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Research Article

Optimization of NeQuick 2 TEC Predictions over Nigeria using Solar Flux

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Abstract

In this study, optimization of NeQuick 2 TEC predictions over Nigeria using the Solar Flux at 10.7 cm was investigated. Measured F10.7 was compared with those estimated by NEQUICK 2 model. It was observed that optimal F10.7 was not always in agreement with those measurements at solstice. Observed F10.7 variability was compared with optimal F10.7 variability at all stations for a period of four years. The result from this work gives an idea on the spatial and temporal distribution of observed F10.7 and optimal F10.7 values at various ionospheric stations over Nigeria, which in turn will be useful tool for communication, aviation sectors, military defense and space weather researchers in estimating ionospheric behaviors necessary for direction findings, correction of ionospheric effects on positioning and navigation systems. Above all this work shows that in spite of the high activities in the Sun, there are appreciable F10.7 variations over the Nigerian ionosphere with high F10.7 values in the equinoctial months. A Study of the variability of observed F10.7 and optimal F10.7 from NEQUICK model predictions at different region during different solar and geomagnetic conditions is suggested for further works.

Keywords: NEQUICK2 model, Ionosphere, optimization, solar flux.

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Introduction

NeQuick model generates TEC along a given ray path as well as electron density distributions for a given height, UT, month, geographic latitude and longitude giving the potentiality for satellite-satellite as well as ground-satellite link corrections. The model adopts a simple formulation (Semi-Epstein layer) and the Epstein formulation for the bottom side ionosphere, with a thickness parameter advancing linearly with height. A set of ionogram parameters (CCIR1 coefficients) is a basis NeQuick model. The two vital parts of the model are: The top side model for the height region above the F2-layer peak and the bottom side model for the height region below the peak of the F2-layer. The monthly average of solar radio flux at about 10 cm wavelengths (F10.7) is also needed as a necessary input parameter. The F10.7 index is the noise level generated by the sun at a wavelength of 10.7 cm at the earth's orbit, a measure of the solar activity. It has been establish to correspond exactly with the sunspot number (Rz). The sunspot number is defined from counts as a solar activity index has been substituted by the F10.7 index due to the ease and speed with which it can be determined for many purposes. F10.7 index can be used as a daily index or averaged over longer periods (typically averaged over a month or a year although sometimes a 90 day average is made) to depict the trends in solar activity. The relationship between these quantities is noticeable but there is still appreciable scatter even for monthly-mean values. The following equations are useful for changing between the F10.7 index (F10.7) and sunspot number (Rz). The equations are valid on a statistical (i.e. average) basis [14].

$$F10.7 = 67.0 + 0.572\ Rz + (0.0575\ Rz)^2 - (0.0209\ Rz)^3 \quad (1)$$

$$Rz = 1.61\ FD - (0.0733\ FD)^2 + (0.0240\ FD)^3 \quad (2)$$

Where, Flux Density, FD = F10.7 - 67.0.

A full explanation of the model can be seen in [8] as well as the NeQuick model source code.

The following procedure should be followed (as proposed by AG-IONO) to reproduce the GALILEO ionosphere corrections for single frequency receivers using NeQuick 2 model. The primary goal is to optimize the NeQuick 2 model as a function of the effective ionization level (Az) to the observed STEC values. The Az parameter (F10.7 corrected including the latitudinal dependence) is the driver for the model optimization to the reference measurements at the selected monitor stations. For every station, all the satellite links are taken into account and the sum of squares of observed minus computed STEC are calculated [2]:

$$(\Delta STEC)^2 = \sum_{GPSlink}[STEC_{0bserved}(Az) - STEC_{Modeled}(Az)]^2 \quad (3)$$

STEC Observed values from each GPS monitor station to every satellite in view are required. STEC Modeled values along each ray path from receiver to satellite are calculated using the NeQuick 2 model, as a function of the Az parameter. The next step is to minimize $(\Delta STEC)^2$ as a function of the Az parameter, to find the optimum Az and thus defining the daily Az value for the station. This has been implemented at intervals of 24 hours and at a sampling rate of 30 minutes for the data.

In order to characterize the electron density of the ionosphere up to 1000 km and up to the *F*2 layer peak, this model makes use of modified Di Giovanni Radicella (DGR) profile formulation. A semi-Epstein layer which shows the electron density distribution in the topside alongside height dependent thickness parameter empirically determined.

The model has been adopted by the International Telecommunication Union, Radio communication Sector (ITU-R) Recommendation as a suitable method for TEC modeling [8]. The fundamental inputs of the NeQuick 2 model code are: position, time and solar flux (or sunspot number); the output is the electron concentration at the given location in space and time. Furthermore, the NeQuick package includes particular routines to determine the electron density along any ray-path and the equivalent TEC by numerical integration.

Nequick model is used to deduce ionospheric delays in the Raw Data Generation (RDG) capability of the Galileo System Simulation Facility (GSSF) [10]. It was adopted in the Global Ionospheric Scintillation Model (GISM) to ascertain the background ionosphere [5].

A very vital use of the NeQuick 2 model is, without doubt, its implementation as the model for ionospheric corrections in the single frequency operation of the European GALILEO satellite navigation system [3]. For its usage by the GALILEO system the model will be driven by an (effective ionisation level) Az, defined as follows [2]:

$$Az(\mu) = a0 + a1\mu + a2\mu2 \tag{4}$$

Where μ is the modip, a geomagnetic coordinate made known by [13], and the coefficients *a0, a1, a2* are distributed to the user to permit Az calculation at any chosen location. At system level, a set of universal broadcasted monitoring stations will be used to determine the slant TEC required to calculate the values of the global parameters *a0, a1, a2* which describe the global behavior of Az for a particular day. NeQuick 2 model driven by the parameters broadcast during the next day is applied at user level to calculate the slant TEC along any ray-path satellite-receiver.

The performance of Nequick 2 has been evaluated as shown in the literatures [1, 4, 6, 7, 9, 11 and 12]. The results from each of these researches portray how Nequick 2 model has been applied in the optimization of TEC in different locations.

Materials and method

Sources of data

The observed F10.7 data used in this work were obtained from the daily F10. The F10.7 value data is a daily data for the period of four years (2011 – 2014). Additionally, the optimal value (F10.7) data were generated using a MATLAB program incorporated with NEQUICK 2 model. The F10.7 value generated is the optimal F10.7 value.

Data generation

The F10.7 values obtained were arranged with the corresponding day of the year. The F10.7 values were generated using the optimal or best sunspot number that produces the best TEC value for that particular station using a MATLAB program incorporated with NEQUICK model. The data were generated for fourteen GPS station in Nigeria using the latitudes and longitudes of these stations for a period of four years (2011 – 2014). The mean values of F10.7 from these stations in Nigeria were then obtained using Excel program to obtain a single daily Nequick (optimal) F10.7 value for Nigeria for a period of four years (2011 – 2014).

Data plotting

The daily Nequick (optimal) value for each station was computed to get the mean value across Nigeria and these values were plotted alongside the GNSS (observed) value across Nigeria for validation of Nequick 2 model.

Results and discussion

The processed data for daily variations of optimal F10.71 values of Nigeria stations (9.08^{o}N, 8.68^{o}E) during the months of the years 2011, 2012, 2013 and 2014 are presented. The corresponding plots for processed data are shown in the following Figures, namely, Figure 1a: Daily F10.71 values for Nigeria observed during 2011, Figure 1b: Daily F10.71 values for Nigeria observed during 2012, Figure 1c: Daily F10.71 values for Nigeria observed during 2013 and Figure 1d: Daily F10.71 values for Nigeria observed during 2014.

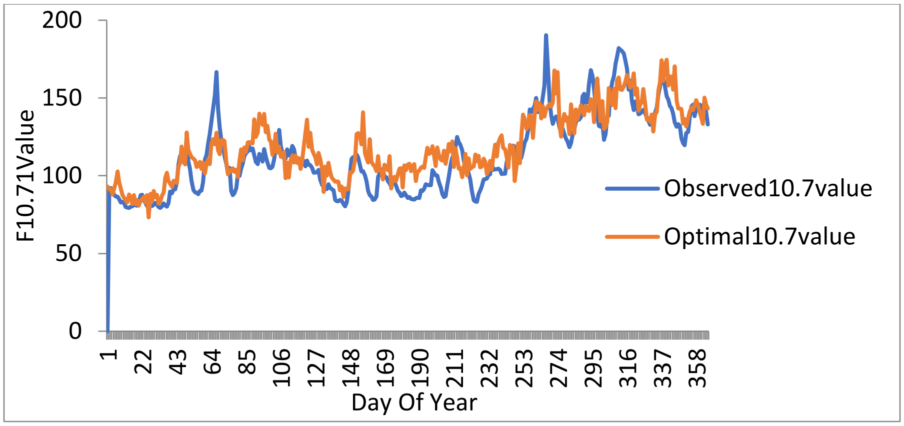

Figure 1a: Daily F10.71 values for Nigeria observed during

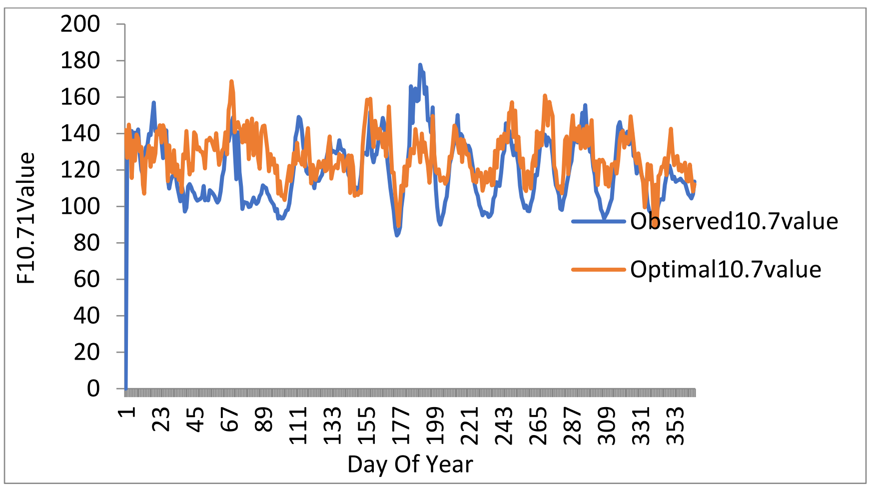

Figure1b: Daily F10.71 values for Nigeria observed during 2012

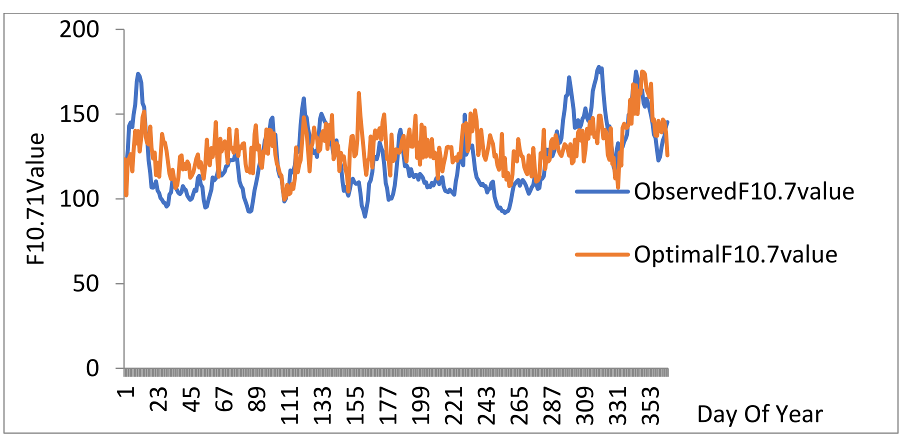

Figure 1c: Daily F10.71 values for Nigeria observed during 2013

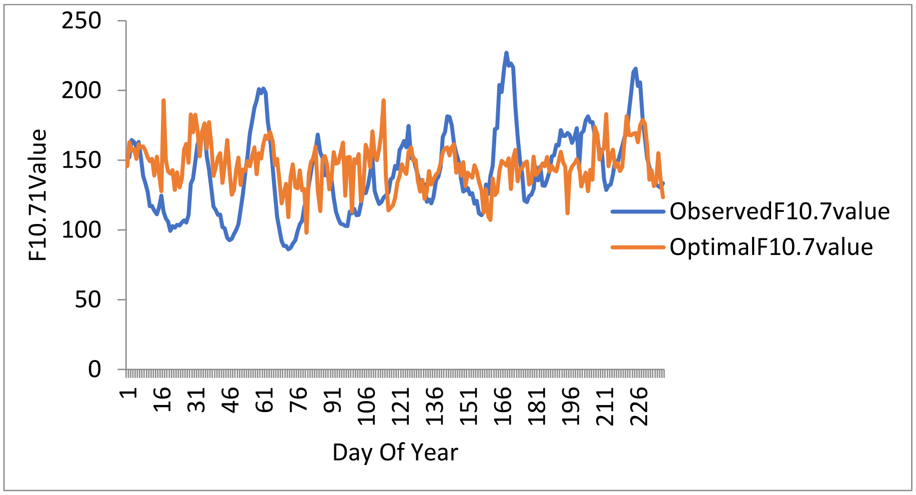

Figure 1d: Daily F10.71 values for Nigeria observed during 2014

The yearly variations of observed F10.7 and optimal F10.7 over Nigeria (9.08°N, 8.68°E) were studied by plotting observed and optimal F10.7 for 2011 as shown in Figure 1a. The results show that the daily variation of F10.71 over Nigeria is characterized by remarkable peaks, occurring in September equinox (observed F10.71) and the others occur in December solstice (optimal F10.71). A daily minimum observed F10.7 and optimal F10.71 occurred in December solstice. This accounts for the high and high TEC values obtained in September equinox and December solstice for most of stations in Nigeria in 2011.

The yearly variations of F10.7 observed in Nigeria during 2011 indicate that the maximum observed F10.7 value of 190 occurred on day 267 (September equinox) and minima observed F10.7 value of 80.6 occurred on day 28 (December solstice). Also, the yearly peak of optimal F10.7 value of 174.3 occurred on day 337 (December solstice) with a minimum optimal F10.7 value of 73 occurred on day 26 (December solstice). This accounts for the high TEC values recorded in equinoctial month and low TEC values recorded in solstice months for most of the stations considered.

The yearly variations of observed F10.7 and optimal F10.7 over Nigeria (9.08°N, 8.68°E) were studied by plotting observed and optimal F10.7 for 2012 as shown in Figures 1b. The results show that the daily variation of F10.71 over Nigeria is characterized by remarkable peaks, occurring in June solstice (observed F10.71) and the other occurring in March equinox (optimal F10.71). A daily minimum observed and optimal F10.71 occurred in June solstice. The yearly variations of F10.7 observed in Nigeria during 2012 indicate that the maximum observed F10.7 value of 177.7 occurred on day 190 (June solstice) and minima observed F10.7 value of 84 occurred on day 175 (June solstice). Also, the yearly peak of optimal F10.7 value of 168.7 occurred on day 69 (March equinox) with a minimum optimal F10.7 value of 88 occurred on day 175 (June solstice).

The yearly variations of observed F10.7 and optimal F10.7 over Nigeria (9.08^{o}N, 8.68^{o}E) were studied by plotting observed and optimal F10.7 for 2013 as shown in Figures 1c. The results show that the daily variation of F10.71 over Nigeria is characterized by remarkable peaks, occurring in September equinox (observed F10.71) and the other occurring in December solstice (optimal F10.71). A daily minimum observed and optimal F10.71 occurred in June solstice and March equinox. The yearly variations of F10.7 observed in Nigeria during 2013 indicate that the maximum observed F10.7 value of 175.8 occurred on day 318 (September equinox) and minima observed F10.7 value of 93.3 occurred on day 161 (June solstice). Also, the yearly peak of optimal F10.7 value of 175 occurred on day 348 (December solstice) with a minimum optimal F10.7 value of 99.6 occurred on day 108 (March equinox). This accounts for the high TEC values recorded in equinoctial month and low TEC values recorded in solstice months.

The yearly variations of observed F10.7 and optimal F10.7 over Nigeria (9.08^{o}N, 8.68^{o}E) were studied by plotting observed and optimal F10.7 for 2014 as shown in Figures 1d. The results show that the daily variation of F10.71 over Nigeria is characterized by obvious peaks, occurring in June solstice (observed F10.71) and the other occurring in December solstice and March equinox (optimal F10.71). A daily minimum observed and optimal F10.71 occurred in March equinox.

The yearly variations of F10.7 observed in Nigeria during 2014 indicate that the maximum observed F10.7 value of 227.1 occurred on day 168 (June solstice) and minima observed F10.7 value of 86.1 occurred on day 72 (March equinox). Also, the yearly peaks of optimal F10.7 value of 193 occurred on days 17 (December solstice) and 114 (March equinox), respectively, with a minimum optimal F10.7 value of 98 which occurred on day 80 (March equinox) and accounts for the high TEC value recorded in solstice month and low TEC values recorded in equinoctial months.

Conclusion

The study investigated the optimization of NeQuick 2 TEC predictions over Nigeria using the Solar Flux at 10.7 cm. From the results, TEC shows spatial and temporal variations and exhibits characteristics like the post sunrise and post sunset peaks, monthly, annual and semiannual variations and day to day variability. Additionally, the yearly variations of observed F10.7 in Nigeria indicated that F10.7 maxima occur during September equinox and minima during June solstice and the yearly variations of optimal F10.7 in Nigeria indicated that F10.7 maxima occur during March equinox and minima during June and December solstices.

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