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Validation of IRI-2012 model at solar minimum at a low latitude station

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Abstract: *The validation of IRI-2012 modelwas carriedout on experimental data obtained at an equatorial station [12.4°N, 1.5°W,dip latitude: 5.9°N]. Four ionosphericparameters, namely, the F2 layer peak electron density (NmF2), the corresponding height (hmF2), the bottom-side parameter (B0) and the shape parameter (B1), were used. The observed data were compared with the data generated from IRI-2012 model, using the two coefficients, URSI and CCIR options of the model.Both the URSI and CCIR options of theIRI-2012 modeleither underestimated or overestimated NmF2 during the period considered, at almost all the hours of the day.*
Keywords: *Equatorial ionosphere, low solar activity, electron density*

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I. Introduction

This study focuses on the validation of the International Reference Ionosphere,the IRI-2012 model, using the magneticallyquiet time experimental data. The sequel to this studyis expected to deal with storm effects.The two coefficients [URSI and CCIR options] of theearlier versions of the IRImodel have their shortcomings[Adeniyi et al.(2008),Lee and Reinisch (2006), Lee et al (2008), Chen *et al* (2006), Blanch *et al.* (2007), Zhang *et al.* (2008), and Sethi*et al.* (2009)]. Remarkable discrepancies were found in the representation of seasonal and solar activity trends of bottomside profile thickness, B0, with the Bilitza (2001) model generally providing better results during daytime, while the Gulyaeva (1987)model performed better during nighttime. Altadill*et al*. (2009)succeeded in developing a significantly improved model based on data from 27 globally distributed ionosonde stations for the years 1998–2006.This improvement is now included in the IRI-2012 model.Another featureof the IRI-2012 model is the consideration ofauroral boundaries. The model now has better representation of density and temperature features in IRI that are related to these boundaries such as the sub-auroral density trough and correlated temperature peak. Mertens*et al*. (2013a, 2013b) developed a new model based on TIMED Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) data and a newer electron temperature model with a more detailed description of the diurnal variation including the early morning overshoot that was not well represented in the earlier models. With IRI-2012 a newer ion composition model is now also introduced for the bottomside ionosphere with some other new improvements.

The validation of IRI-2012 model has been carried out at different locations. These include the validation studies of IRI-2012 model with GPS- based ground observations over a low- latitude station at Singapore (latitude 01.37°N and longitude 103.67°E) by Kumar et al (2014). A close agreement between the IRI-2012 model and GPS-TEC was observed over the Singapore region during all times for the year 2010, indicating that the IRI-2012 model provides improved results over the IRI-2007 model. Kumar *et al.* (2014) analysed data on magnetic storms periods and observed that IRI-2012 model does not predict storm impact which was believed to be one of the great improvement made on this model. Asmare*et al*. (2014) observed that, over the Ethiopian region, the IRI-2012 modelis generally good to predict diurnal VTEC variation during the solar minimum phase as contrasted with the solar maximum phase and the model is found to overestimate both the monthly and seasonal mean hourly VTEC values. They also observed that IRI-2012 is not sensitive to magnetic storm effect. Tariku (2015) examined IRI 2012 model in predicting vertical total electron content (VTEC) variation over Uganda during very low solar activity phase (2009) and during high solar activity phase (2012), by comparing ground-based GPS VTEC inferred from dual-frequency GPS receivers installed at Entebbe (geographic latitude 0.038ºN and geographic longitude 32.44ºE) and Mbarara (geographic latitude -0.60ºN and geographic longitude 30.74ºE) with the VTEC from IRI 2012 model. It was found that the model prediction follows diurnal, monthly and seasonal variation as the observed but the VTEC values from the model are generally larger than that from the GPS readings for both low solar activity and high solar activity phases with the largest variation occurring during low solar activity phase. Moreover the storm effect is not observed.Kumar (2016) inspected the capability of IRI-2012 model in predicting the total electron content (TEC) over seven different equatorial stations during a very low solar activity phase of 2009 and a high solar activity phase of 2012, by comparing the ground-based Global Positioning System (GPS) derived VTEC with those from the IRI-2012 model, and observed that the monthly and seasonal mean value of the IRI-2012 model overestimates the observed GPS-TEC at all the equatorial stations. The over-estimation) in the IRI-2012 model is found to be larger during solar maximum year 2012 than during solar minimum year 2009.

II. Methodology

Magnetically quiet days were chosen and their ionograms were scaled for 24 hours of each day, in the year 1995, a year of low solar activity. The hourly average of the value of each ionosphericparameter for these quiet days were calculated. Ionograms were scaled manually with the aid of the personal computer. Compressed ionogram files were decompressed to obtain the individual ionograms. The inversion of the scaled data was implemented by the polynomial analysis programme (POLAN) developed by Titheridge (1985), to obtain the true height.The data for international reference ionosphere IRI-2012 model was accessed via the IRI website: http://omniweb.gsfc.nasa.gov/vitmo/iri2012_vitmo.htmlfor the quiet days in the months of January, April and October 1995.

The observed data for the ionospheric parameters (NmF_2, hmF_2, B_0 and B_1) were compared with the data generated from IRI-2012 model. Both URSI and CCIR options of the model for quiet days were used. The percentage relative deviation was calculated usingthis expression (Oyekola and Fagundes , 2012),

$$\%\Delta x = \frac{x^m - x^o}{x^o} \times 100 \qquad (1)$$

where %Δx is *percentage relative deviation*, x^m represent *modelled value* and x^o represents *observed value* for each hour of the day.This percentage deviation yielded both positive and negative result for different days and hours of the quiet period, where *positive values indicate overestimation* of the parameter in question by the IRI 2012 model and *negative values signify underestimation* of such parameter by the model when compared with observed data.

Bertoni*et al.* (2006) used a numerical quantifier, namely, the *relative deviation module mean (rdmm)*, to judge the agreement (or disagreement) of the modelled values with the experimental values of the parameters. When the *rdmm*is less than or equal to 0.06 (in the limit), thissignifies a good agreement,while a value greater than 0.06 portrays a poor agreement. In order to examine further the validity of IRI-2012 model, the relative deviation mean module(rdmm) was employed. Two ranges of time [18:00 – 6:00 LT (night time) and 6:00 – 18:00 LT (day time)], were used. Relative deviation module meanwas calculated for the magnetically quiet days, to check for agreement (or disagreement) between observed data and modelled data values. This was done using the expression,

$$\langle \Delta \rangle = \frac{1}{N} \sum_{i=1}^{N} \frac{|x_i^o - x_i^m|}{x_i^o}. \qquad (2)$$

where$\langle \Delta \rangle$ represents relative deviation module mean, x_i^o and x_i^m represents observed values and modelled values respectively, and N is number of terms. This was done for both URSI and CCIR options of the IRI-2012 model, respectively.

III. Results and Discussion

(a) NmF2

Figure 1(a)-(c)shows the diurnal variation of NmF_2compared with the IRI-2012 prediction, for the months of January, April and October, 1995, respectively.In January, the IRI-2012 model underestimates NmF_2 between 08:00LT and 12:00LT andoverestimates it between 12:00LT and 20:00LT.In April, both options of IRI 2012 model give noticeable overestimationof NmF_2 between 11:00LT and 20:00LT while the URSI has the higher overestimation. In October, the model gave conspicuous underestimation between 00:00LT and 04:00LT and overestimation between 9:00LT and 21:00LT.

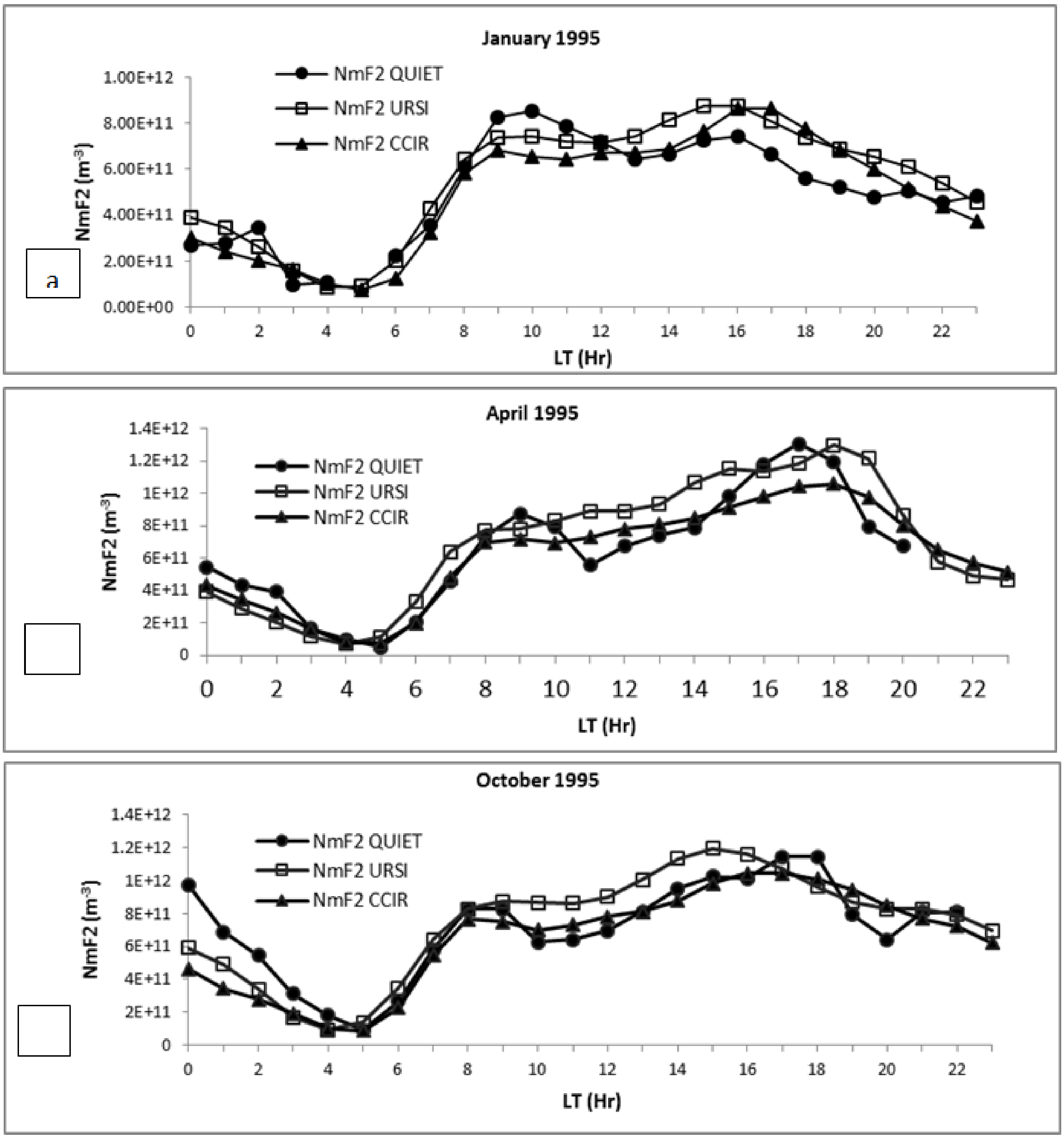
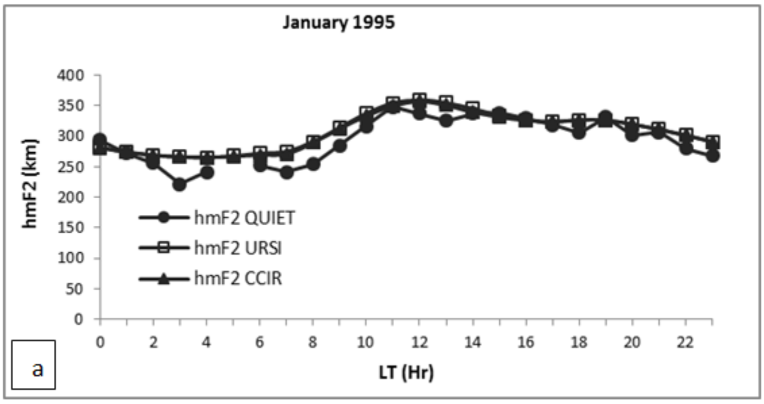


Figure 1(a)-(b): Variation of observedNmF2 and IRI-2012 model values with time of theday

(b) hmF2

Figure 2(a)-(c)shows the variation ofthe peak height (hmF2) and theIRI-2012 model prediction.
The IRI-2012 model slightly overestimated hmF2 at almost all the hours of the day. This occurs for all the months considered.



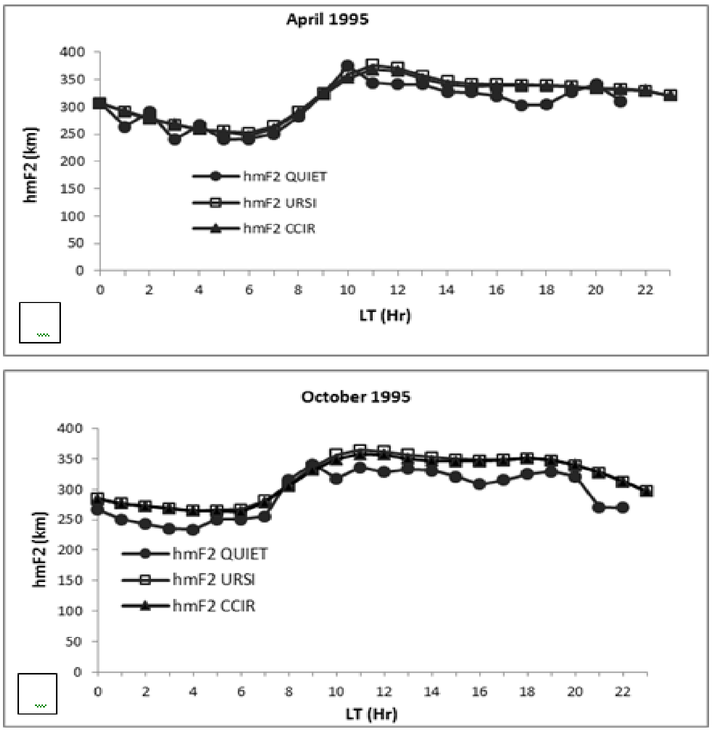


Figure 2(a)-(c): Variation of hmF_2 and IRI-2012 model with time of the day

(c)B_0

Figure 3(a)-(c) depicts the comparison of the variation of quiet time B0 with IRI-2012 model values.The IRI-2012model overestimated $B_0$for all the months considered. This overestimation takes place between 6:00LT and 22:00LT for all the months.

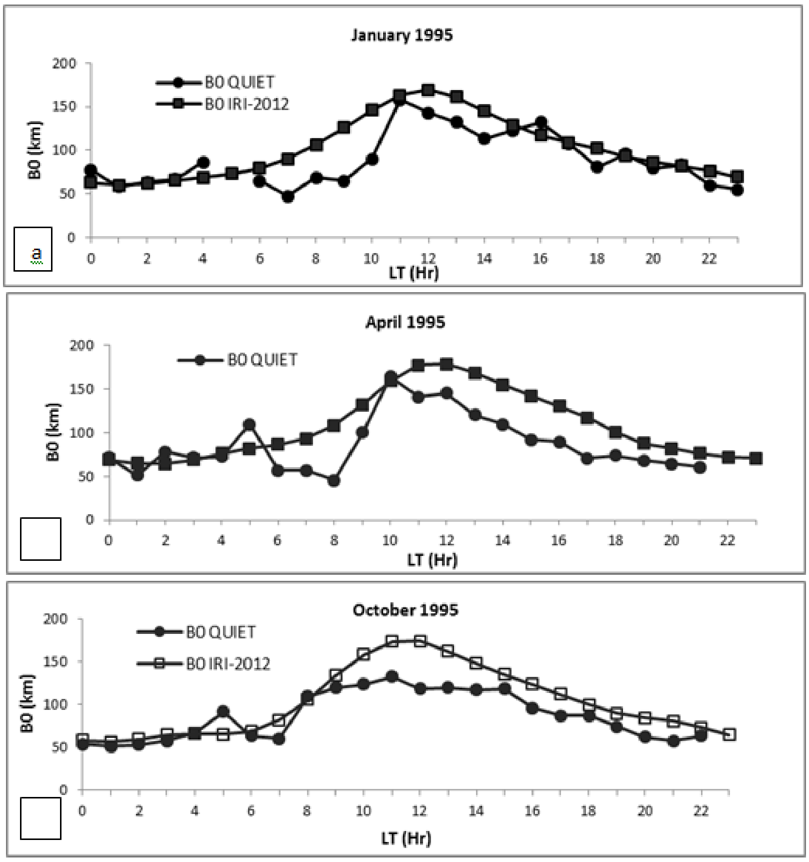


Figure 3(a)-(b): Variation of observed B0 and IRI-2012 model with time of the day

(d) B1

Figure 4(a)-(b) shows the comparison of the variation of the bottomside shape parameter (B1) with IRI-2012 model.The model overestimated B1 during night time hours from 00:00LT to 09:00LT and underestimated it during day time hours from 09:00LT to 15:00LT.

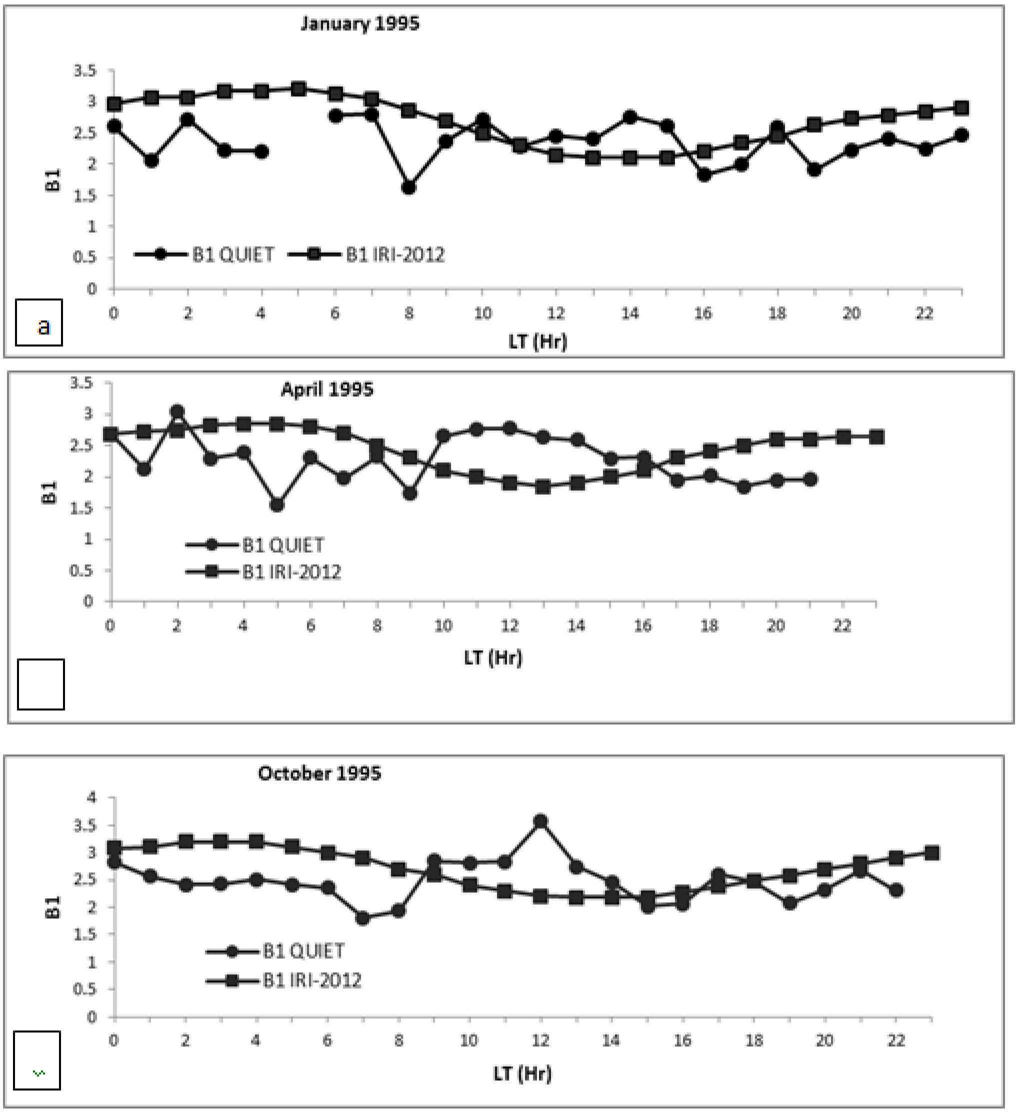


Figure 4(a)-(c): Variation of B_1 and IRI 2012 model with time of the day

IV. Relative Deviation Module Mean Results

(a) NmF2

The relative deviation module mean, generated from NmF_2values during magnetically quiet period, shows that the values were all greater than 0.06, for both URSI and CCIR, except for January 29 that gave 0.0242 for URSI day time.The best results obtained were 0.1515 for URSI daytime, 0.2550 for URSI nighttime.For CCIR, the rdmm was 0.1543 for daytime and 0.2189 for nighttime.Judging by the rdmm values obtained, the two options of the model exhibit poor agreement with experimental values of NmF2.

(b) hmF2

The rdmm values of hmF2were very close to the threshold value of 0.06.The best results obtained in the month of April were 0.0594for URSI daytime, 0.065 URSI nighttime, 0.0592 URSI monthly; 0.0481 CCIR daytime, 0.0639 CCIR nighttime, and 0.0524 CCIR monthly. This indicates that the model prediction for hmF2 was very close to the observed values.

(c) B0 and B1

For both B0 and B1, the rdmm values were all greater than 0.06. This suggests that the model predictions did not coincide with the observed values of B0 and B1, respectively.

V. Conclusion

The values of four ionospheric parameters, namely, NmF2, hmF2, B_0, and B_1, extracted from ionograms have been used for this work. Theseobserved values were compared with the corresponding values obtained from the IRI-2012 model.The relative module mean was calculated for these parameters. Visual observation of the graphical comparison disclosed that IRI-2012 model either underestimated or overestimated NmF2 during the period considered. The model slightly overestimated hmF2 at almost all the hours of the day.B0 and B1 were both overestimated by the model within the period considered. The results of analysis by means of the relative deviation module mean tallied with the conclusions arrived at from visual observation. All of this shows that the model requires adjustments for it to make accurate predictions.

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CAPTIONS FOR FIGURES

[23]. Figure 1(a)-(b): Variation of observedNmF2 and IRI-2012 model values with time of theday

[24]. Figure 2(a)-(c): Variation of hmF_2 and IRI-2012 model with time of the day

[25]. Figure 3(a)-(b): Variation of observed B0 and IRI-2012 model with time of the day

[26]. Figure 4(a)-(c): Variation of B_1 and IRI 2012 model with time of the day