Annals of Environment

Research Article

Performance Estimation of NEQUICK 2 Model for Ionospheric Analyses in Kaduna, Kebbi and Bauchi

[1]Lawal Joseph Adeiza, [2]Gila Arhiwo Manga, [3]Okoh Daniel and [4]Udochukwu Bernadette Chidomnso

[1]Department of Physics, Confluence University of Science and Technology, Osara, Kogi State, Nigeria.
[2,4]Department of Physics, Joseph Sarwuam Tarka University, Makurdi, Nigeria.
[3]Centre for Atmospheric Research, Abuja, Nigeria.

Received 1 June 2024; Acceptance 14 June 2024; Published 27 June 2024.

Abstract

Global Navigation Satellite System (GNSS) data along with the Nequick 2 Model were used to study the monthly TEC profiles for Nigerian GNSS Reference Network Stations for a period of four years (2011 – 2014) as year of high solar activity. These stations fall within the low latitude region. This work examines the performance estimation of Nequick2 model for Ionospheric analyses in Kaduna, Kebbi and Bauchi GPS stations from 2011 – 2014, years of high solar activity. The NEQUICK – TEC were computed using MATLAB programming language and Gopi software. The results obtained showed that the monthly variability of TEC has a pre – dawn minimum followed by an early morning steady increase, an afternoon maximum and then a post sunset gradual reduction in TEC with the equinoctial and solstice months depicting nighttime estimation of TEC. VTEC generally increased from 05:00hrUT and reached its maximum value at approximately 13:00hrUT – 14:00hrUT during all seasons and locations considered. GPS TEC measurement presented a similar behavior for all four seasons with relatively higher amplitudes of monthly maximum in equinoctial months (March, April, September, October), while solstice months (November, December, January, February) present lower value. This could be because the Sun shines directly over the equatorial region during equinoctial months and thus leads to the strongest ionization over these regions, a joint effect of solar zenith angle, the EUV ionization and the magnetic field geometry. Variations in TEC were also seen to show solar dependence.

Keywords: NEQUICK2 model, Ionosphere, GNSS, TEC, Solar Activity.

Introduction

Ionospheric modeling has been employed as a substitute method to capture the universal, regional, or local characteristics of the ionosphere. For instance, Physics based models like Ionospheric Forecast Model

Correspondence to: Lawal Joseph Adeiza, e-mail: lawalja@custech.edu.ng

How to Cite: Lawal et al. (2024). Performance Estimation of NEQUICK 2Model for Ionospheric Analyses in Kaduna, Kebbi and Bauchi. *Annals of Environment,* **1(6**). DOI: 10.5281/zenodo.12547616

(IFM) give the universal assessment of electron and ion temperatures and also the predominant molecular densities at different ionospheric regions [22]. In a like manner, Physics based data operated model of the ionosphere and neutral atmosphere named Global Assimilation Ionospheric Measurements (GAIM) gives the ionospheric layers peak parameters, three dimensional electron density profile, and vertical TEC (VTEC) [23].

Electron Density Assimilative Model (EDAM) developed by Angling and Jackson-Booth [1] provides real-time ionospheric characteristics by incorporating various data sets into a background model. In order to reconstruct and forecast TEC based on Global Navigation Satellite System (GNSS) measurements, global and regional models like family of Neustrelitz TEC Models (NTCM) have been developed [11]. In addition, to estimate the three-dimensional ionospheric electron density in space and time from bottom side to topside ionosphere empirical models like NeQuick was developed.

Nequick model was proposed in order to ascertain the electron density in the ionosphere analytically [9]. Ionospheric layer peak parameter value is used as an anchor point to reproduce electron density profile by the electron density profiler – NeQuick model [20]. NeQuick model, utilizes the Consultative Committee for International Radio (CCIR) maps for ionospheric peak parameters (such as foF2) modeling. Ionosonde measurements for mid and low latitude region of the Northern Hemisphere collected over long duration are used to develop the CCIR map [13].

NeQuick 1 is proposed to be used by the Galileo single frequency receiver, this model is also used by International Telecommunication Union (ITU). NeQuick 2 is the upgraded model of NeQuick 1 following the topside shape parameter remodeling of the model [6, 17]. The performances of NeQuick model have been carried out in various regions and it has been observed that both versions, compared to other models, suit for GALILEO single frequency ionospheric error correction [5, 10].

Jodogne in [12] examined the modeled VTEC (using NeQuick 1) with measurements obtained at mid latitude regions and noted good agreement. In addition, Bidaine in [4] assessed both versions of the model with measurements from the ionosonde at mid latitude region and noticed a good improvement of VTEC computed by the model. However, the author [7] have opined that NeQuick with new topside formulation (NeQuick 2) does not depict improvements in reproducing the STEC at low latitude regions, this is as a result of the merits and shortcomings of the International Satellite for Ionospheric Studies (ISIS) data obtained in the low latitudes. Furthermore, the birth of NeQuick 2 model is as a result of the limitation of older versions of IRI model to predict TEC values at various ionospheric stations. This inability of IRI model has been enhanced in the latest version, NEQUICK 2.

In order to utilize the model for various purposes, it is very vital to observe the performance of the model for separate solar activity periods at various regions. Specifically, it is very essential to enhance the performances of NeQuick 2 model at low-latitude regions where little data have been used for the development of the model [6, 13].

Ionosphere measurements imputed into the model assists in enhancing the performances of empirical models. [14] and [16] explicitly discussed the different methods of assessing empirical models with measurements. STEC data ingestion using single or multi stations measurements is a means of enhancing the performances of NeQuick in reproducing the experimental STEC [16]. The primary idea of the data ingestion is to ascertain the effective ionization level or local effective solar radio flux (Az), which reduces the difference between the experimental STEC and the modeled values. This has been shown for a daylong data acquired for the North America region during extreme solar activity period using NeQuick 1. Findings have also indicated significant enhancement in the model performances.

In the present study, we will assess the performances of NeQuick 2 in characterizing the low-latitude ionosphere in Kaduna, Kebbi and Bauchi stations during high solar activity periods.

Additionally, in the recent times, little or no research has been found in the literature about this phenomenon with stations in Nigeria at heights up to 1000 km. To this end, this study investigates the behaviour of the ionosphere at heights up to 1000 km using Nequick 2 model across three GPS stations in Nigeria.

Materials and method

Sources of Data

The GNSS – TEC data used in this work were obtained from Nigerian Permanent GNSS Reference Network (NIGNET) from http://server.nignet/data.rinex/. The GPS – TEC data are for the period of four years (2011 – 2014) for seven GPS stations in Nigeria, whose geographic coordinates are given in Table 1.

Table 1: GNSS Stations and their Geographic Co – ordinates

GPS Station	Code	Location	Latitude	Longitude
ABUZ	Ahmadu Bello University Zaria, Kaduna State.		11.15^{o}N	7.64^{o}E
BKFP	Birnin Kebbi Federal Polytechnic, Kebbi State.		12.46^{o}N	4.22^{o}E
CGGT	Centre of Geodesy and Geodynamics, Toro, Bauchi State.		10.12^{o}N	9.11^{o}E

The GPS – TEC data obtained were in a Slant Total Electron Content (STEC) Format from satellite to ground GPS receivers. STEC depends on the Slant TEC function of the Satellite and receiver location, and hence had to be converted to Vertical Total Electron Content (VTEC) that depends on the geographical location and time of the satellite and receiver. To achieve this, a Receiver Independent Exchange (RINEX), a GPS – TEC software program called Gopi (version 2.5) was used to convert STEC TO VTEC.

The NEQUICK – TEC data were generated using a MATLAB program incorporated with NEQUICK 2 model. The NEQUICK – TEC generated is the NEQUICK – VTEC.

Data Generation

The GNSS – TEC obtained is a VTEC format arranged with the corresponding time of the day that the VTEC was obtained. The time of the day was in hours format, which ranges from 0:00 hours to 23:90 hours (0.1 hours interval). The GNSS – TEC were arranged in 0.5 hours intervals. The procedure was repeated for all the three GPS stations where the GNSS – TEC were obtained. There were days/hours where there were no data recorded in some of the GPS stations, such days/hours were represented by Nan; which is a MATLAB programming language that means 'Not a Number'.

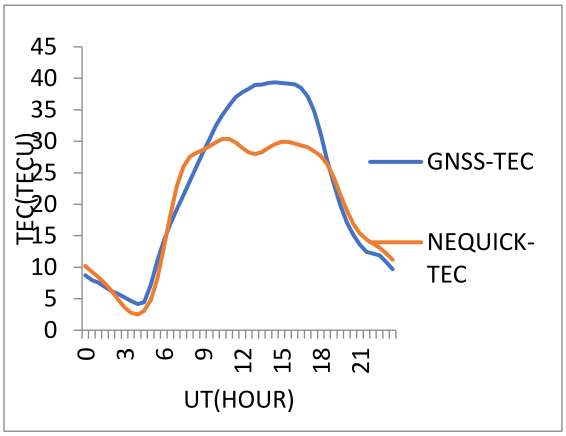
The upper boundary of 1000 km was set on the NEQUICK 2 model in order to obtain NEQUICK – TEC at that particular height in ionosphere. The choice of 1000 km was because it was located in the topside (F_2) region where the concentration of ionospheric electron density is higher than any other region. The NEQUICK – TEC obtained was in VTEC format that had been arranged in their corresponding time of the day that the VTEC was obtained. The time of the day was in hours that range from 0:00 hours to 23:50 hours. The NEQUICK – TEC at that height of 1000 km was generated using MATLAB software program for the three GPS stations in Nigeria using the latitudes and longitudes of these stations for the period of four years (2011 – 2014).

Plotting of data

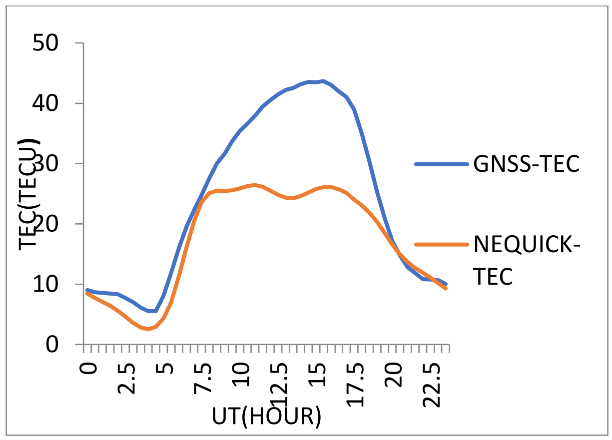
In each of the year and station, a monthly plot of GPS – TEC and NEQUICK – TEC with respect to time were made using Microsoft Excel software program for the three GPS stations in Nigeria for the period of four years (2011 – 2014).

Results and discussion

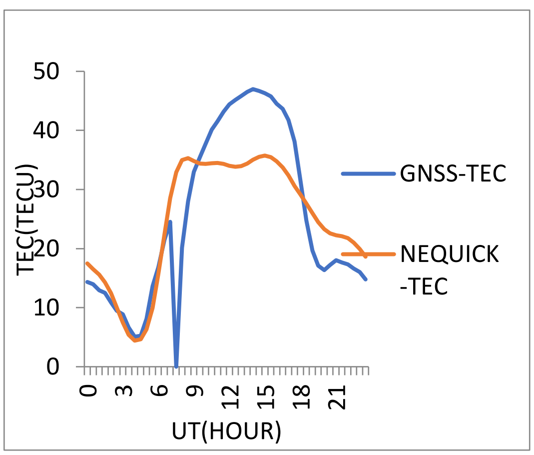
The Hourly variations in GNSS – TEC and NEQUICK – TEC are grouped according to solar seasons. These are March Equinox, June Solstice, September Equinox and December Solstice from 2011 – 2014. Hence, the hourly variations in the GNSS – TEC and NEQUICK – TEC for ABUZ, BFKP, CGGT, are presented in Figures 1 – 3.



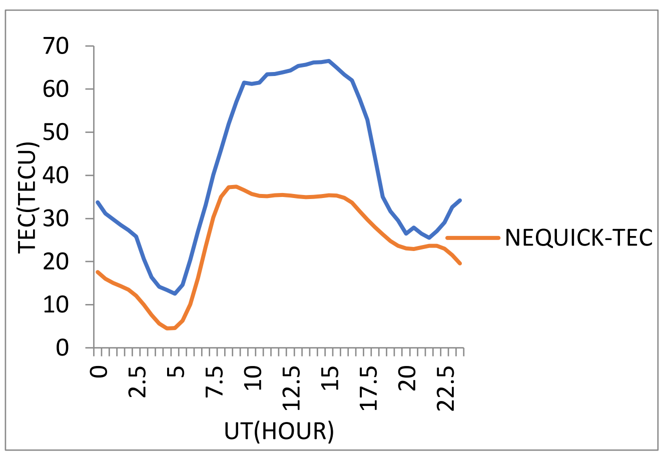
(a)



(b)

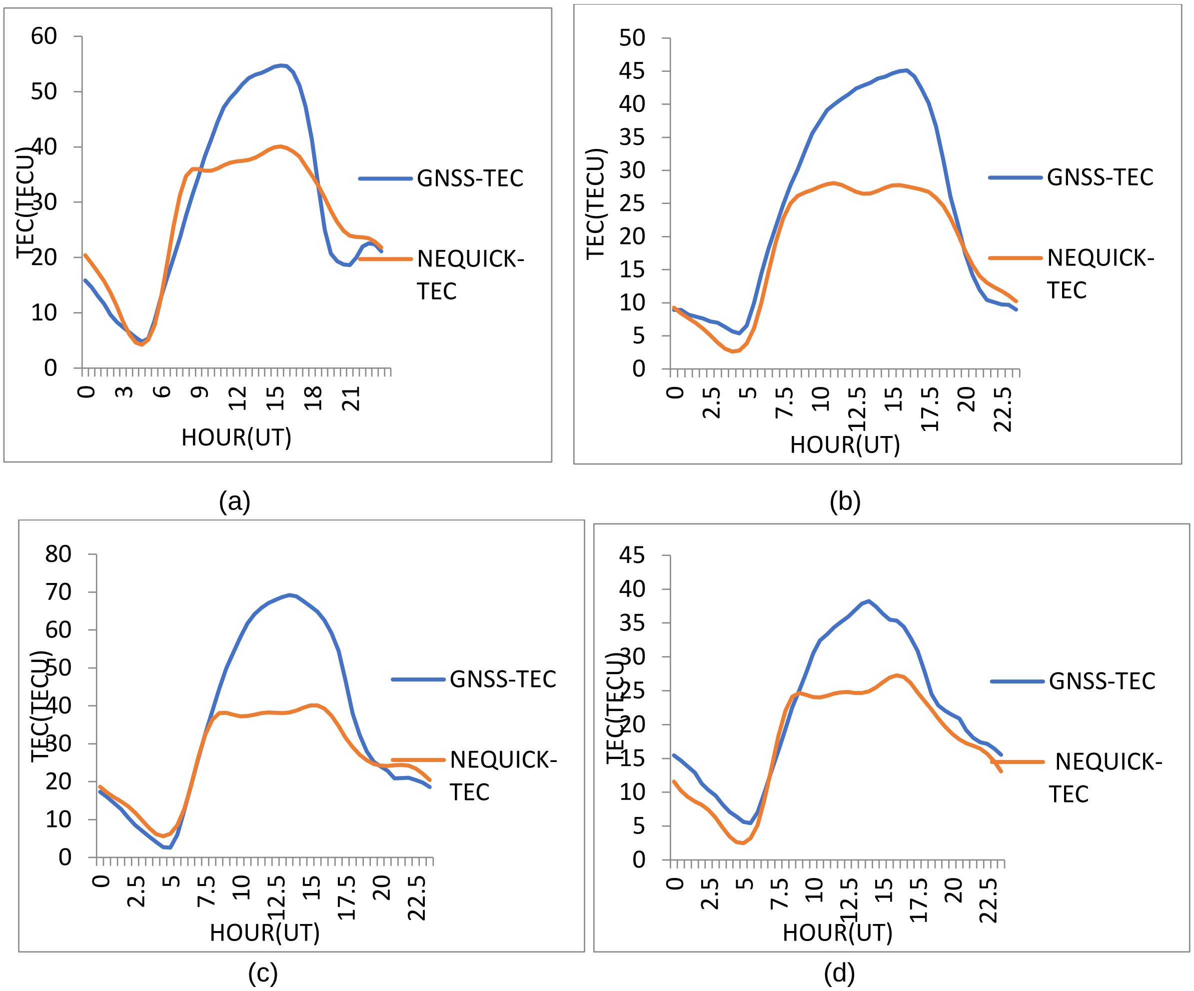


(c)



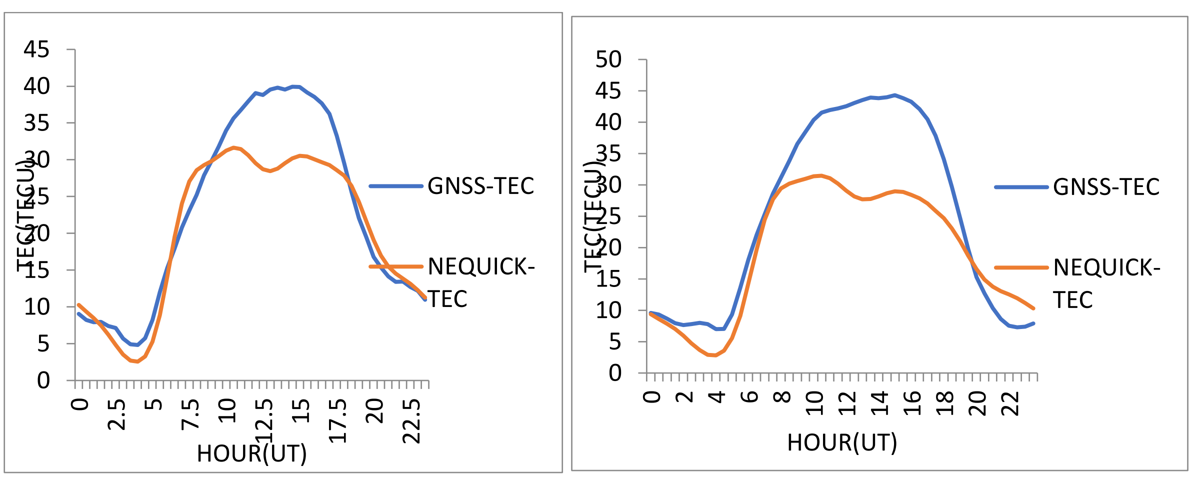
(d)

Figure 1: Hourly Variations in GNSS – TEC and NEQUICK – TEC at ABUZ during: (a) March Equinox 2011; (b) June Solstice 2012; (c) September Equinox 2013 and; (d) December Solstice 2014.

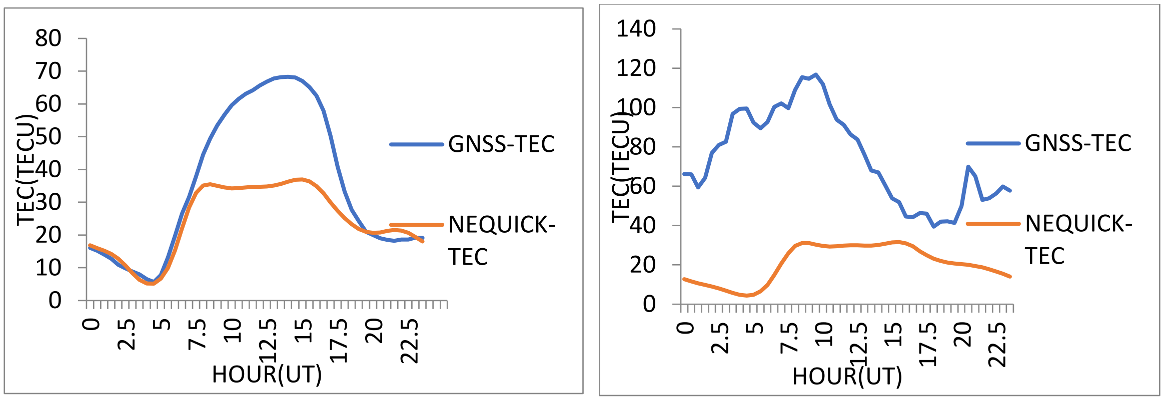


(a) (b) (c) (d)

Figure 2: Hourly Variations in GNSS – TEC and NEQUICK – TEC at BKFP during: (a) March Equinox 2012; (b) June Solstice 2013 (c) September Equinox 2014 and; (d) December Solstice 2011.



(a) (b)



(c) (d)

Figure 3: Hourly Variations in GNSS – TEC and NEQUICK – TEC at CGGT during: (a) March Equinox 2011; (b) June Solstice 2013; (c) September Equinox 2011 and; (d) December Solstice 2012.

Figure 1a shows that during March equinox, large variations of TEC were observed between GPS – TEC and NEQUICK – TEC in day time, while night time variations are found to be almost constant for GPS – TEC and NEQUICK – TEC. These variations in TEC maybe attributed to the changes in solar activities which are associated with changes in the intensity of incoming radiations. Hourly minimum VTEC of 4.1 and 2.5 TECU for GPS – TEC and NEQUICK – TEC respectively were observed at about 04:00 UT. There was a steep rise of VTEC to 39.2 TECU and 30.0 TECU for GPS – TEC and NEQUICK – TEC respectively with a constant or steady variation between 10.00 and 17.5 UT and a drop to twilight minimum. From Figure 1a, Nequick 2 model estimates TEC from 0:00 to 06:00 UT and 19:00 to 23:00 UT; hence estimating TEC during the time interval. Nequick 2 model under estimates TEC from 10:00 to 19:00 UT. This is in line with the observation made by [8] which states that the NeQuick 2 model to compute TEC behaves better during night-time than during day-time and better during low than during high solar activity.

During June solstice 2012 (Fig. 1b), the results indicate that the hourly variations of TEC in ABUZ show an obvious peak structure in the post noon time. Hence, the VTEC exhibits a steady rise from about sunrise (04:00 UT) to an afternoon maximum (15:00 UT) during June Solstice 2012.

The hourly maxima of GPS – TEC and NEQUICK – TEC of about 43.7 and 26.0 TECU respectively were observed at about 16:00 UT with minima VTEC of 5.5 and 2.5 TECU, respectively, recorded at about 04:00 UT. Nequick 2 model estimates TEC from 0.00 to 06:00 UT and 19:00 to 23:00 UT. During this time interval, Nequick 2 model estimates TEC. This completely agrees with a similar work done by [3], where they asserted in their experimental study, that the NeQuick 2 model produced better results.

From the results of September equinox 2013 (Fig. 1c) observations show that GPS – TEC and NEQUICK – TEC were in phase from 03:00 to 07:00 UT, which indicate that Nequick 2 model validates TEC for that period of time. From 07:00 to 10:00 UT, Nequick 2 model over estimates TEC which may be attributed to the lack of data between 07:00 and about 09:00 UT for the equinoctial month. This can be observed in the steep curve with a subsequent rise of GPS – TEC. Nequick 2 model under estimate TEC from 09:00 to 19:00 UT, where it estimates TEC before a drop is recorded for both GPS – TEC and NEQUICK – TEC.

Hourly maxima and minima for GPS – TEC and NEQUICK – TEC of about 46.7 and 35.7 TECU and 5.1 and 4.4 TECU, respectively were observed at about 15:00 and 04:00 UT. September equinox recorded a higher TEC value for the month under consideration for this station. This is in agreement with a similar work carried out by [15], where they found that the NeQuick results showed that the maximum variation in TEC appears in the equinox and the minimum occurs in the summer.

During December solstice (Fig. 1d) both GPS – TEC and NEQUICK – TEC present similar trends in signature for most of the solstice months. VTEC of this station has relatively higher values with the peak hourly value occurring at noon time. This is because the sun shines directly over equatorial region during the season and this leads to prolong and strongest hourly ionization over this period. This completely agrees with a similar work by [17] which state that the NeQuick 2 Model was especially effective and useful wherever ionosphere has more intense effects and larger perturbing offsets on ranging observables, like it happens at low geographic latitudes.

Hourly VTEC variation in BKFP station (Fig. 2a) shows a gradual rise in VTEC from about 04:00 to 10:00 UT during March equinox 2012 for both GPS – TEC and NEQUICK – TEC. Nequick 2 model estimates TEC within this time interval because GPS – TEC and NEQUICK – TEC were in phase. From 09:00 to 18:00 UT Nequick 2 model under estimates TEC and it also estimates TEC at 18:00 UT before a drop is recorded for both GPS – TEC and NEQUICK – TEC.

Hourly maximum GPS – TEC and NEQUICK – TEC of 54.7 and 40.0TECU respectively were observed at 16:00 UT and the minimum GPS – TEC and NEQUICK – TEC of 4.8 and 4.2 TECU respectively were recorded at 05:00 UT. This is in agreement with the work done by [19] which asserted that Nequick 2 model shows a good performance.

Figure 2b shows that the hourly variation of VTEC during June Solstice, 2013 exhibits a steady increase from about sunrise to an afternoon maximum and then falls to attain minimum just before sunset. The hourly variations in GPS – TEC and NEQUICK – TEC in this station show many characteristics typical of low latitude ionosphere such as a VTEC minimum at pre – dawn and gradual increase with the time of the day attaining a maximum in the afternoon and a gradual decrease after sunset [7]. The result also shows that the hourly peak values of VTEC occur around 14:00 to 16:00 UT. The curves show appreciable hour – to – hour variations of TEC, particularly during the mid – day to pre – dawn hours which may be attributed to the changes in the solar activity which is associated with changes in the intensity of the incoming solar radiation.

An hourly GPS – TEC and NEQUICK – TEC of 44.9 and 27.7 TECU respectively were observed at about 15:00 – 16:00 UT which gradually dropped to twilight at about 23:00 UT just before sunrise. Hourly minimum VTEC of 5.4 and 2.6 TECU for GPS – TEC and NEQUICK – TEC respectively were observed between 04:00 and 05:00 UT. This result agrees with the observation made by [8] that the NeQuick 2 model has a better TEC estimation during night-time than during day-time during high solar activity.

Hourly variations of VTEC for September equinox, 2014 (Fig. 2c) shows that Nequick model estimates TEC for this station from 0:00 to 08:00 UT during which GPS – TEC and NEQUICK – TEC were purely in phase. From 08:00 to 19:00 UT, Nequick 2 model under estimates TEC before recording a drop in a TEC to twilight minimum. NEQUICK – TEC shows a flat peak value during this time.

Hourly Peak VTEC values occur from about 13:00 to 15:00 UT throughout the season, with the highest values being exhibited during the equinoctial month for BKFP station. Hourly maximum GPS – TEC and NEQUICK – TEC of 69.2 and 40.1 TECU respectively were observed at about 13:00 and 15:00 UT. A minimum GPS – TEC and NEQUICK – TEC of 2.7 and 5.6 TECU were recorded at about 05:00 UT. The comparison between the NEQUICK – TEC and GPS – TEC carried out show a good agreement. This agrees with the work carried out by [15] in which they asserted that the NeQuick results showed that the maximum variation in TEC appears in the equinox and the minimum occurs in the summer.

From the plot of December Solstice 2011 for BKFP station (Fig. 2d) the hourly GPS – TEC and NEQUICK – TEC peak values of 38.2 and 27.0 TECU were observed at about 15:00 UT with minimum values of 5.6 and 2.6 TECU recorded at about 05:00 UT.

Figure 2d shows a minimum VTEC value recorded at pre – dawn and gradual increase with the time of the month for both GPS – TEC and NEQUICK – TEC which were in phase. From pre – noontime to post noontime Nequick model under estimates TEC before a drop in TEC for GPS – TEC and NEQUICK – TEC during nighttime. The exceptional result of BKFP station where the lowest VTEC was recorded during

December solstice as compared to equinox season is a thing of concern particularly for ionospheric researchers (Fig. 2d).

The hourly variations of VTEC for March equinox, 2011 (Fig. 3a), show that GPS – TEC and NEQUICK – TEC were in phase from 0:00 to 09:00 UT. Nequick 2 model under estimates TEC from about to about 18:00 UT, the model estimates TEC as TEC drops to minimum.

Hourly maximum GPS – TEC and NEQUICK – TEC of 39.9 and 30.5 TECU respectively were observed at about 15:00 UT (noontime). This is in agreement that the solar radiation which is strongest at this time interval of the month is the primary cause of the ionization process in the ionosphere. Minimum GPS – TEC and NEQUICK – TEC values of 4.8 and 2.6 TECU respectively were observed at about 05:00 UT, at about the start of sunrise which corresponds to the period when solar ionization due to the preceding sunrise is getting minimal. This is in agreement with a similar work done by [4] which asserted that NeQuick 2 model found a good improvement in the computation of VTEC.

GPS – TEC and NEQUICK – TEC present similar trends in signatures showing monthly variation in TEC which is clearly controlled by the solar activity and the Zenith angle during June solstice, 2013 (Fig. 3b). Result indicates that a monthly maximum GPS – TEC and NEQUICK – TEC of 44.3 and 31.5 TECU respectively were observed at about 15:00 and 11:00 UT. Hourly minimum GPS – TEC and NEQUICK – TEC of 6.9 and 2.8 TECU were recorded at the period before sunrise.

The signature of GPS – TEC and NEQUICK – TEC shows that Nequick model estimates TEC from about 0:00 to 08:00 UT and the model under estimates TEC from 08:00 to 19:00 UT (sunrise to post noontime). VTEC shows a drop to minima during night time. This agrees with a similar work done by [2] who observed that Galileo model provided a better TEC estimation.

From the results of VTEC in CGGT station for September equinox, 2011 (Fig. 3c) Nequick 2 model estimates TEC from 0:00 to 08:00 UT since GPS – TEC and NEQUICK – TEC were in phase, the model under estimates TEC from 08:00 to about 18:00 UT. Both GPS – TEC and NEQUICK – TEC show that the hourly peak of VTEC occurred during the day time with minima values occurring at pre – dawn and gradually increased with the time of the day thereby attaining a maximum value in the afternoon and a gradual decrease after the sunset. This is in line with the observation made by [8] which suggested that the NeQuick 2 model to determine TEC is possible during night-time than day-time during high solar activity.

Hourly minimum VTEC values of 5.7 and 5.2 TECU respectively were observed from 04:00 to 05:00 UT with hourly maximum VTEC values of 68.0 and 36.9 TECU observed from 14:00 to about 15:00 UT for GPS – TEC and NEQUICK –TEC, respectively. September equinox recorded the highest VTEC value for this station which supports the fact that the sun shines over the equator during the equinoctial months and thus leads to strongest ionization during this period. This agrees with a similar work done by [15] where they asserted that the NeQuick results showed that the maximum variation in TEC appears in the equinox and the minimum occurs in the summer.

From the plots, for December Solstice, 2012 (Fig. 3d) in CGGT station, the monthly GPS – TEC and NEQUICK – TEC pattern observed show different trends with those of the same station for March equinox, June solstice and September equinox; this could be due to the fact that December solstice recorded high solar activity as compared to other seasons for this station. This high TEC values have been attributed to the solar EUV ionization coupled with the upward vertical E X B drift.

Hourly minimum GPS – TEC and NEQUICK – TEC of 39.5 and 4.4 TECU were observed at about 18:00 and 05:00 UT, respectively. Hourly peak GPS – TEC and NEQUICK – TEC of 116.8 and 31.67 TECU were recorded at about 09:00 UT (pre – noontime) and 16:00 UT (post – noontime).

The signatures of GPS – TEC and NEQUICK – TEC shows that Nequick 2 model under estimates TEC during night time and noontime but estimates TEC during post noontime (16:00 to 17:00 UT). The signatures show that GNSS – TEC and NEQUICK – TEC are out of phase. This disagrees with a similar work done by [8] that states that the NeQuick 2 model to compute TEC behaves better during night-time than during day-time and better during low than during high solar activity.

GPS – TEC and NEQUICK – TEC recorded the highest TEC values as against the least TEC value for December solstice obtainable in other stations of the country. This completely disagrees with a similar work carried out by [15] where they found that the NeQuick results showed that the maximum variation in TEC appears in the equinox and the minimum occurs in the summer.

Conclusion

In this study, the Nequick TEC and GNSS TEC are purely in phase during night – time (0.00 – 06:00 UT and 18:00 – 23:00 UT) than during day – time (11:00 – 16:00 UT). Thus, Nequick 2 Model estimates TEC better during night time than during day time. Additionally, Nequick results showed that the maximum variation in TEC appears in March equinox and the minimum occurs in December Solstice with intermediate values during June Solstice.

The hourly peak value of the VTEC occurs around 13:00 and 14:00 UT with a minimum at pre – dawn and gradually increased with the time of the day, thereby attaining a maximum value in the afternoon and a gradual decrease after the sunset. Also, the maximum VTEC was observed during the equinoctial months with the minimum VTEC in solstices. The peak time of the hourly variation was found earlier at higher latitudes than at lower latitudes with a minimum VTEC which was consistently found to be earlier than 05:00 UT at all stations.

References

[1]. Angling, M. J. and Jackson-Booth N. K. (2011). A short note on the assimilation of collocated concurrent GPS and ionosonde data into the Electron Density Assimilative Model, *Radio Science,* **46**:13 – 20.

[2]. Angrisano, A., Gaglione, S., Gioia, C., Massaro, M., Robustelli, U and Santamaria, R. (2011). Ionospheric models comparison for single-frequency GNSS positioning, Department of Applied Sciences – PArthenope Navigation Group (PANG) "Parthenope", University of Naples, Italy.

[3]. Belabbas, B., Schlueter, S. and Sadeque, M. Z. (2009). Impact of NeQuick Correction Model to Positioning and Timing Accuracy using the Instantaneous Pseudo Range Error of Single Frequency Absolute Positioning Receivers, Deutsches Zentrum f¨ur Luft- und Raumfahrt (DLR), Germany. Pp1 – 14.

[4]. Bidaine, B., and Warnant R. (2010). Assessment of the NeQuick model at mid-latitudes using GNSS TEC and ionosonde data, *Advances in Space Research,* **45**: 1122–1128.

[5]. Bidaine, B. and Warnant R. (2011). Ionospheric modeling for Galileo single frequency users: Illustration of the combination of the NeQuick model and GNSS data ingestion, *Advances in Space Research*, **47**: 312–322.

[6]. Coïsson, P., Radicella, S. M., Leitinger, R. and Nava, B. (2006): Topside electron density in IRI and NeQuick: Features and Limitations, *Advances in Space Research,* **37:** 937-942.

[7]. Coïsson, P., Radicella, S. M., Nava, B. and Leitinger R. (2008a). Low and equatorial latitudes topside in NeQuick, *Journal of Atmospheric and Solar Terrestrial Physics,* **70:** 901–906.

[8]. Coı¨sson P., Nava, B., Radicella, S.M., Oladipo, O.A., Adeniyi, J.O., Gopi Krishna, S., Rama Rao, P.V.S. and Ravindran, S. (2008b). NeQuick bottomside analysis at low latitudes *Journal of Atmospheric and Solar-Terrestrial Physics*, **70**(1): 1911–1918.

[9]. Di Giovanni, G., and Radicella, S. M. (1990). An analytical model of the electron density profile in the ionosphere, *Advances in Space Research,* **10**: 27–30.

[10]. Farah, A. M. A. (2008). Comparison of GPS/Galileo single frequency ionospheric model with vertical TEC maps, *Artificial Satellite,* **43**(2): 75–90.

[11]. Jakowski, N., Mayer, C., Hoque, M. M. and Wilken, V. (2011). Total electron content models and their use in ionosphere monitoring*, Radio Science*, **46**:18 – 25.

[12]. Jodogne, J. C., Nebdi, H. and Warnant R. (2004). GPS and TEC from Digisonde data compared with NeQuick model, *Advanced Radio Science*, **2**: 269–273.

[13]. Jones, W. B., and Gallet R. M. (1962). The representation of diurnal and geographical ionospheric data by numerical methods, *Journal of Research of the National Bureau of Standards,* **66**: 419–438.
[14]. Komjathy, A., Langley, R. B. and Bilitza D. (1998). Ingesting GPS-derived TEC data into the International Reference Ionosphere for single frequency radar altimeter ionosphere delay corrections, , *Advances in Space Research,* **22**: 793–801.
[15]. Mahrous, A. M., AbuElezz, O. A., Abdallah, A. M. and Fleury, R. (2014). Comparison between the NeQuick Model and VTEC Estimation by GPS Measurements over Egypt, *Politecnico di Torin, Torino, Italy, .* **10**(1):5772 –8773.
[16]. Nava, B., Radicella, S. M., Leitinger, R. and Coïsson P. (2006). A near-real-time model-assisted ionosphere electron density retrieval method, *Radio Science,* **41**:16 – 24.
[17]. Nava, B., Coïsson, P. and Radicella S. M. (2008). A new version of the NeQuick ionosphere electron density model, *Journal of Atmospheric and Solar-Terrestrial Physics*, **70**: 1856–1862.
[18]. Orus, R., Arbesser-rastburg, B., Prieto-cerdeira, R., Hernandez-pajares, M., Juan J.M., and Sanz J. (2007). Performance of different Ionospheric models for single frequency Navigation receivers, , IBSS-07. Proceeding, Boston
[19]. Orus, R. and Prieto-cerdeira R. (2008): GIOVE-A Experimentation campaign: ionospheric related analysis, presented at NAVITEC, (Noordwijk).
[20]. Radicella, S. M., and Leitinger R. (2001). The evolution of the DGR approach to model electron density profiles, *Advances in Space Research,* **27**: 35–40.
[21]. Radicella, S. M., Nava, B. and Coïsson P. (2008). Ionospheric models for GNSS single frequency range delay corrections, *Fisica de la Tierra,* **20**: 27–39.
[22]. Schunk, R. W., Sojka, J. J. and Eccles I. V. (1997). Expanded capabilities for the ionospheric forecast model, Air Force Research Laboratory, Hanscom Air Force Base, Massachuettes, Pp149.
[23]. Schunk, R. W., Sojka, J. J. and Eccles I. V. (2004). Global Assimilation of Ionospheric Measurements (GAIM), *Radio Sciences,* **39**:2 – 9.