

Validation of a method for ionospheric electron density reconstruction by means of vertical incidence data during quiet and storm periods

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Abstract

A preliminary validation of the technique developed using the NeQuick ionospheric model and the «effective ionization parameter» A_z , based on vertical total electron content data ingestion, was carried out in a previous study. The current study was performed to extend the analyzed conditions and confirm the results. The method to validate this technique is based on a comparison between hourly F_2 peak values measured with Vertical Incidence (VI) soundings and those calculated with the new technique. Data corresponding to different hours and seasons (equinox, summer solstice, and winter solstice) during the period 2000-2003 (high and medium solar activity conditions) were compared for all available ionosonde stations. The results show a good agreement between f_oF_2 and h_mF_2 values obtained with the new technique and measurements from vertical incidence soundings during quiet and storms conditions.

Key words *electron density model – vertical incidence ionograms – ionospheric data ingestion*

1. Introduction

One of the most unpredictable sources of error for single frequency satellite navigation and positioning systems is due to the ionosphere. A good knowledge of the behavior of the ionospheric regions is essential to obtain a better representation of parameters like the Total Electron Content (TEC) which is directly proportional to the time delay of electromagnetic signals.

A technique to reconstruct the spatial and temporal structure of the electron concentration in the ionosphere has been developed using the

NeQuick ionospheric electron density model driven by an «effective ionization parameter» called A_z (Nava *et al.*, 2003). NeQuick is a quick-run model for ionospheric applications developed at The Abdus Salam ICTP in Trieste (Italy) and the University of Graz (Austria). It has been used by the European Space Agency - ESA satellite navigation and positioning programs and adopted by Recommendation P.531-6 of the ITU-R (International Telecommunication Union, Radiocommunication sector) (now superseded by P.531-7; ITU, 2001).

A_z values are determined minimizing the differences between experimental and modeled vertical TEC global maps. The result is a global grid of A_z values for a specific condition which allows us to calculate with the NeQuick model the electron density at any point in the ionosphere including the F_2 peak parameters values.

The aim of this paper is to compare these calculated F_2 peak values with independent and simultaneous global observations in order to validate the technique. These measurements, the criti-

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cal frequency in the F_2 region (f_oF_2) and the height of the maximum of ionization (h_mF_2), are obtained experimentally from ground-based vertical ionospheric sounders located around the world.

A preliminary validation was done (Miró Amarante *et al.*, 2003) using data corresponding to four quiet days in the year 2002 (high solar activity conditions). The main results and conclusions of this analysis will be included in this paper.

2. Ionospheric parameters measured with vertical incidence soundings

The DIDbase software developed by Lowell University lets us extract ionograms from a network of digisondes distributed around the world. This possibility allows manual scaling of the available ionograms to measure the real values of the main ionospheric parameters (critical frequency, height, Ionospheric Total Electron Content - ITEC: Huang and Reinisch, 2001).

The analysis has been done for different conditions summarized in table I. For each period, all the available ionospheric stations were selected (fig. 1). The number of locations varies

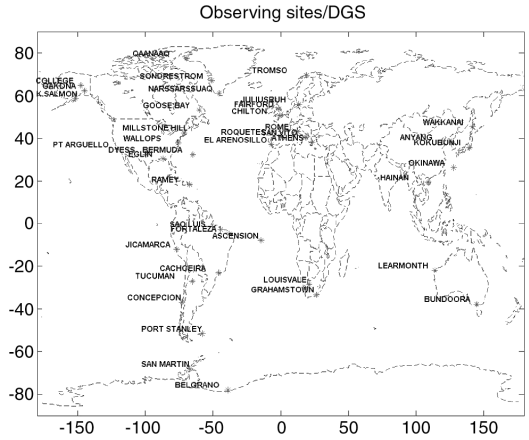


Fig. 1. Observing sites available for the periods analyzed.

from 13 during the period of March 2000 up to 27 for the 3rd of June 2002.

The manual scaling of the ionograms (almost 8300 ionograms) was done for each considered case and f_oF_2 and h_mF_2 were extracted to be compared with the reconstructed values.

Table I. List of selected periods for the validation of the reconstruction method.

Day	Month	Year	A_p	Dst	Sunspot number
25	03	2000	8	-9	185
26	03	2000	3	-1	170
27	03	2000	4	1	155
28	03	2000	4	1	169
15	04	2002	6	-8	138
03	06	2002	10	-21	133
11	10	2002	6	-38	121
25	11	2002	15	-46	56
19	11	2003	12	-179	70
20	11	2003	150	-152	90
21	11	2003	42	-76	97
22	11	2003	30	-63	83
23	11	2003	22	-38	109

3. Ionospheric parameters calculated with the reconstruction technique

Two global grids corresponding to f_oF_2 and h_mF_2 were obtained from the NeQuick model driven by the «effective ionization parameter» A_z . This parameter is calculated by means of the technique described in Nava *et al.* (2003) in such a way that the differences between experimental and NeQuick model vertical TEC are minimum. The experimental vertical TEC maps used for the minimization are generated with two different techniques. The first is the one developed by CODE (Centre for Orbits DEterminations, <http://www.cx.unibe.ch/aiub/ionosphere.html>) with two hour intervals and the second one was generated by the University of La Plata, Argentina with one hour intervals (Meza *et al.*, 2002; and Brunini *et al.*, 2004).

The calculated F_2 peak values at the available digisonde locations (fig. 1) are extracted

from these two global grids by interpolation since the A_z maps have a grid spacing of 2.5° in latitude and 5° in longitude.

4. Comparison between measured and calculated peak values

As an example, the critical frequency f_oF_2 and the maximum height h_mF_2 for Millstone Hill (middle latitude Northern Hemisphere) and Grahamstown (middle latitude Southern Hemisphere) are shown in fig. 2a-d (quiet period) and fig. 3a-d (storm period). Calculated F_2 peak values using CODE (f_oF_2 CODE) and La Plata (f_oF_2 LAPLATA) vertical TEC maps are plotted together with the experimental ones (f_oF_2 SAO, obtained with Sao-Explorer, <http://ulcar.uml.edu/SAO-X/SAO-X.html>).

The figures show a good agreement between both f_oF_2 data sets (f_oF_2 CODE- f_oF_2 SAO and

f_oF_2 LAPLATA- f_oF_2 SAO) during quiet conditions while the differences between calculated and experimental values increase for geomagnetic disturbed conditions. The results are considerably worse in the case of h_mF_2 . However, this is not surprising. NeQuick uses the CCIR (ITU-R) maps for f_oF_2 and $M(3000)F_2$ and an internal map for f_oE to calculate h_mF_2 by means of Dudeney's form of the Bradley and Dudeney (1973) formula (see Dudeney, 1983) which works quite well for average (monthly median) conditions but can give larger errors in individual cases. Minimizing differences in electron content also means some minimization for f_oF_2 but h_mF_2 is not affected. The height error of true height analysis of ionograms can also be quite large.

The left panel of fig. 4 presents the scatter plot of f_oF_2 (F_2 peak electron density) reconstructed with the NeQuick model against the corresponding f_oF_2 ionosonde measurements for quiet periods (2000 and 2002). This example

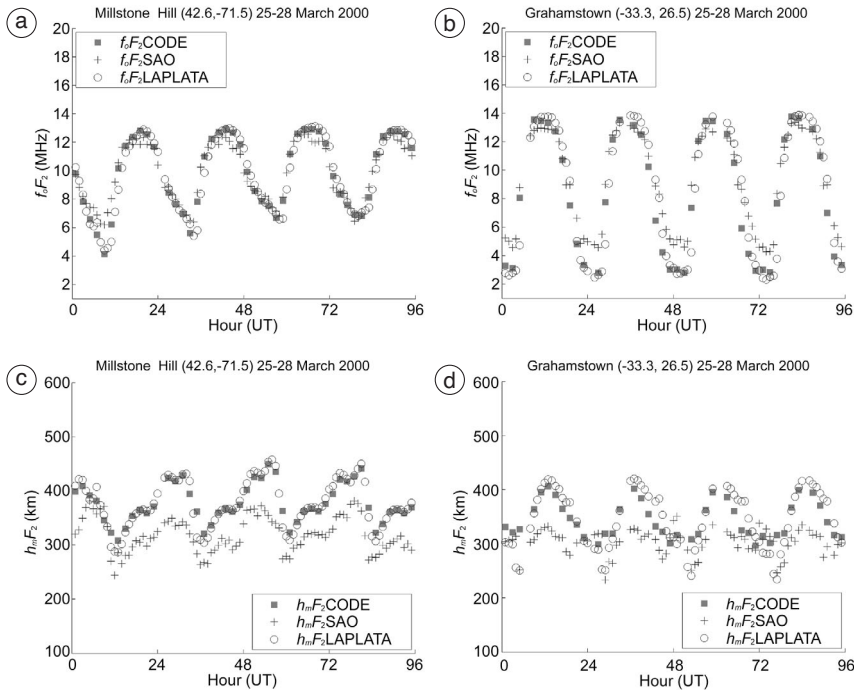


Fig. 2a-d. f_oF_2 (a) and h_mF_2 (c) for Millstone Hill (middle latitude Northern Hemisphere); f_oF_2 (b) and h_mF_2 (d) for Grahamstown (middle latitude Southern Hemisphere), during March 2000 (quiet period).

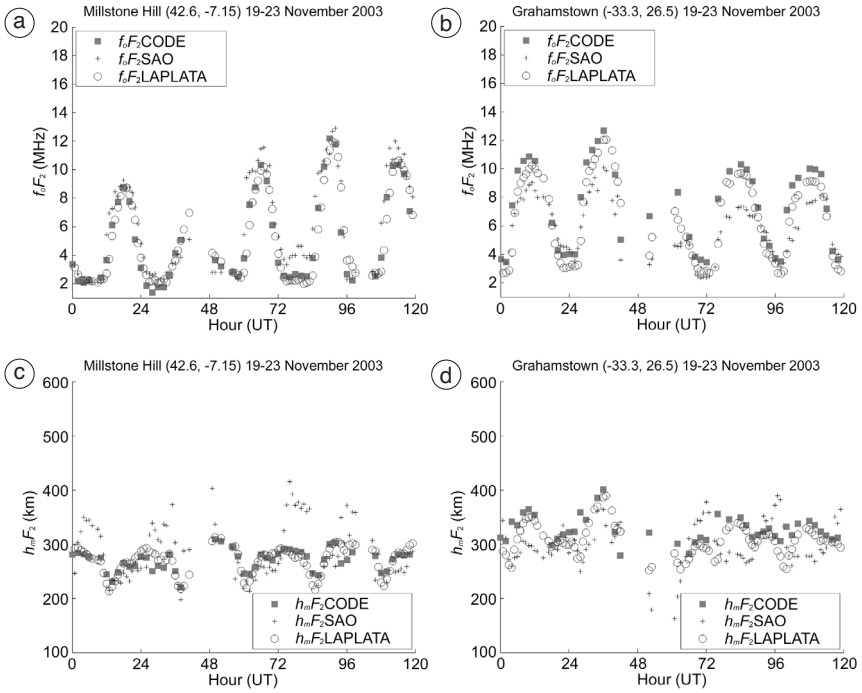


Fig. 3a-d. f_oF_2 (a) and h_mF_2 (c) for Millstone Hill (middle latitude Northern Hemisphere); f_oF_2 (b) and h_mF_2 (d) for Grahamstown (middle latitude Southern Hemisphere), during November 2003 (storm period).

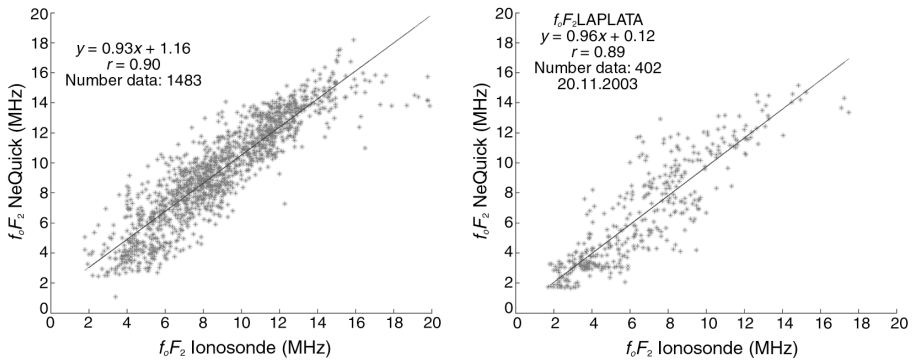


Fig. 4. Linear regression fitting for reconstructed and experimental f_oF_2 during quiet (*left*) and storm (*right*) conditions.

corresponds to CODE experimental vertical TEC maps. The scatter plot shows a high degree of correlation between the two independent estimates of f_oF_2 . The line drawn corresponds to

the best-fit line. Examination of the intercept of the best-fit line shows that on average the f_oF_2 NeQuick values exceed those from digisondes by ~ 1.16 MHz during quiet period. The

storm conditions are also shown on the right panel in fig. 4. This example corresponds to 20th November 2003 (A_p index = 150) and shows how the agreement between both data sets is also obtained for a very disturbed day. It is important to point out that this storm occurred under middle solar activity conditions (sunspot number = 90) and the analysis was done considering together all the ionospheric effects (positive and negative storms) distributed around the world.

The selected data are classified to create distributions with different conditions of solar activity, vertical TEC mapping technique and quiet or storm periods. The results of the linear regression fitting corresponding to each distribution are summarized in tables II and III for f_oF_2 and h_mF_2 respectively.

The correlation coefficients R make clear the difference in accuracy for reconstruction of f_oF_2 and h_mF_2 . In the case of the critical frequency the correlation coefficient is approximately 0.90 which means that the fitting between both data set is excellent. However this value does not exceed 0.70 for the peak height possibly for the reasons indicated above when discussing the results shown in figs. 2a-d and 3a-d. The f_oF_2 reconstruction is also good during the studied storm period with values higher than 0.86. It must be noted that regardless of the actual values of the correlation coefficient all the results indicate a very high statistical significance.

The comparison between the two vertical TEC mapping techniques (CODE and La Plata) does not show a clear dependence on the tech-

Table II. Linear regression fitting results for f_oF_2 ($f_oF_2\text{NeQuick} = A * f_oF_2\text{Ionosonde} + B$; R is the correlation coefficient and N the number of selected data).

f_oF_2 (MHz)		La Plata				CODE			
Period		A	B	R	N	A	B	R	N
Calm	2000	0.98	0.20	0.89	1096	1.01	-0.10	0.91	547
	2002	No data				0.94	1.44	0.91	936
Storm period	19.11.2003	0.90	-0.06	0.91	469	0.96	-0.04	0.93	241
	20.11.2003	0.96	0.12	0.89	402	1.00	0.24	0.89	204
	21.11.2003	0.76	0.74	0.86	379	0.79	0.98	0.87	181
	22.11.2003	0.91	0.17	0.88	463	0.96	0.23	0.89	232
	23.11.2003	0.86	0.48	0.89	457	0.92	0.53	0.90	225

Table III. Linear regression fitting results for h_mF_2 ($h_mF_2\text{NeQuick} = A * h_mF_2\text{Ionosonde} + B$; R is the correlation coefficient and N the number of selected data).

h_mF_2 (km)		La Plata				CODE			
Period		A	B	R	N	A	B	R	N
Calm	2000	0.34	187.7	0.53	1094	0.35	183.9	0.48	546
	2002	No data				0.55	128.6	0.60	529
Storm period	19.11.2003	0.75	70.0	0.70	325	0.72	72.5	0.68	165
	20.11.2003	0.62	129.4	0.50	279	0.56	141.9	0.46	140
	21.11.2003	0.72	90.1	0.50	242	0.80	68.2	0.52	113
	22.11.2003	0.76	80.1	0.66	324	0.72	83.1	0.67	164
	23.11.2003	0.72	90.2	0.68	323	0.62	113.3	0.66	156

nique of the vertical TEC map used to derive A_z values. The number of points corresponding to La Plata technique is higher because these maps are obtained hourly.

The dependence on solar activity is only noticeable for $h_m F_2$ where the fitting improves when solar activity decreases. However, further analysis considering low solar activity and storm conditions under very high solar activity should be done in the future.

5. Conclusions

The comparison of F_2 peak values generated by the new technique of 3D reconstruction of the electron density and the corresponding vertical incidence ionosonde data covering a wide area of different geographical, seasonal and hourly conditions indicates that:

- The critical frequency of the F_2 layer shows a very good agreement between both data sets during high and middle solar activity quiet periods.

- This agreement is also good for the November 2003 storm considering together all the ionospheric effects (positive and negative storm effects) distributed around the world.

- The $h_m F_2$ parameter shows a worse agreement than $f_o F_2$ values and the worst results have been found for high solar activity.

- The results obtained are not dependent on the technique of the vertical TEC maps used, CODE and La Plata.

Therefore, it has been demonstrated that the new technique can be used to build scenarios that reproduce global ionospheric conditions in a realistic way.

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