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Improvement of B2bot correction factor for NeQuick 2 during the high solar activity at Saint Croix

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ABSTRACT

This work is a continuation of the previous work to focus on NeQuick 2 modeling effort during the high solar activity. The purpose of this paper is to implement further adaptation on B2bot correction factor. Single station technique is used to a set of slant TEC data at Saint Croix station (CRO1). The result indicates B2bot parameter of the NeQuick 2 varies during the day. The results provide an example to improve NeQuick 2 at a given location.

1. Introduction

NeQuick (presently implemented as version 2) is a three dimensional and time dependent ionospheric electron density model developed at Aeronomy and Radiopropagation Laboratory (ARPL), ITCP and IGAM, University of Graz. It has specifically been designed for trans-ionospheric propagation applications and it allows the calculation of the electron density at any given location in the ionosphere and also the Total Electron Content (TEC) along any ground station–to–satellite ray-path [1-2]. The NeQuick has been used to develop a near-real-time ionosphere electron density retrieval technique based on model adaptation to GPS-derived TEC data [3]. At present, NeQuick version 2 has been implemented to get the global ionospheric map [4-5].

In the previous work, the adaptation scheme was applied for the entire month of the specific location to monitor the discrepancies for *foF2* between the experimental and modeled data [6]. In the present work, it is found that the $B2_{bot}$ parameter varies at a single location which drives the correlation of experimental and retrieval *foF2* values.

Seasonal median values for the B2bot was tested and compared with the modeled formulae during the low solar activity at a given location by Wang et al. [7]. In this paper the new adaptation

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techniques are used during the high solar activity period to improve the $B2_{bot}$ parameter during the high solar activity for one-month long data.

2. NeQuick model

The model is based on the DGR ''profiler'' proposed by Di Giovanni and Radicella [8] and finally modified by Radicella and Zhang [9]. Modified DGR profile formulation [10] is used to describe the electron density of the ionosphere above 100 km and up to the *F2* layer peak which includes five semi-Epstein layers [11] with modeled thickness parameters. The NeQuick 2 is based on three profile anchor points: The E layer peak, the *F1* peak and the *F2* peak from the four ionosonde parameters: *foE, foF1, foF2* and *M (3000) F2*. The *F2* bottomside of the model can be expressed by a semi- Epstein layer with a height-dependent thickness parameter [12, 13]:

$$N_{Epstein}(h : h\max, N\max, B2_{bot}) = \frac{4N\max}{\left(1+\exp\left(\frac{h-h\max}{B2_{bot}}\right)\right)^2}\exp\left(\frac{h-h\max}{B2_{bot}}\right) \tag{1}$$

Where N_{max} is the layer peak electron density, h_{max} is the layer peak height and $B2_{bot}$ is the layer thickness parameter. The thickness parameters for the *F2* layer is given by

$$B2_{bot} = \frac{0.385NmF2}{(dN/dh)_{\max}} \tag{2}$$

The unit of the semi-thickness parameter $B2_{bot}$ in *km* and it depends on the maximum of the electron density derivative with respect to height [4, 8].

$$\ln\left(\left(\frac{dN}{dh}\right)_{\max}\right) = -3.467 + 1.714\ln(foF2) + 2.02\ln(M(3000)F2) \tag{3}$$

where dN/dh is in $10^9 m^{-3} km^{-1}$ and *foF2* in *MHz*.

3. Data analysis

This work is a continuation of the previous work [6] and is focused on the high solar activity and modeling effort. In the present work, single station technique has been applied to the GPS derived TEC data obtained from the CRO1 receiver (lat. 17.75N, longitude 295.41 E). The 27 days of March 2000 (a geomagnetic quiet period in high solar activity), slant TEC data at 30 sec. time interval have been used. Day 17 and 28 are not taken into account due to unavailability of ionosonde data. The TEC data on March 01, 2000 and March 02, 2000 were unavailable. For simplicity, the sampling interval has been increased to 1 hour and only slant TEC data corresponding to satellite links with an elevation greater than 10^{o} have been considered. Hence 3,866 slant TEC data and 649 *foF2* values have been used for the statistical analysis. In addition, 27 days of manually scaled *foF2* data at 1-hour time interval have been obtained from Puerto Rico ionosonde (PRJ18) that is located in the vicinity of CRO1 receiver (18.5 N, -67.1 E).

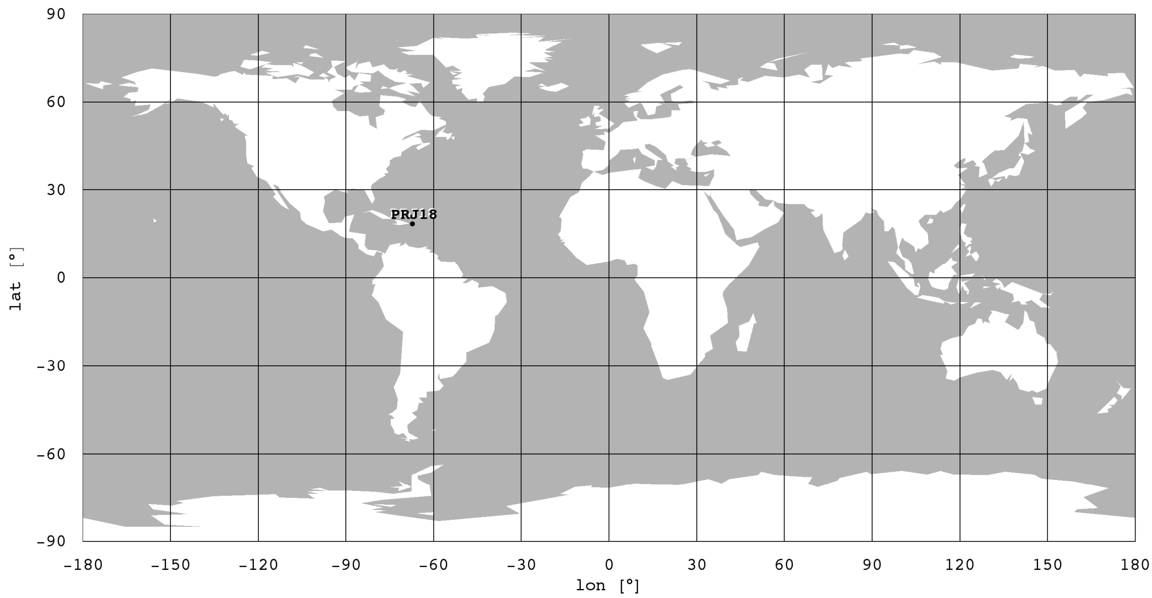

Fig. 1. Location of Puerto Rico ionosonde (black) and nearly co-located GPS receiver whose data have been used to adapt the model to the location of interest for March 2000.

If all the experimental and retrieval *foF2* values are plotted using the model driven by *Az* as a function of time, in general it is possible to observe the pattern illustrated in figure 2. The figure 2 corresponds to the day March 26, 2000 and shows that in the first part of the day (between 3 to 9 UT) the modeled *foF2* is underestimated, whereas in the last part of the day (after 14 UT) the modeled *foF2* is overestimated. This means that though the modeled TEC matches with the experimental TEC by the means of root mean square, as required by the single station technique. Therefore, the *foF2* data are not always adequately described. A simplified explanation of this result can be given in terms of the model slab thickness τ, defined as

$$\tau = \frac{TEC}{N_{\max}} \tag{4}$$

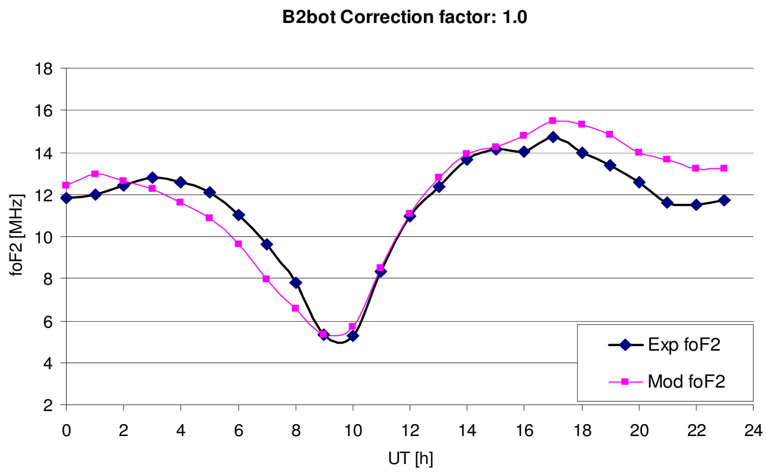

Fig. 2. Experimental and modeled *foF2* value for each hour on the day 26 in March 2000.

The vertical electron density profiles as shown in figure 3 have the same *TEC* but different N_{max} (namely *foF2*) and therefore different τ . Therefore, the results of these studies have also indicated that further improvement of NeQuick model formulation in terms of slab thickness is needed. Since the slab thickness is a function of $B2_{bot}$ a further adaptation scheme may to apply [14].

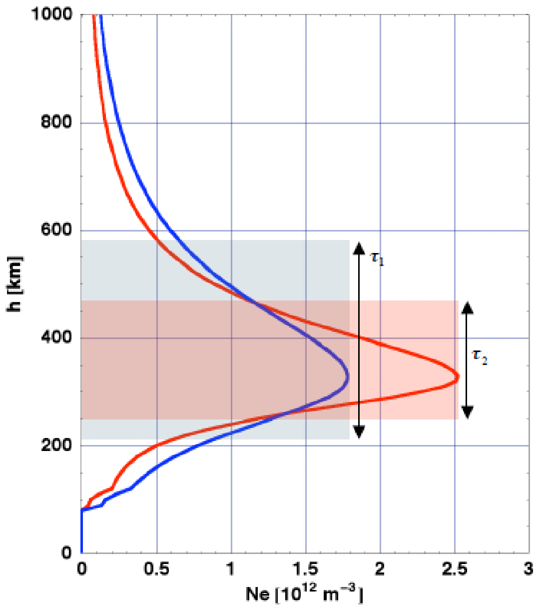

Fig. 2. An example of two modeled electron density profiles having the same TEC but different N_{max} (*foF2*) and slab thickness τ_1 and τ_2

4. Further adaptation technique

In addition to the adaptation to *TEC*, a procedure to adapt the NeQuick also to *foF2* data for a given location has been implemented. The procedure, proposed in Nava et al., is based on the "correction" of the $B2_{bot}$ model parameter [15].

More precisely, we assume to have at a given time a GPS receiver tracking *n* satellites and determining a set of *n* slant TEC values and a collocated ionosonde providing the relevant *foF2* value. If we apply the single station technique to this set of slant TEC for different values of a $B2_{bot}$ correction parameter, we obtain one *Az* value that minimizes the RMS of TEC mismodelings for each value of the $B2_{bot}$ correcting factor. Then the $B2_{bot}$ correcting factor that allows the NeQuick to match the experimental *foF2* is chosen together with the corresponding *Az*. Using these values of *Az* and $B2_{bot}$ correction factor, the NeQuick 2 can be used to compute the 3D electron density at the given location and time. And by definition the reconstructed slant *TEC* and *fof2* values will reproduce correctly the experimental ones. Hence, the calculation of the two parameters, *Az* and *B2bot* correction factor allow a more specific NeQuick adaptation to a given location for a given epoch.

In order to illustrate this adaptation scheme, the single station technique has been applied for the values of a $B2_{bot}$ correction parameter ranging from 0.5 to 1.5 with step 0.1. In particular, the retrieved *foF2* values corresponding to a given panel has been obtained with a specific value of the $B2_{bot}$ correcting factor. One of the examples is showed in figure 3 where the *foF2* values are taken with respect to each UT of the Day 03 in March, 2000 where the $B2_{bot}$ correction factor is variable quantity ranging in between 0.5 and 1.5.

The variation of $B2_{bot}$ correction factor has been tested for the entire month in order to obtain the correlation between $B2_{bot}$ correction factors and local time at a given location. The $B2_{bot}$ correction factor on March 3, 2000 is shown in Fig. 3.

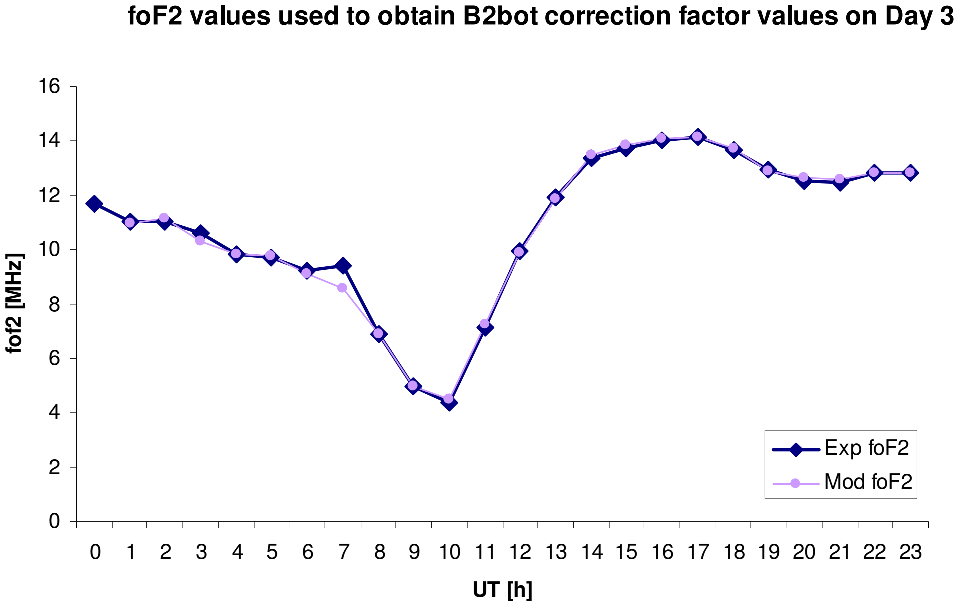

Fig. 3. The experimental foF2 (blue) and modeled foF2 (violet) are plotted with respect to the universal time (UT). Retrieved *foF2* for different values of the $B2_{bot}$ correction factor (after adapting TEC) on March 3, 2000.

The effectiveness of the modified retrieval technique has been evaluated through the statistical comparison between experimental and retrieved *foF2* data. More in detail, the statistics has been based on scatter plot of the retrieved against experimental values where the differences between experimental and retrieved values are defined as errors. The scatter plots illustrated in Figure 4 indicate a good agreement between experimental and retrieved data as requested by the *Az* technique and as indicated by the best fit line coefficient. In the left panel, in terms of TEC, the correlation coefficient R^2 is 0.97 which remains the same as before since the thickness parameter modification does not affect the TEC data.

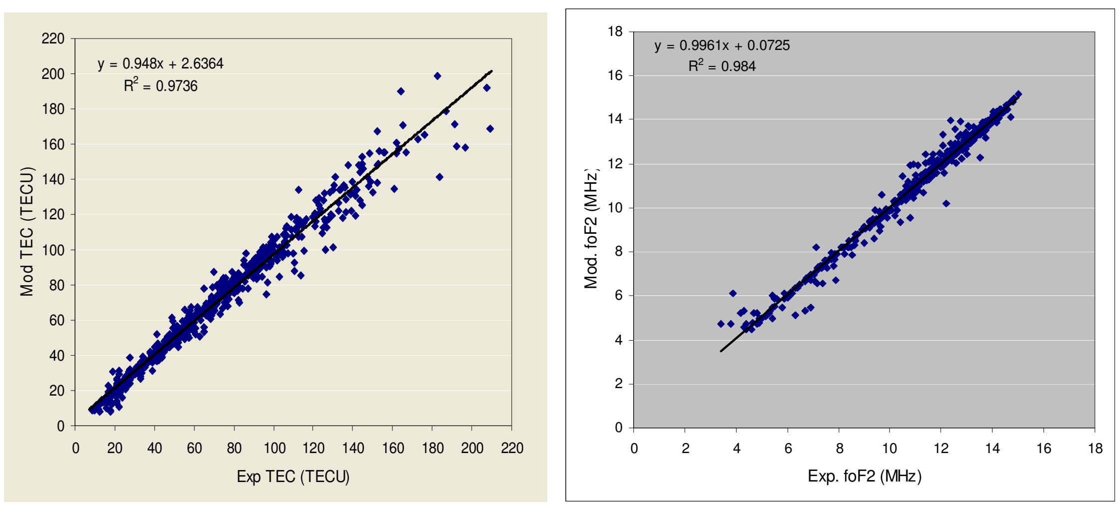

Fig. 4. NeQuick Driven by *Az* after the further adaptation. **Left:** modeled against modified slant TEC data for all UT in March 2000. **Right:** modeled against modified *foF2* data for all UT in March 2000.

In the right panel, a fairly better agreement between experimental and retrieved *foF2* data can be observed as confirmed by the correlation coefficient which is 0.99 while for the previous work [5], without the $B2_{bot}$ modification, the correlation coefficient was 0.89. The over estimation of *foF2* indicates that after the model adaptation to TEC, the retrieved *foF2* are higher than the measured ones. Since the manually operated *foF2* values are chosen after the modeled TEC data, the correlation of *foF2* is higher than the correlation of TEC, which is an overestimation.

Table 1 shows the statistical analysis for the *foF2* when the model driven by *F10.7, Az* and after the modification of the thickness parameter. As seen from the table the correlation coefficient (0.99) is higher, lower error average (-0.029), lower standard deviation (0.330) and lower outliers (-2.22, 2.01) are observed after the modification.

Table 1
Statistical comparison of model driven by *Az* without modification of B2bot (2nd Column) and after the modification of $B2_{bot}$ correction (3rd Column).

	Using *Az* without modification of $B2_{bot}$	**Using *Az* with modification of $B2_{bot}$**
Error Average	-0.243	-0.029
Standard Deviation	1.0057	0.330
Correlation Coefficient	0.9	0.99
(Minimum, Maximum)	-2.88, 3.11	-2.22, 2.01

It is also noted that, statistical comparison in terms of TEC is not shown since the *foF2* is changing by the $B2_{bot}$ modification taking into account that TEC is remaining constant.

The $B2_{bot}$ correction factor that minimizes the difference between experimental and retrieved *foF2* has been extracted on each UT. The corresponding ionization parameter, *Az* that minimizes the root mean square (RMS) of TEC mismodelings is considered. The relevant *Az* values as a function of UT are plotted in figure 5 for the day March 26, 2000.

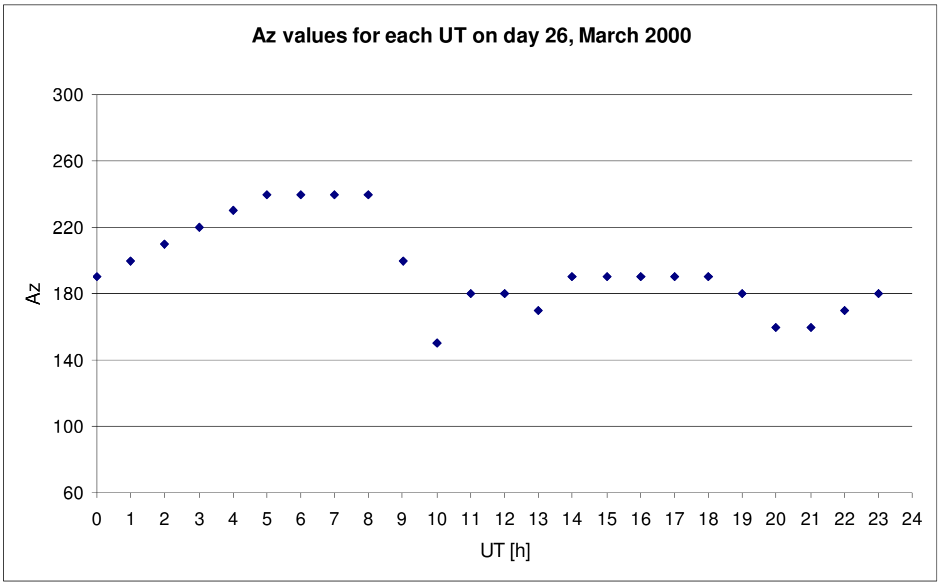

Fig. 5. Best *Az* value for each UT on the day 26 March 2000.

The model has been implemented for the entire month of the data to get the identical pattern for the $B2_{bot}$ correction factor with respect to each UT. The average correction factor on each UT is plotted on figure 6.

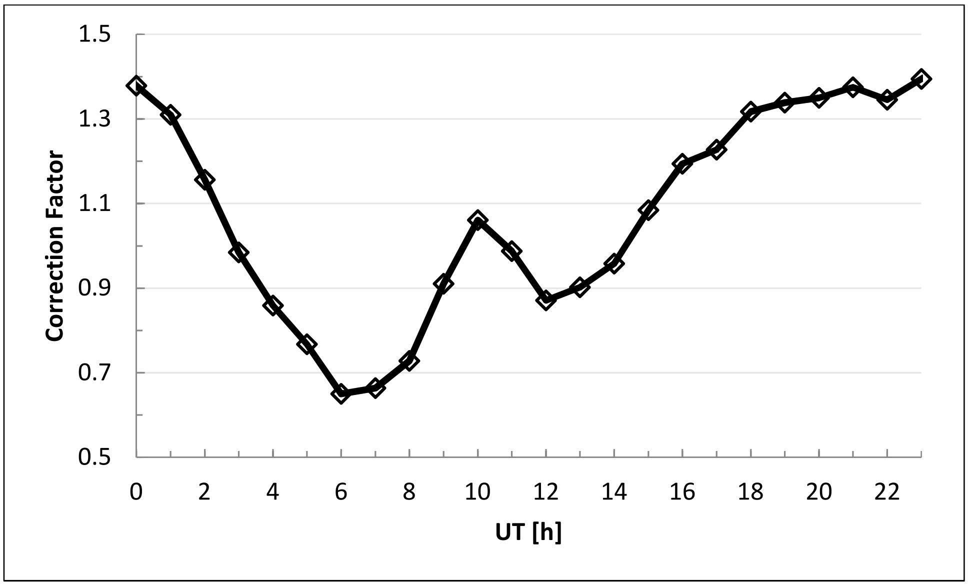

Fig. 6. Retrieved *foF2* for different values of the $B2_{bot}$ correction factor. For each epoch the mean value of the correction factor of March 2000 is plotted with respect to UT.

It is observed that after 12 UT, the $B2_{bot}$ correction factor generally increases. The correction factor decreases between 0 UT and 6 UT. The $B2_{bot}$ correction factor is the highest between 18 UT and 24 UT. The corresponded slab thickness varies diurnally. It is therefore related with the $B2_{bot}$ correction factor.

The thickness parameter is directly related to solar radiation [16]. The solar radiation during the period is nearly constant for the ionosphere. Therefore, the variation of the thickness parameter and the $B2_{bot}$ correction factor at a given location depends on the local time.

5. Conclusions and future work

The results provide an example to improve NeQuick 2 at a given location. The data analysis performed indicates that there is a remarkable improvement in terms of *foF2* reconstruction capabilities. It also appears that the correction factor of the NeQuick 2 varies diurnally. We hope to investigate the pattern of diurnal variation with longer period of data during the other solar activity.

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