PHYSICAL SCIENCES

NEQUICK MODEL PREDICTIONS AND THE OBSERVED TOTAL ELECTRON CONTENT (TEC) OVER NIGERIA

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ABSTRACT
The Sun and its various activities such as coronal mass ejection (CME), solar flare, and solar wind is the major driver of the magnetosphere processes that have a strong bearing on the ionosphere. The equatorial ionosphere is in a constant state of perturbation because of the parallel alignment of the geomagnetic field with the surface, this is termed equatorial ionosphere anomaly. This resulted in the east - west electromagnetic field drift which is known as equatorial electrojet and the night time occurrence of scintillation/plasma bubble which is a major challenge to effective utilization of global navigation satellite systems (GNSS) especially in the equatorial region for navigation, positioning and communication. Various models have been established in the prediction of ionospheric processes and perturbations in order to establish the stability and effectiveness of modern technologies which rely solely on the ionosphere. One of such models is the NeQuick2 of the International Centre for Theoretical Physics (ICTP) Trieste which is use to predict the state of the ionosphere and it Total Electron Content (TEC). Effort were being made in this work to compare NeQuick2 model prediction with the observational data obtained from Nigeria GNSS network of two stations in Nigeria namely Enugu (UNEC) and Zaria (ABUZ). The research examines TEC during both intense geomagnetic storm period and quiet period over the two GNSS stations in Nigeria. It was discovered that NeQuick2 model may not accurately predict TEC behaviour over Nigeria, situated in the region of equatorial ionosphere anomaly. The implications are further discussed.

Keywords: *Geomagnetic storm, GNSS, Equatorial ionosphere, Ionosphere models*

INTRODUCTION

The Sun and its various activities (Figure 1 and 2) such as coronal mass ejection (CME), solar flare, and solar wind is the major driver of the magnetosphere processes that have a strong bearing on the ionosphere. The ionosphere is the region of the upper atmosphere where sufficient ionized species (electrons) exist to affect radio waves propagation (Kutiev *et al*., 2013). The structure and shape of the ionosphere is driven mainly by solar activity. The equatorial ionosphere is in a constant state of perturbation because of the parallel alignment of the geomagnetic field with the surface. This resulted in the east - west electromagnetic field drift which is known as equatorial electrojet and the night time occurrence of scintillation/plasma bubble that poses a major challenge to effective utilization of global navigation satellite systems (GNSS) especially in the equatorial region for navigation, positioning and communication (Buonsanto, 1999). Fluctuations in the total electron content cause ionospheric delay that resulted in GNSS positioning error (Omojola and Abimbola, 2015). Various models have been established in the prediction of ionospheric processes and perturbations in order to establish the stability and effectiveness of modern technologies which rely solely on the ionosphere. One of such models is the NeQuick2.

NeQuick gives an analytical representation of the vertical electron density profile. It was developed by the International Centre for Theoretical Physics (ICTP) Trieste, Italy and the Institute for Geophysics, Astrophysics and Meteorology university of Graz, Austria (Nava, 2014, Coisson *et al.*, 2008) as a quick run model tailored for trans- ionospheric propagation applications. It is an empirical model mainly driven by the monthly average solar flux (F10.7) and the ionospheric F2 peak parameters computed by the International Telecommunication Union (ITU) foF2 and M (3000) F2 models (ITU R – 1995). Recently, NeQuick version 1 was substituted for NeQuick2 and is the one currently recommended by ITU (ITU – R P.531 – 12) the package include routine to evaluate the electron density along any ground – to – satellite ray path and also estimate the corresponding total electron content by numerical integration (Nava *et al.*,2008, Radicella, 2009).

GNSS signal measurements interaction with the ionosphere has become one of the major tools for the estimation of total electron content along satellite – to – receiver ray path (Minkwitz *et al*., 2015, Nava, 2008). The range error of GNSS signals correspond to the total electron content (TEC) along propagation path, it is dependent on frequency (F) of propagation according to equation 1

$$Range\ error = \frac{\pm 40.3TEC}{F^2}\ \text{(m)} \qquad \ldots\ldots\ldots\ldots 1$$

Total electron content is the total number of electrons in a unit square meter cross sectional area along satellite – receiver ray path (Equation 2)

$$TEC = \int_R^S N_e ds \qquad \ldots\ldots\ldots 2$$

TEC is usually expressed in total electron content units (TECU), 1 TECU is equivalent to 10 16 electrons/m^2 Ne is the total number of electrons in each square meter area through the differential distance (ds) along satellite receiver ray path.

The equatorial ionosphere of African sector in general, is an area which has the largest land mass that fall within the equatorial ionosphere anomaly region with a complex electrodynamics morphology which is yet to be fully understood (Tariku, 2015)

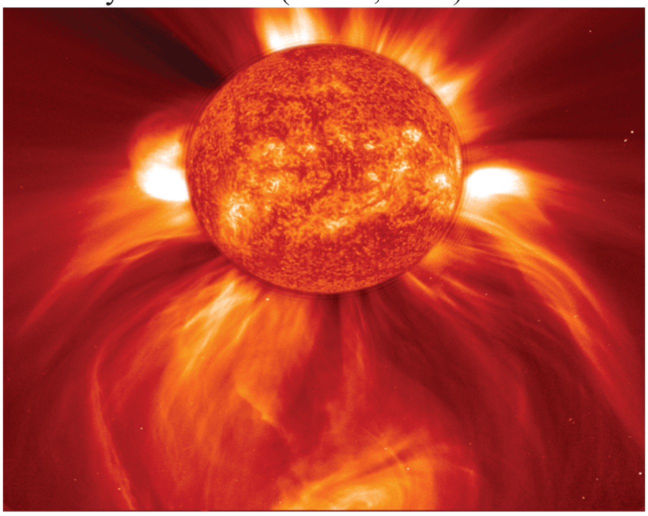

Figure 1: Active Sun

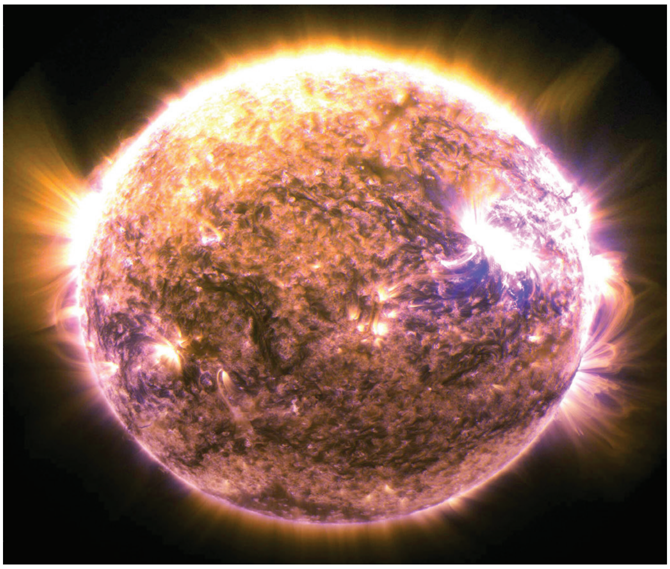

Figure 2: Quiet Sun

(Figure 1 and 2 was adapted from the website of international space weather initiative (ISWI))

This work seeks to validate NeQuick 2 model with observational data obtained from Nigeria GNSS network over the two stations during intense geomagnetic storms and a geomagnetically quiet period. It is always a necessity to validate empirical models with the observational data sources.

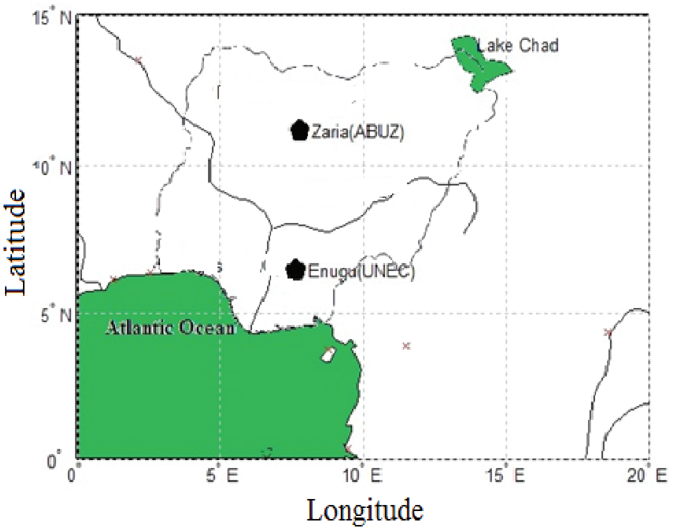

Figure 3: Map of Nigeria showing the location of the two Nignet stations

MATERIALS AND METHODS

The three (3) selected storms for this can be classified as intense. Standard nomenclature for intense storms usually have disturbance storm time (Dst-index) minimum of less than (Stankov *et al.*, 2010). The Dst-index data for storm period and the quiet time was downloaded from World Data Centre for geomagnetism (WDC) Kyoto, Japan (wdc.kugi.kyoto-u.ac.jp/dst) which was corroborated by the International Quiet Day (IQD) and international Disturbed Days (IDD) data from Geosciences Australia website (www.ga.gov.au/oracle/geomag/igd_form.jsp). Daily RINEX file data for the selected quiet day and storm day were downloaded from Nigeria GNSS stations website (server.nignet.net/data). The two stations are Zaria (ABUZ: Latitude; 11.1517^{0}E, Longitude; 7.6486^{0}N) and Enugu (UNEC: Latitude; 6.4237^{0}E, Longitude; 7.5048^{0}N) both located in Nigeria (Figure 3). NeQuick2 estimated VTEC was obtained from the website (http://t-ict4d.ictp.it/nequick2)

Gopi GPS – TEC analysis software version 2.9.3 was used to estimate the vertical total electron content (VTEC) over the stations. The NeQuick 2 model VTEC was plotted over the GNSS VTEC observed over the two stations for both storm period and quiet time using Matlab for further analysis in order to validate NeQuick 2 VTEC estimation with the observational data over the two stations.

The Percentage deviation was calculated using the relation in equation 3

$$\%devuation = \frac{Observation\ VTEC - NeQuick2\ VTEC}{Observation\ VTEC} \text{ X } 100 \quad ....3$$

RESULTS AND DISCUSSION

Vertical TEC (VTEC) as estimated by NeQuick2 model and the GNSS observational data (GPS – VTEC) was plotted with the disturbance storm time (Dst) on a three panel plots for the two stations (Figure 4, 5, 6, 7, 8, 9). The NeQuick2 model generally under estimate TEC in the noon period for both geomagnetically disturb period and quiet period which agrees with Coisson *et al.,* (2008) that NeQuick model underestimate TEC in the equatorial region, but this work reveal that NeQuick2 also over estimate TEC in the pre noon and post noon period over the two stations in Nigeria which a higher value during the geomagnetically quiet day.

a. ABUZ STATION

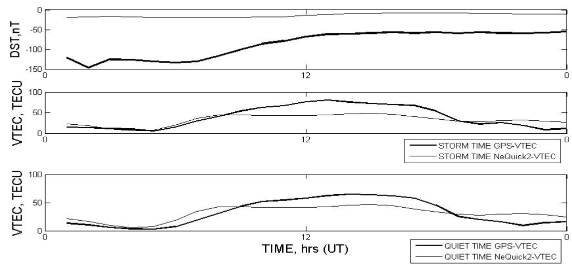

Figure 4: GNSS and NeQuick2 VTEC plots for the intense geomagnetic storm and the quiet period in October 2011 at ABUZ

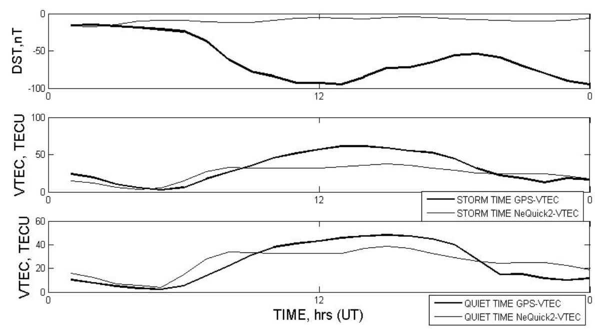

Figure 5: GNSS and NeQuick2 VTEC plots for the intense geomagnetic storm and the quiet period in October 2012 at ABUZ

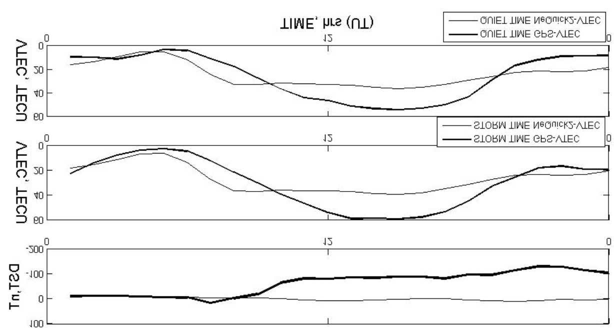

Figure 6: GNSS and NeQuick2 VTEC plots for the intense geomagnetic storm and the quiet period in October 2013 at ABUZ

b. UNEC STATION

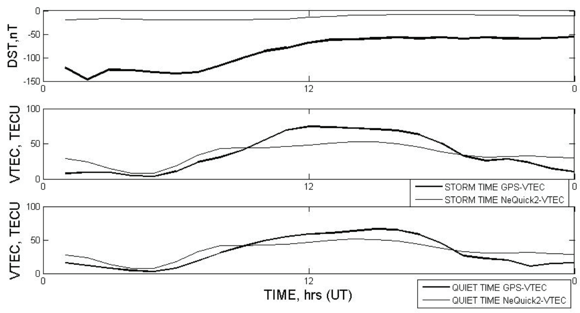

Figure 7: GNSS and NeQuick2 VTEC plots for the intense geomagnetic storm and the quiet period in October 2011 at UNEC

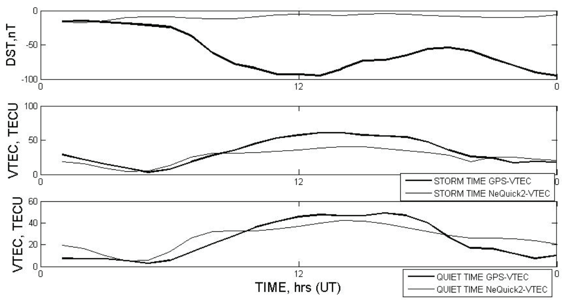

Figure 8: GNSS and NeQuick2 VTEC plots for the intense geomagnetic storm and the quiet period in October 2012 at UNEC

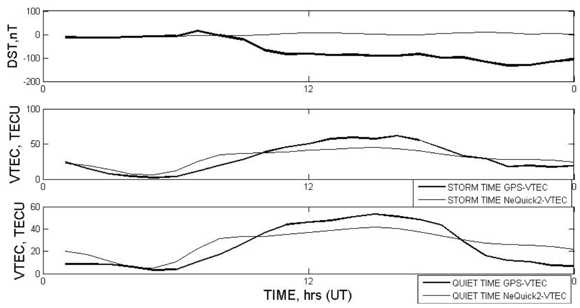

Figure 9: GNSS and NeQuick 2 VTEC plots for the intense geomagnetic storm and the quiet period in October 2013 at UNEC

There is no much difference between the model predictions during intense geomagnetic storm and during quiet period which means the model may not give accurate prediction of the geomagnetic storm effect.

The model may still not be able to include accurate solar flux parameter of the equatorial region of African sector and the seasonal and diurnal variation in the equatorial ionosphere electrodynamics.

Percentage deviations over the two stations show a higher pre – noon and post noon over estimation for the geomagnetically quiet day (Figure 10, 11, 12, 13, 14 and 15) with the highest occurring in the March (Figure 12 and Figure 15).

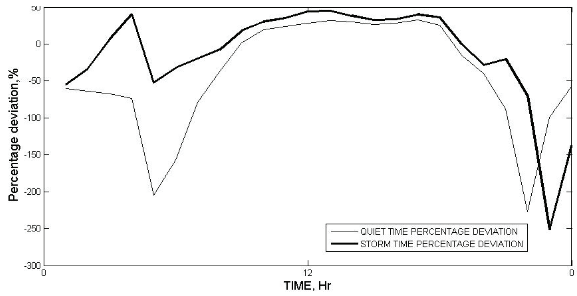

Figure 10: Hourly Percentage deviation over ABUZ during the storm day and quiet day in October, 2011

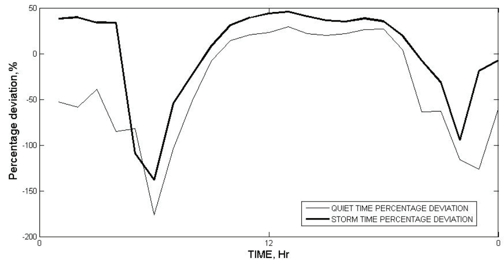

Figure 11: Hourly Percentage deviation over ABUZ during the storm day and quiet day in October, 2012

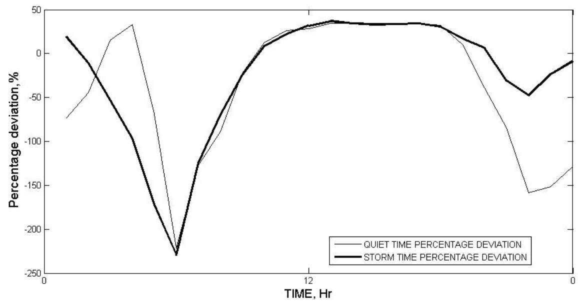

Figure 12: Hourly Percentage deviation over ABUZ during the storm day and quiet day in March, 2013

UNEC Stations

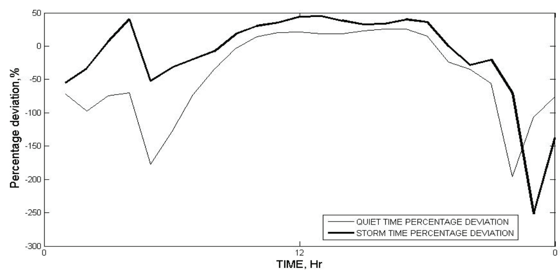

Figure 14: Hourly Percentage deviation over UNEC during the storm day and quiet day in October, 2011

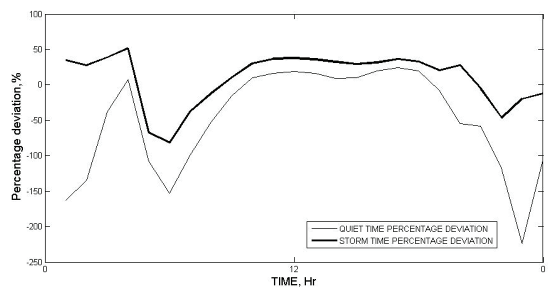

Figure 13: Hourly Percentage deviation over UNEC during the storm day and quiet day in October, 2012

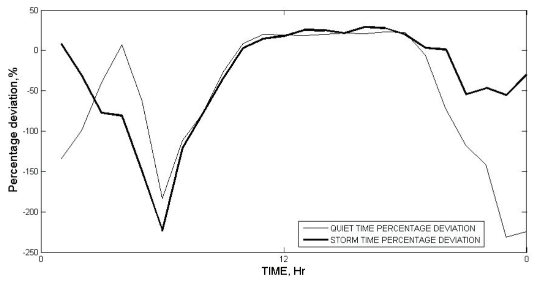

Figure 15: Hourly Percentage deviation over UNEC during the storm day and quiet day in October, 2013

CONCLUSION

We have studied Total electron content as predicted by NeQuick 2 model and the GNSS estimated TEC from the observation data. We have also calculated the percentage deviation of the observed Tec from the NeQuick model prediction. It can be inferred that NeQuick 2 model may not yet give an accurate TEC prediction over the equatorial region of African sector.

NeQuick 2 over estimate TEC in the pre-noon and post noon period over the equatorial station of African sector and also under estimate TEC in the noon period. The pre noon and the post noon over estimation are higher during geomagnetically quiet period than during the intense geomagnetic storm for the two stations.

Since range error is directly proportional to TEC along propagation path (Amit *et al.*, 2010) and 6.15 TECU correspond to 1m range error on L1 frequency and 1.7m range error on L2 frequency. Improper modeling of TEC may have a devastating effect on global navigation satellite systems and all technologies that relied on GNSS in the region under study.

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