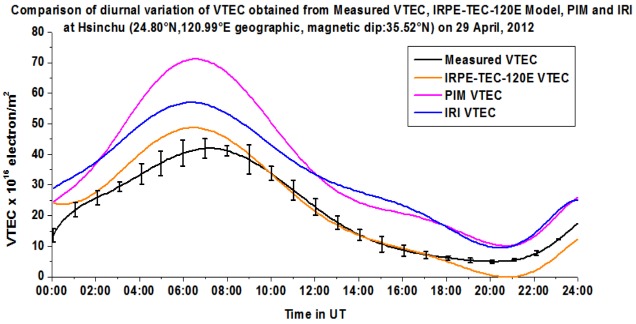


Fig.2 Diurnal TEC variation comparison for IRPE-TEC-120E model with IRI and PIM

4. Introduction of Neutral Winds as Model Inputs

It has been established that the TEC is also dependent on the neutral wind flow and velocity of its major components (meridional wind and zonal wind) [9, 10]. The model IRPE-TEC-88E has been modified with the incorporation of the magnitudes and directions of the meridional wind and zonal wind as model inputs. The meridional wind and zonal wind velocities are obtained from horizontal wind model (HWM07) [11] and these values are also provided as model inputs. The newly developed model (IRPE-TEC-88E(HWM)) is also tested for the period of April, 2012. The validation results show improved performance specially at the time of diurnal peak VTEC. Figure 3 shows a representative validation case for April 29, 2012.

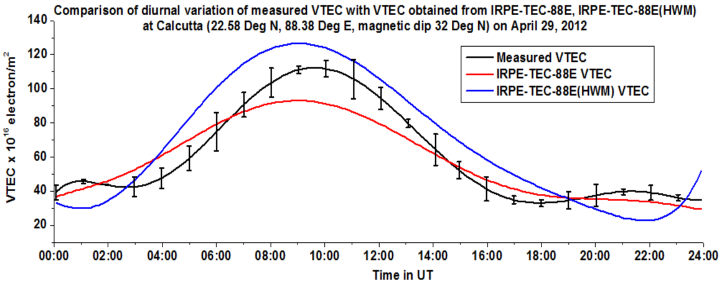


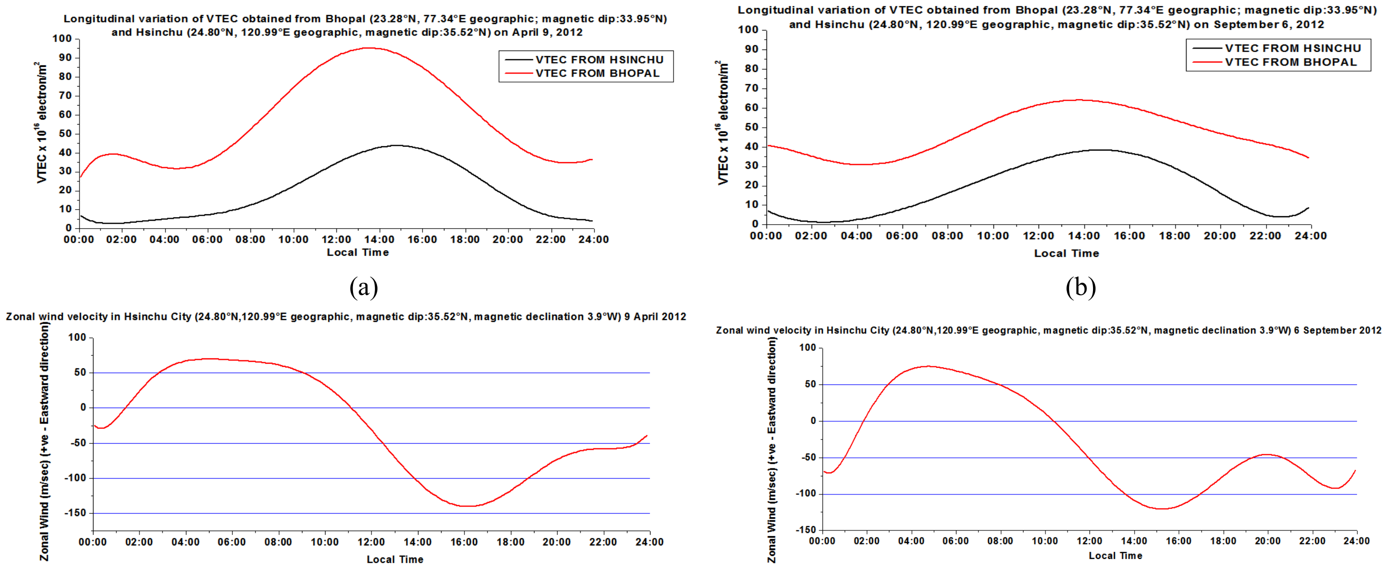
Fig.3 Performance of IRPE-TEC-88E after incorporating neutral wind as model inputs

5. Longitudinal TEC variation analysis with Neural Network driven Models

The longitudinal variation of TEC is characterized by variation of magnitude and direction of geomagnetic declination angle and the velocity and direction of the zonal wind. The magnetic field aligned ion drift velocity V_{zonal} (positive for upward drift) due to thermospheric horizontal zonal winds U_e (positive for eastward winds) can be related by the equation (1).

$$V_{zonal} = -U_e \sin D \cos I \qquad (1)$$

I is the geomagnetic inclination (positive for northern angle). V_{zonal} is either upward or downward depending on the sign of declination angle D (positive for eastward angle) and the sign of zonal winds U_e. Longitudinal variation of TEC between the longitudes 77˚E and 120˚E has been observed for the vernal and autumnal equinoxes of 2012 with the prediction from IRPE-TEC-77E at Bhopal (23.28°N, 77.34°E geographic; magnetic dip 33.95°N) and that of IRPE-TEC-120E at the station Hsinchu (24.80°N, 120.99°E geographic, magnetic dip 35.52°N). VTEC at Bhopal is found to be more than that of Hsinchu after eliminating the effects of the solar terminator (Figure 4(a) and 4(b)). Both stations are situated at almost identical geomagnetic inclination angle so the longitudinal TEC variation will only be attributed to the variation of geomagnetic declination angle and the magnitude and direction of zonal wind. Bhopal was situated on the agonic line in 2012. So the TEC of this station can be assumed independent from magnetic field aligned ion drift velocity $V_{zonal.}$ Hsinchu lies at 4°W declination angle. For zonal wind with a westward direction, V_{zonal} is downward on the west valued declination angle regions (as in case of Hsinchu). The downward field aligned drift velocity V_{zonal} moves the ions to lower altitudes where their recombination rate is higher because recombination rate is increasing exponentially toward lower altitudes. Thus the overall TEC in that region is reduced. The zonal wind across Hsinchu is found to be westward at the diurnal peak of TEC (from HWM07, shown in figure 4(c) and 4(d)). This explains the downward ion drift velocity causing larger recombination rate in Hsinchu. This may contribute to less value of TEC at Hsinchu than Bhopal specially at the time of diurnal maximum.



(a) (b)

(c) (d)

Fig. 4 Longitudinal variation of TEC along Bhopal (77ºE) and Hsinchu (120 ºE) in (a) vernal and (b) autumnal equinox and corresponding zonal wind variations in Hsinchu (c) and (d) respectively

6. Conclusion

The presence of large spatial and temporal gradients of TEC in the equatorial region coupled with its variability under different geophysical conditions renders wide differences between the actually observed electron content and PIM and IRI model computations. The result reflects the fact that these models are unable to properly represent the dynamic nature of the equatorial plasma transport processes and do not account for the variability of the sharp spatial gradients of ionization in this region across 77 °E to 120 °E. Models like IRI and PIM give smoothed variation of the VTEC irrespective of the geophysical conditions thereby making the output less sensitive to spatial and temporal variation of VTEC over the low latitude regions. All the Neural Network based TEC models developed show significant improvements over PIM and IRI for properly describing equatorial ionospheric characteristics. The incorporation of neutral wind as model inputs show improvement of TEC prediction at the diurnal peak period. The longitudinal variation of TEC can also be characterized with the help of these neural network based models and the variations can be explained by the effect of zonal wind as well as the geomagnetic declination angle of the stations.

7. References

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