Comparison of Equatorial Ionization Anomaly Gradients from Multistation GPS TEC and Artificial Neural Network for Scintillation Prediction in the Indian Longitudes

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Abstract

The equatorial ionosphere frequently exhibits sharp latitudinal and diurnal TEC (Total Electron Content) variations as well as intense post-sunset ionospheric irregularities. Correlation between daytime TEC gradient (equatorward and poleward) and post-sunset ionization irregularities observed from Equatorial Ionization Anomaly (EIA) crest region exists in literature. The highly varying TEC in these low latitudes cannot be accurately predicted by standard ionospheric models. An Artificial Neural Network (ANN) based TEC model has been designed in this region for prediction of TEC gradients. A comparison of measured TEC gradient with that obtained from model is presented in this paper. The correlation between predicted TEC gradients and post-sunset intensity of scintillations from EIA crest has also been studied in this paper.

1. Introduction

Latitudinal TEC (Total Electron Content) gradient from Equatorial Ionization Anomaly (EIA) is very large in this equatorial region [1, 4, 7]. The poleward gradient is higher than equatorward TEC gradient for most of the time [1, 4, 7]. A correlation between sharp gradient of TEC from EIA crest to either side (poleward or equatorward) and intensity of post-sunset scintillations around northern crest of EIA has already been established [1, 5, 6, 8, 11]. A suitable threshold TEC gradient value has been determined for occurrence of post-sunset scintillations in the anomaly crest region along 88°E [1]. But the measurement of TEC gradient over different latitude needs multi station TEC analysis over a long period.

The necessity of continuous operation of ground based receivers over multi station can be removed by appropriate TEC prediction model over those stations.TEC gradient computed from these predicted TEC can be used to forecast possible ionospheric scintillation after post-sunset period. Ionospheric amplitude scintillation can be expressed by S_4 which is referred to the ratio of standard deviation of signal intensity and average signal intensity. $S_4 \geq 0.4$ (SI>8dB) is considered to be an indication of noticeable amplitude scintillation for transionospheric signals.

Standard ionospheric TEC prediction models such as IRI (International Reference Ionosphere), PIM (Parameterized Ionospheric Model), NeQuick cannot follow the dynamic variation of TEC [3, 9, 10]. For proper correlation between TEC gradient obtained from measured TEC and predicted TEC, real time Artificial Neural Network (ANN) based TEC model is essential. Development of an ANN based TEC model and subsequent poleward TEC gradient computation from this model have been reported in this paper.

2. Data Base for ANN based TEC model

Multi station dual frequency GPS TEC recording system along fixed longitude 88°E covering latitude span of 20°N-28°N is operational from the stations mentioned below. An ANN based TEC model (IRPE-TEC-88E(HWM)) has been developed using dual frequency GPS-TEC dataset for these stations [9, 10]. The periods of training dataset obtained from these stations are also mentioned simultaneously.

Calcutta (22.58°N, 88.38°E geographic, magnetic dip 34.02°N) Training data duration: January 2007-September 2011
Baharampore (24.09°N, 88.25°E geographic, magnetic dip 36.87°N) Training data duration: April-September 2011
Farakka (24.79°N, 87.89°E geographic, magnetic dip 38.15°N) Training data duration: April 2012
Siliguri (26.72°N, 88.39°E geographic, magnetic dip 41.54°N) Training data duration: September 2011, April 2012 under equinoctial campaign mode.

The model inputs are (i) day number of year, (ii) time of the day (UT), (iii) subionospheric latitude, (iv) subionospheric longitude, (v) daily sunspot number, (vi) meridional wind and (vii) zonal wind. The model produces Vertical STEC (VTEC) in one minute interval. Equivalent Slant TEC (STEC) can be converted to VTEC after multiplying STEC with slanting factor. The magnitudes of neutral wind components (meridional wind and zonal wind) are obtained from HWM07 model [2]. This model has been validated for April 2013 and August September 2013. Training data period and validation data period are kept separate to avoid data biasing. Only geomagnetic quiet days (Dst ≥ -50 nT) are considered for model training and validation. GPS-TEC data over elevation angle 50° are used in order to avoid multipath

error. An improvement of prediction accuracy for this ANN based TEC model over standard ionospheric models such as IRI, PIM and NeQuick has already been established [9, 10]. This model can be used to provide more accurate poleward TEC latitudinal gradient across varying latitudes than other standard ionospheric models. Any correlation between these predicted poleward TEC gradients at 8UT, 9UT and 10UT and occurrence of post sunset L-band scintillation ($S_4 \geq 0.4$ or SI>8dB) around northern crest of EIA has been studied. TEC data is expressed in TECU (1 TECU = 10^{16} electron/meter^2)

3. Results and Determination of Performance of VTEC Model

The predicted VTEC at 9 UT (8:45-9:15 UT) for a representative geomagnetic quiet day (3rd April, 2013) is shown in Fig. 1.

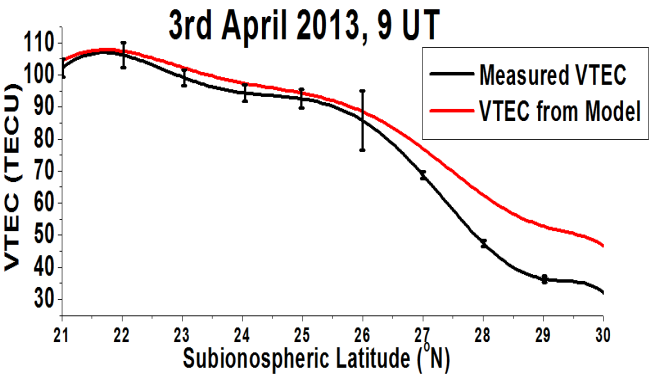

Figure 1. Comparison of latitudinal TEC variation between measured VTEC and predicted VTEC at 9UT (8:45-9:15 UT) on 3rd April, 2013 (Sunspot No. 101). ±1σ standard deviation is given after interval of one subionospheric latitude over measured VTEC.

Similar operation is performed for geomagnetic quiet days from 21 August to 21 September 2013. Observations from one representative geomagnetic quiet day, 19 September 2013 is shown in Fig. 2.

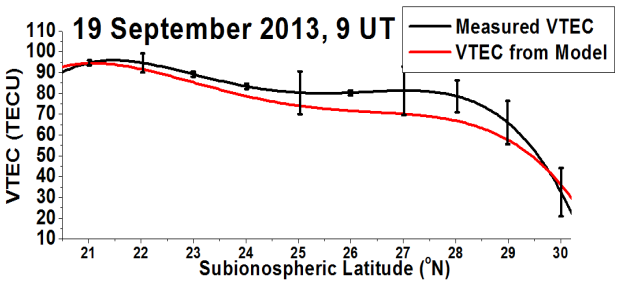

Figure 2. Comparison of latitudinal TEC variation between measured VTEC and predicted VTEC at 9UT (8:45-9:15 UT) on 19 September, 2013 (Sunspot No. 63). ±1σ standard deviation is given after interval of one subionospheric latitude over measured VTEC.

From Fig. 1 and Fig. 2, it can be observed that the predicted VTEC has shown close correspondence with measured VTEC for almost all latitudes for that given day. The correlations between latitudinal VTEC gradients have been obtained from the data set of measured real time VTEC and VTEC obtained from ANN based VTEC model. For 9UT (8:45-9:15 UT) of April 2013, it has been observed that real time VTEC gradient and gradient obtained from VTEC model are correlated by 78.16% for all geomagnetic quiet days. The same for the duration from 21 August, 2013-21 September 2013 is 70.54%. The results are summarized in Table 1.

Table 1. Correlation Coefficients (in percentage) between real time VTEC gradient and VTEC gradient from model

	9UT(8:45-9:15 UT)
April 2013	78.16
August 21, 2013-September 21, 2013	70.54

Similar analysis is conducted for entire April 2013 and August 21-September 21, 2013. Comparison of TEC gradients at 9UT (8:45-9:15 UT) in April 2013 obtained from measured VTEC and predicted VTEC from ANN based TEC models are shown in Fig. 3. Only days with maximum $S_4 \geq 0.4$ (SI>8dB) are shown in Fig. 3. Similar observations are conducted in autumnal equinox for the period of August 21-September 21, 2013 (Fig. 4).

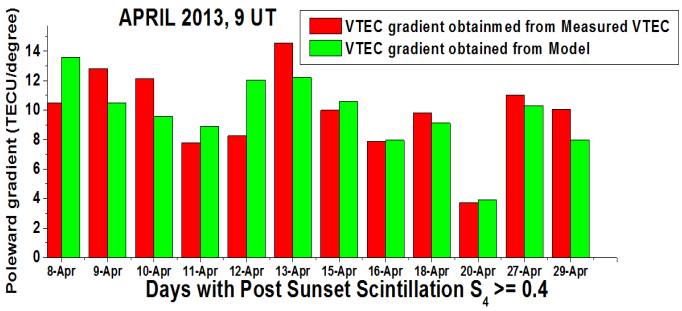

Figure 3. Comparison of latitudinal TEC gradient between measured VTEC and predicted VTEC at 9UT (8:45-9:15 UT) in April 2013 for days with post sunset scintillation (Maximum $S_4 \geq 0.4$). Monthly Sunspot no. for April 2013 = 107.

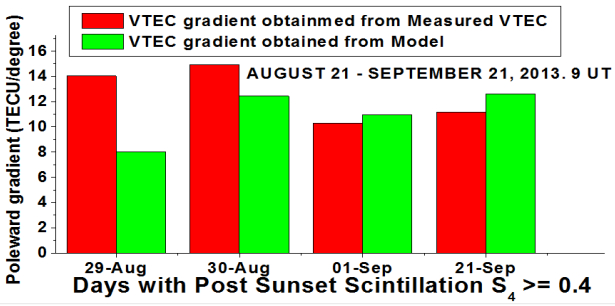

Figure 4. Comparison of latitudinal TEC gradient between measured VTEC and predicted VTEC at 9UT (8:45-9:15UT) in August 21-September 21, 2013 for days with post sunset scintillation (Maximum $S_4 \geq 0.4$). Monthly Sunspot no. for August 2013 = 92 and September 2013 = 55.

4. Determination of Threshold Poleward VTEC gradient for Post-Sunset Scintillation around northern crest of EIA

Variation (if any) of maximum S_4 around northern crest of EIA along with poleward VTEC gradient (both from measured VTEC and predicted VTEC from model) during 8UT, 9UT and 10UT is studied for April 2013. The results during 9UT are shown in Fig. 5. Similar analysis has been conducted for August 21- September 21, 2013 and it is shown in Fig. 6.

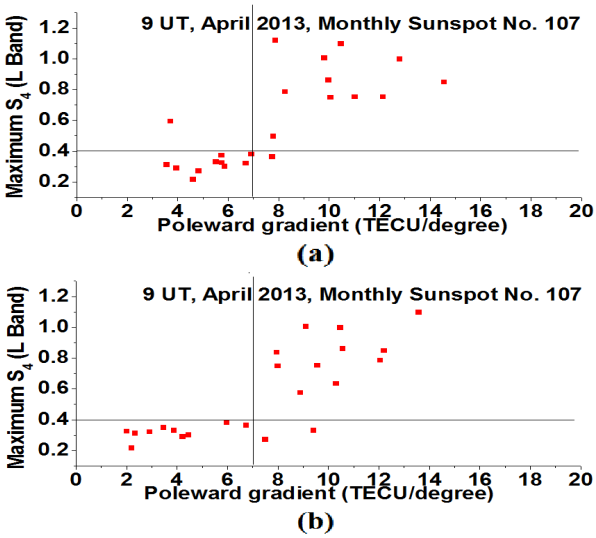

Figure 5. Variation of Daily maximum S_4 around northern crest of EIA with poleward VTEC gradient for 9 UT, April 2013 obtained from (a) measured VTEC and (b) from VTEC model.

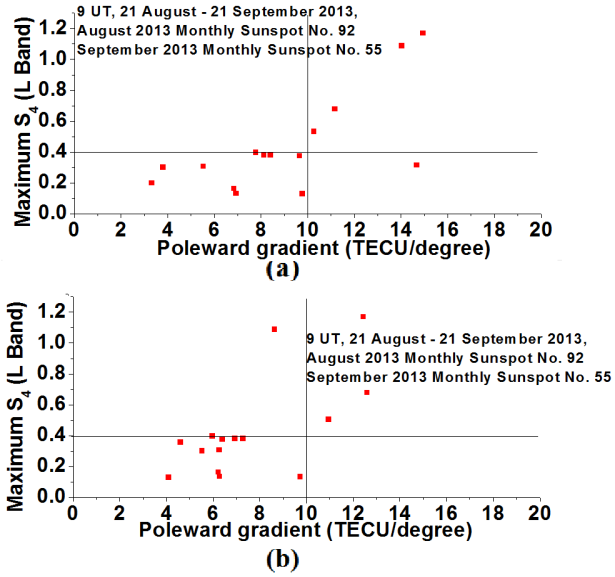

Figure 6. Variation of Daily maximum S_4 around northern crest of EIA with poleward VTEC gradient for 9 UT, August 21- September 21, 2013 obtained from (a) measured VTEC and (b) from VTEC model.

The chosen threshold value for poleward gradient for night time $S_4 \geq 0.4$ is 7 TECU/degree at 9 UT in April 2013. The threshold value during 9 UT during 21 August – 21 September, 2013 is 10 TECU/degree. After testing Chi-square test (χ^2) using these threshold values, it has been observed that VTEC gradient above these threshold values are correlated with $S_4 \geq 0.4$ with 0.1% significance level which is very much acceptable. Predicted VTEC gradients from ANN based VTEC model are also correlated with $S_4 \geq 0.4$ for same threshold values with 0.1% significance level in both the equinoxes. Similar analysis has also been conducted during 8UT and 10UT in April 2013 and 21 August – 21 September, 2013.

6. Conclusion

The TEC gradient computed from ANN based VTEC model has shown good correlation with the gradient obtained from real time VTEC in vernal as well as in autumnal equinoctial months in high solar activity period. The predicted poleward VTEC gradient can be used as an alternative to multi station real time measurements of TEC. The threshold VTEC gradients for post-sunset scintillation obtained from measured VTEC have also shown significant correlation model driven VTEC gradients. This it can be summarized that the predicted VTEC from ANN based VTEC model can forecast post-sunset L-band Scintillation with highly significant association in this low latitude region. This removes necessity for multi station TEC measurement over a long period.

7. References

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