ASSESSMENT OF NEQUICK MODEL AT LAGOS, NIGERIA USING GPS TEC

A. O. Adewale[1], **Y. O. Migoya Orué**[2], **E. O. Oyeyemi**[1]
[1]Department of Physics, University of Lagos, Nigeria; olajide3000@yahoo.com
[2]Aeronomy and Radiopropagation Laboratory, ICTP, Via Beirut 7, Trieste, Italy; yenca@ictp.it

Abstract

Diurnal variation of vertical total electron content (VTEC) over Lagos, Nigeria (6.52° N, 3.39° E, dip latitude 3.03° S) during low solar activity period (2010) and a comparison with NeQuick–model-derived VTEC, are presented in this paper. VTEC generally increases from 0600 h LT and reaches its maximum value at approximately 1400 to 1700 h LT during all months considered. Our result shows that NeQuick model provide a good prediction during daytime and nighttime at Lagos, although some improvements are still required in order to have increase navigational accuracy for single frequency Global Positioning System (GPS) receivers. The pre-sunrise and noontime deviations between modelled and observed VTEC could arise because either the peak electron density of the F2 region (NmF2) or the shape of the electron density profile, or both, are not well modelled.

Keywords: *Ionosphere; Total Electron Content (TEC); NeQuick; GPS.*

INTRODUCTION

Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS) and GALILEO Satellite System, are satellite based navigation systems that can help to meet the Vision 20:2020 of the present administration in Nigeria. Specifically, GNSS applications can be used to increase food security, manage natural resources, provide efficient emergency location services, improve surveying and mapping, and provide greater precision and safety in land, water and air navigation systems. The benefits of GNSS for Nigeria (and in Africa) have been recognized (Adewale *et al.*, 2012). International organizations have initiated the deployment of GNSS ground based stations for both geodetic and conservation activities, and scientific exploration. These stations have been logging data and several research works are being carried out. The present study is part of the numerous works undertaken by scientists from Africa collaborating with other scientists all over the world. The GPS, the US component of the GNSS, is a satellite-based navigation system consisting of a network of 24 satellites in 6 orbital planes with 4 satellites in each plane. The GPS satellites orbit at an altitude of about 20,200 km with an orbital plane inclination of 55 degrees to the Earth's equator. Each satellite transmits signals at two frequencies, 1575.42 MHz (L1) and

1227.60 MHz (L2). The Earth's ionosphere is an important error source for GPS signals. The ionosphere, extending from a height of about 50 km to about 1000 km above the earth, is a region of free electrons and ions in quantities sufficient to affect propagation of radio signals. For single-frequency GPS receivers, the most common receivers in the market, the range error caused by the ionosphere is currently the largest source of error in positioning accuracy. In order to correct this error, single frequency users must use ionospheric delay models. The Klobuchar model (Klobuchar, 1987) is being used by the GPS receivers and this model is able to reduce 50% - 60% root mean square error (RMSE) of the total ionospheric delay. The European component of GNSS, GALILEO, uses the NeQuick model (Radicella and Leitinger, 2001; Nava *et al.*, 2008) to correct the ionospheric error contribution so as to improve the positioning accuracy from single-frequency receivers. NeQuick is an ionospheric electron density model, known as a "profiler", developed at the Aeronomy and Radiopropagation Laboratory (ARPL) of The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy and the Institute for Geophysics, Astrophysics and Meteorology (IGAM) of the University of Graz, Austria (Radicella and Leitinger, 2001). In order to reach the ionosphere error correction level objective of NeQuick and to maintain its global model status, the model has to be investigated using total electron content (TEC) data from stations outside Europe.

Several authors have investigated the performance of NeQuick model at different locations (Migoya Orué *et al.*; 2008; Co¿sson *et al.*, 2008; Bidaine and Warnant, 2010; Adewale *et al.*, 2011; Adewale *et al.*, 2012). Adewale *et al.* (2011), using data from Lagos (6.52°° N, 3.39°° E; dip latitude 3.03° S), reported that IRI-2007 (NeQuick option) gave a relatively poor TEC prediction between 0200 h and 0600 h LT, with the TEC percentage deviation ("TEC) having values greater than 50% during all seasons considered in year 2009. The "TEC never exceeded 50 % at any other hour of the day except at 0800 h LT during both December solstice and September equinox. The NeQuick option was run from IRI web interface (http://ccmc.gsfc.nasa.gov/modelweb/models/iri_vitmo.php) and the upper boundary of electron density profile in the IRI model was specified as 2000 km and B0 Table option for bottomside electron density shape parameter was used. A newer version of NeQuick model is now available that can integrate the electron density profile to an altitude of 20 000 km, hence it is important to validate this new version of NeQuick. The purpose of this research is to study the diurnal and seasonal variation of GPS-TEC over Lagos and to validate the latest version of NeQuick model using observed TEC parameters from Lagos, Nigeria, an equatorial station. The result of this study will show the potential of European NeQuick model at predicting TEC values over Lagos, Nigeria.

NEQUICK MODEL AND DATA

NeQuick is based on the Di Giovanni - Radicella (DGR) model (Di Giovanni and Radicella, 1990) which was modified to give vertical electron content from ground to 1000 km consistent with the European Cooperation in the field of Scientific and Technical Research (COST) 238 regional electron content model (Radicella and Zhang, 1995). NeQuick is a "profiler" which makes use of three profile anchor points: E layer peak (at a fixed height of 120 km), F1 peak, F2 peak. It uses the ionosonde parameters foE, foF1, foF2 (critical frequencies) and M3000(F2) (propagation factor) to model the anchor points. The bottom side of the electron density profile consists of the superposition of three Epstein layers which peak at the anchor points. The Epstein layers have different thickness parameters for their bottom and top sides (5 "semi-Epstein" layers). The topside of the electron density profile consists of the topside of an Epstein layer with a height dependent thickness parameter (Coïsson *et al.*, 2006; Nava *et al.*, 2008). The NeQuick source code package used for this study uses the following inputs: height (km), latitude (degrees N), longitude (degrees E), month (1, 2,...12), 10.7 cm solar radio flux (flux units) and Universal Time (hours). The output (function value) is vertical total electron content (VTEC) in TECunits (TECU).

The experimental data used for this research were obtained from the Low-latitude Ionospheric Sensor Network (LISN) website (http://jro.igp.gob.pe/lisn). The observation files obtained from LISN were processed by the GPS-TEC analysis application software, developed by Gopi Seemala of the Institute for Scientific Research, Boston College, U.S.A. In order to minimize the multipath effects on GPS data, elevation cut off of 30Ú was used. In addition to eliminating the errors from multipath, we also remove satellite and receiver biases from the TEC values used in this present study. The satellite and receiver bias values were obtained from the data center of Bern University, Switzerland. The slant TEC (STEC) calculated from phase and group TEC is polluted with the receiver and satellite biases. The VTEC is derived from STEC by using the equation:

$$\mathrm{VTEC} = [\mathrm{STEC} - (b_R + b_S)] / S(E) \qquad (1)$$

where b_R is the interfrequency differential receiver biases and b_S the interfrequency differential satellite biases. The mapping function S(E) (Mannucci *et al.*, 1993) employed is given by

$$S(E) = \frac{1}{\cos(z)} = \left\{ 1 - \left(\frac{R_E \times \cos(E)}{R_E + h_S} \right)^2 \right\}^{-0.5} \qquad (2)$$

with

z = zenith angle of the satellite as seen from the observing station,

R_E = radius of the Earth,

E = the elevation angle in radians, and

h_s = the altitude of the thin layer above the surface of the Earth (taken as 350 km).

We have used hourly average values of VTEC for May, June, July, August, September, October and November 2010. Data for other months were not available. The observed values of VTEC are compared with the values predicted by the latest version of NeQuick model.

The root-mean-square error (*RMSE*) has been used to quantify the performance of the NeQuick;

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{1}{N}\left(VTEC_{obs} - VTEC_{NeQ}\right)^2} \quad (3)$$

where N is the number of data points and $VTEC_{obs}$ and $VTEC_{NeQ}$ are the observed and modelled VTEC values, respectively.

RESULTS

Figures 1-3 show the diurnal plots of the comparison between the observed average GPS-VTEC values and NeQuick model predictions. The standard deviation (stdev) of the experimental data from the mean value is also shown in the plot. The stdev values never exceeded 10 TECU except in October. The figures show that the minimum VTEC value for both experimental VTEC and NeQuick VTEC occurred around 0500 h – 0600 h LT for all the months. The time of maximum values for experimental and NeQuick VTEC occurred during the 1400 h – 1700 h LT period. The result for June Solstice (JUNSOLS) (May, June and July) shows good agreement between experimental and NeQuick VTEC except during 0300 h – 0700 h LT and 1100 h – 1500 h LT. Figure 1 shows VTEC depletion in NeQuick plot which is not shown in the experimental data. Figure 2 shows the result for September Equinox (SEPEQUI) (August, September and October). The result shows that NeQuick overestimates experimental VTEC by up to 5 TECU during 1000 h – 1700 h LT. Table 1 shows the root mean square error (RMSE) between measured and modelled values of VTEC for all the months. Our result shows that the RMSE is lowest in the JUNSOLS and highest in November. Figure 4 shows the difference (DTEC) between experimental and predicted VTEC. DTEC generally increases from 0000 h LT and reaches pre-sunrise maximum around 0500 h LT, after which it decreases to a minimum around 0800 h LT. It has noontime maximum around 1200 h – 1400 h LT. The difference between experimental and predicted VTEC lies within ±10 TECU.

Table 1: Root mean square error (RMSE) between measured and predicted values of VTEC

Month	**RMSE**
May	2.21
June	2.00
July	2.63
August	3.23
September	3.80
October	4.24
November	4.49

DISCUSSION

We have investigated the diurnal variations of experimental VTEC and its comparison with NeQuick model during a year of low solar activity over an equatorial station. The standard deviation of observed VTEC in October between 1500 and 1900 LT shows the higher variation that exists from the mean value when compared to other periods. This dispersion might be caused by day-to-day ionospheric variability, which is controlled by equatorial electrojet (Bhuyan and Borah, 2007). A lower standard deviation in other months indicates that the observed VTEC tend to be very close to the mean. Our result shows that observed and predicted VTEC values exhibit the usual diurnal variation of a minimum in the pre-sunrise hours (0500 h – 0600 h LT) and a maximum between 1400 and 1700 LT. These variations are associated with the production of solar radiations during daytime (Fejer *et al.*, 1991; Lee and Reinisch, 2006). Our result also shows that NeQuick model overestimates and underestimates the observed VTEC at different hours of the day. In the newest version of NeQuick model, the formula for peak electron density height of F2 layer (hmF2) (Radicella and Zhang, 1995) are based on the Dudeney (1978, 1983) formula. The semi-thickness parameter for the F2 layer are expressed by various formulas relating hmF2, thickness parameter and peak electron density of the F2 region (N_mF_2) as explained in Nava *et al.* (2008). The pre-sunrise and noontime deviations between modelled and observed VTEC could arise because either the N_mF2 or the shape of the electron density profile, or both, are not well modelled by the NeQuick model. Ezquer *et al.* (1998) and Migoya Orué *et al.* (2008) also attributed this discrepancy to the profile shape in the model.

CONCLUSION

This paper examined VTEC variation over Lagos, Nigeria during the year 2010, a year of low solar activity (with an average sunspot number of 16.0) and also considered the validation of the NeQuick model VTEC values. VTEC values generally increase from 0600 h LT and reach a maximum value during 1400 h – 1700 h LT. The results show that the NeQuick modelled values follow the diurnal and seasonal variation patterns of the observed values of VTEC. In general, NeQuick model provides a relatively good prediction during daytime and nighttime at Lagos in May and June; the prediction is poor during the daytime in August, September, October and November. Adewale *et al.*, (2011) reported that IRI-2007 gave a relatively poor TEC prediction between 0200 h and 0600 h LT. They used the NeQuick option in IRI-2007 and we have used the new improved NeQuick model in this analysis. Hence some improvements are still required in order to have increase navigational accuracy for single frequency receivers. This is necessary because NeQuick modelling of TEC plays a significant role in GNSS accuracy, especially for single-frequency receivers since the model has been chosen for correcting the ionospheric error contribution and effort is being made to integrate the model into a global algorithm providing every user with daily updated information.

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REFERENCES

1. Adewale, A.O., Oyeyemi, E.O., Adeniyi, J.O., Adeloye, A.B, and Oladipo, O.A. (2011). Comparison of total electron content predicted using the

IRI-2007 model with GPS observations over Lagos, Nigeria. *Indian Journal of Radio and Space Physics* **40**: 21-25.

2. Adewale, A.O., Oyeyemi, E.O., Cilliers, P. J., McKinnell, L.A., and Adeloye, A.B. (2012). Low Solar Activity Variability and IRI 2007 predictability of Equatorial Africa GPS TEC. *Advances in Space Research* **49**, 316–326.
3. 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.
4. Bhuyan, P.K., and Borah, R.R. (2007). TEC derived from GPS network in India and comparison with the IRI. *Advances in Space Research* **39**: 830-840.
5. Coïsson, P., Radicella, S.M., Leitinger, and R. Nava, B. (2006). Topside electron density in IRI and NeQuick: features and limitations. *Advances in Space Research* **37**: 937-942.
6. 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, 1990.
7. Dudeney, J.R. (1978). An improved model of the variation of electron concentration with height in the ionosphere. *Journal of Atmospheric and Terrestrial Physics* **40**, 195–203.
8. Dudeney, J.R. (1983). The accuracy of simple methods for determining the height of the maximum electron concentration of the F2-layer from scaled ionospheric characteristics. *Journal of Atmospheric and Terrestrial Physics* **45**, 629–640.
9. Ezquer, R.G., Jadur, C.A., and de Gonzalez M. (1998). IRI-95 TEC predictions for the South American peak of the equatorial anomaly. *Advances in Space Research* **22** (6), 811-814.
10. Fejer, B.G., de Paula, E.R., Gonzales, S.A. and Woodman, R.F. (1991). Average vertical and zonal plasma drift over Jicamarca. *Journal of Geophysical Research* **96**: 13901-13906.
11. Klobuchar, J.A. (1987). Ionospheric time delay Algorithm for single frequency GPS users. *IEEE Transaction on Aerospace and Electronic System (AES),* **23**(3): 325-331.
12. Lee, C.C. and Reinisch, B.W. (2006). Quiet-condition hmF2, NmF2 and B0 variations at Jicamarca and comparisons with IRI-2001 during solar maximum. *Journal of Atmospheric and Solar-Terrestrial Physics* **68**: 2138-2146.
13. Mannucci, A.J., Wilson, B.D., and Edwards, C.D. (1993). A new method for monitoring the earth's ionosphere total electron content using the GPS global network. In: proceedings of ION GPS-93, Institute of Navigation, 1323-1332.
14. Migoya Orué, Y.O., Radicella, S.M., Coïsson, P., Ezquer, R.G., and Nava, B. (2008). Comparing TOPEX TEC measurements with IRI predictions. *Advances in Space Research* **42**, 757–762.

15. Nava, B., Co¿sson, 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.
16. Radicella, S.M. and Zhang, M.L. (1995). The improved DGR analytical model of electron density height profile and total electron content in the ionosphere. *Annali di Geofisica* **XXXVIII** (1), 35–41.
17. Radicella, S.M., and Leitinger, R. (2001). The evolution of the DGR approach to model electron density profiles. *Advances in Space Research* **27** (1): 35-40.