Comparison of ionospheric profile parameters with IRI-2012 model over Jicamarca

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Abstract. We used the hourly ionogram data obtained from Jicamarca station (12° S, 76.9° W, dip latitude: 1.0° N) an equatorial region to study the variation of the electron density profile parameters: maximum height of F2-layer (hmF2), bottomside thickness (B0) and shape (B1) parameter of F-layer. The period of study is for the year 2010 (solar minimum period). The diurnal monthly averages of these parameters are compared with the updated IRI-2012 model. The results show that hmF2 is highest during the daytime than nighttime. The variation in hmF2 was observed to modulate the thickness of the bottomside F2-layer. The observed hmF2 and B0 post-sunset peak is as result of the upward drift velocity of ionospheric plasma. We found a close agreement between IRI-CCIR hmF2 model and observed hmF2 during 0000-0700 LT while outside this period the model predictions deviate significantly with the observational values. Significant discrepancies are observed between the IRI model options for B0 and the observed B0 values. Specifically, the modeled values do not show B0 post-sunset peak. A fairly good agreement was observed between the observed B1 and IRI model options (ABT-2009 and Bill 2000) for B1.

1. Introduction

The bottomside ionospheric electron density profile below the F-layer are described by the maximum electron density (NmF2), the maximum height of F2 layer (hmF2), the thickness (B0) and the shape parameter (B1). These parameters are important for understanding the morphology of the ionosphere and for ionospheric modeling, e.g. the International Reference Ionosphere (IRI). The illustration of these profile parameters is given in figure 1. The altitude distributions of these profile parameters exhibit diurnal, seasonal and solar activity variations, which depend on the geographical location of the observational station. The B0 and B1 parameter were introduced by the IRI model to describe the ionospheric electron density thickness and shape below the F2 region. The B0 parameter is obtained from the ionospheric profile Ne (h) and calculated as the height difference between the peak height of F2-layer (hmF2) and the height where the electron density equals to 0.24*NmF2 in the absence of Fl-
layer or the F1 peak height \((hmF1)\) if the latter occur [1]. \(B1\) determines the shape of the profile between the two heights from which \(B0\) parameter is estimated [2].

In the previous works, the comparative study between the observational profile parameters and IRI-2001 model at Jicamarca station \((12^\circ\text{S}, 76.9^\circ\text{W}, \text{dip latitude: } 1.0^\circ\text{N})\) has been earlier studied during solar maximum [3] and during solar minimum conditions [4]. A comparison between the observational B-parameter \((B0\text{ and } B1)\) and the IRI-2012 model was recently carried out in the African sector [5], where they observe a fair agreement between the model predictions and \(B1\) parameter. However, they observe that the model prediction agrees with the observational \(B0\) values during the nighttime period and obtained some degree of differences during the pre-sunrise towards the midday period. A similar result was obtained at the Dibrugarh \((27.5^\circ\text{N}, 95^\circ\text{E}, 43^\circ\text{dip})\), a low mid-latitude station where they have attributed the discrepancies between the IRI-2012 model option as due to the limitation of the data composition (location) used in building the ABT-2009 model option and the auto-scaling of F1 layer in the ionogram inversion software[6]. IRI model is a data-driven model which has been undergoing periodic updates in order to improve the model prediction. For this reason, the present study, re-examine the ionospheric parameters obtained from digisonde measurements at Jicamarca station, located in the Southern American sector and make a comparison with the updated version of the IRI-2012 model during the period (the year 2010) following the deep solar minimum.

![Figure 1. Illustration of the ionospheric electron density profile.](image)

2. **Data Analysis**

The DPS-4 digisonde measurement used in this study is located at Jicamarca \((12^\circ\text{S}, 76.9^\circ\text{W}, \text{dip latitude: } 1.0^\circ\text{N})\), an equatorial location in the Southern American sector. We have used hourly ionograms during the year 2010, a year of low solar activity with 27-day averaged solar radio flux, \(F10.7 = 80\text{ sfu}\). The ionogram traces were inverted into “true” height electron density profiles \(Ne(h)\) by the True Height Profile Inversion program (NHPC), which is run in the Digisonde Ionogram Data Visualization/ Editing Tool (SAO-X) software. The SAO explorer program allows us to estimate the profile parameters; \(hmF2\), \(B0\), and \(B1\) from the raw ionogram data. The routine techniques for calculating \(B0\) and \(B1\) is by best fitting using the least-square fitting approach, the experimental profiles with the formula used in IRI model in equation (1)
\[ Ne(h) = NmF2 \exp^{-XB1 \cosh(X)} \quad \text{where} \quad X = \frac{hmF2 - h}{B0} \]  

(1)

Monthly averages of these parameters are calculated from the selected ten (10) days quietest period. The quietest period is days with no record of geomagnetic disturbances. All the selected quiet period have \( \Sigma Kp \leq 24 \). Largely due to the paucity of data, only the months of January to July and November to December data are analyzed for this study. The months are then grouped into seasons: equinoctial months (March and April), summer months (November to February) and winter months (May and June), respectively.

The observational results are compared with the IRI-2012 model. The IRI-2012 model is accessible via http://irimodel.org. In the IRI-2012 model, the IRI-CCIR option was used to compared with observational \( hmF2 \) because CCIR-maps of \( hmF2 \) was obtained through its close correlation with propagation factor \( M(3000)F2 \) [3]. For the \( B0 \) parameter, the IRI-2012 offers three choices: ABT-2009 model option [1], Bill-2000 model option [2] and Gul-1987 model option [7]. For the \( B1 \) parameter, Bil-2000 and Gul-1987 model options used the same \( B1 \) model and thus give same values of \( B1 \) prediction. The performance of the IRI model prediction relative to the observational results was estimated by finding the deviation of the model options from the experimental (observational) values.

\[ \Delta_{\text{IRI prediction}} = \alpha_{\text{observational}} - \varphi_{\text{IRI option}} \]  

(2)

Where the term \( \Delta_{\text{IRI prediction}} \) is the deviation of the model prediction from the observational values (\( \alpha_{\text{observational}} \)) and \( \varphi_{\text{IRI option}} \) indicates the model option use for various profile parameters.

3. Results and Discussion

3.1. Diurnal variations of \( hmF2, B0, \) and \( B1 \)
For the equinoctial months, the diurnal monthly mean values of \( hmF2, B0, \) and \( B1 \) are given in the left panel in figure 2(a, d and g). In figure 2(a), \( hmF2 \) generally increases during the sunrise hour to \( \sim 1000 \) LT. The observed increase in \( hmF2 \) can be attributed to the plasma drift during the daytime and this occurrence can be explained as due to the cross product of electric field (E) and magnetic field (B) at the equatorial latitude. Consequently, the ExB drift raises electron density to a higher altitude where the ratio of gyrofrequency to the ion collision frequency is large. This process is generally known as Equatorial Anomaly (EIA). At midday, the increase in \( hmF2 \) ceased and the magnitude remains fairly constant. The restriction of the growth of plasma height is known as ionospheric ceiling [8]. The ionospheric ceiling is due to the isoelectron density delineations which are aligned with the magnetic field lines near the dip equator [8]. These mechanisms affect the morphology of \( B0 \) parameter as well (see figure 2d). Observe that \( B0 \) increases during sunrise towards the midday. At post sunset, around 1800-1900 LT, \( hmF2 \) increased gradually and reached a peak value at about 2000 LT for the months of March and April. The observed \( hmF2 \) post sunset peak is as a result of the upward velocity of the pre-reversal enhancement (PRE). The PRE resulting from eastward polarized electric field causing the rise of plasma to drift upward (ExB drift velocity) because of F-region dynamo mechanism when the conductivity of E-layer already decayed at post-sunset. The post-sunset peak is observable for \( B0 \) as well. The increase in the magnitude of \( B0 \) around this time indicates that PRE upward velocity not only modulates the height of F2-layer but also increases the bottomside thickness (\( B0 \)) below the peak height of F2-layer. During the nighttime period towards the pre-noon around 2100 to 0700 LT, the magnitude of \( hmF2 \) decreases and this also affect the values of \( B0 \) parameter. In general, the \( B0 \) values during the daytime period are higher than the nighttime period. We observe that \( B1 \) do not respond to any of the mechanism (earlier mentioned) that causes redistribution of electron density at the bottomside F2 region. The \( B1 \) values are centered on \( \sim 2 \) during the periods from 0800-1800 LT and
outside this time; its peak value is \( \geq 2.6 \). The \( B1 \) values generally exhibit morning and nighttime peaks.

The diurnal monthly average values of the ionospheric profile parameters of \( hmF2 \) (figure 2b), \( B0 \) (figure 2e) and \( B1 \) (figure 2h) for the summer months are given in figure 2 (middle panel). Generally, the morphologies of these parameters are similar to that in the equinoctial months. We observe that post sunset peak values of \( hmF2 \) and \( B0 \) are smaller as compared to the equinoctial months. The late reversal time of PRE values during the summer month at about 2100-2200 LT is attributed to the longer persistent of the upward velocity of the lifted ionospheric plasma to higher altitude [3].

![Figure 2](image_url)

Figure 2. The diurnal seasonal average values of the ionospheric profile parameters of \( hmF2 \), \( B0 \) and \( B1 \) at Jicamarca station under quiet time condition for the year 2010. Each panel indicates different seasons: the left panel gives the equinoctial months (2a, 2d, and 2g), the middle panel indicates summer months (2b, 2e, and h) and the right panel shows the winter months (2c, 2f, and 2i).

The diurnal monthly averages of the ionospheric profile parameters \( hmF2 \) (figure 2c), \( B0 \) (figure 2f) and \( B1 \) (figure 2i) for the winter months are given in the right panel of figure 2. We observe that the amplitude of \( hmF2 \) is lowest in the winter than in the other seasons. The post-sunset peak of \( B0 \) parameter diminishes and the midday values are lower when compared with other seasons. Since \( B0 \) is measured from the peak height of F2 layer to the peak height of F1 layer or to the \( h0.24 \) (height of \( 0.24*NmF2 \) when F1 does not exist), this explains why the variations in the magnitude of either \( hmF2 \) or \( NmF2 \) affect the observed values of \( B0 \). A close observation in the variation of \( B1 \) parameter revealed a similar trend across the three seasons. Observe in figure 2, that the midday minimum values of \( B1 \) coincide with the period in which the thickness parameter \( B0 \) reaches its maximum value. This observation has been reported in similar findings at Cyprus (35° N, 33° E) by Panda and Haralambous [9].

### 3.2. Comparison between observational results (\( hmF2 \), \( B0 \), and \( B1 \)) and IRI model

The contour plot of the diurnal monthly values of observational \( hmF2 \) and the IRI-CCIR \( hmF2 \) model option in the IRI-2012 model are given in figure 3a-b. The estimated model deviation (see equation 2) from the observational value is given in figure 3c. The IRI-CCIR gave a fairly representation of \( hmF2 \)
during the pre-sunrise period between (0000 -0700 LT). During the day, the model overestimates \( hmF2 \) between 0800-1500 LT for all the months presented. The existence of a post-sunset peak in the observational results around the period of about 1800-1900 LT was not modeled by the IRI-CCIR option. From figure 3c, a small deviation can be found between the model values and the observational results during the period of 0000-0800 LT and 1400-1800 LT.

The observational values of \( B0 \) obtained from digisonde measurement (figure 4a) and the model options for \( B0 \) in the IRI-2012 model: ABT-2009 option (figure 4b), Bill-2000 option (figure 4d), and Gul-1987 option (figure f) are presented as a contour plot in figure 4. The location of the annual maxima differs between the IRI-2012 model options predictions and the observational results. For the Gul-1987 model option, a small deviation between the modeled values and the observational results can be observed during 0000-7000 LT for all the months. In term of the season, the greatest discrepancies are observed during the summer months (January, February, November, and December) and equinoctial months (March and April). For Bill-2000 option, a small deviation between the model prediction and the observational results is found between the period 0000-3000 LT for all the months. During 0400-1000 LT a negative deviation was observed. Our result is consistent with a study carried out by Lee et al. [4] and with similar findings by Kalita and Bhuyan [6]. For the ABT-2009 model option, a small deviation between the modeled values and the observational results is observed during 1400 LT and 2200-2400 LT for all the months. A negative difference between the observational results and ABT-2009 model prediction is observed during the daytime between 1000-1300 LT in all the months.

The observational values of \( B1 \) obtained from digisonde measurement (figure 5a) and the model options for \( B1 \) in the IRI-2012 model; ABT-2009 option (figure 5b), and Bill-2000 option (figure 5d) are shown in figure 5, respectively. The observational values of \( B1 \) during the day are smaller than during the morning and nighttime periods for all the months. Observe that the model options of \( B1 \) in the IRI-2012 model are similar with that of the observational values. In the IRI model, the Bill-2000 and Gul-1987 use the same \( B1 \) model and hence give a similar prediction. As a consequence, only the contour plot of Bill-2000 is presented in figure 5. The deviation of the model prediction and the observational results given in figure 5c and 5e shows that IRI-2012 fairly represent the observational \( B1 \) in all the months.

4. Conclusion
The electron density profile parameters obtained from the digisonde sounder installed at Jicamarca station during the year 2010 were used to study the variation of \( hmF2, B0, \) and \( B1 \) during solar minimum. We observed that the magnitude of both \( hmF2 \) and \( B0 \) are highest during the equinoctial
months (April and March) than the rest of the months. We observe the effect of upward PRE velocity to be responsible for the observable $hmF2$ and $B0$ post-sunset peak. The prediction made by the

![Figure 4](image1.png)

**Figure 4.** (a) The observational values of $B0$ obtained from digisonde measurement and the model options for $B0$ in the IRI-2012 model: (b) ABT-2009 option, (d) Bill-2000 option and (f) Gul-1987 option. The IRI-2012 model deviations from the observational values (details in the text) are: (c) $\Delta B0_{ABT-2009}$, (e) $\Delta B0_{Bill-2000}$, and $\Delta B0_{Gul-1987}$

![Figure 5](image2.png)

**Figure 5.** (a) The observational values of $B1$ obtained from digisonde measurement and the model options for $B1$ in the IRI-2012 model: (b) ABT-2009 option and (d) Bill-2000 option. The IRI-2012 model deviations from the observational values (details in the text) are: (c) $\Delta B0_{ABT-2009}$ and (e) $\Delta B0_{Bill-2000}$
IRI-CCIR hmF2 model during the pre-moon period is close to the measured hmF2 values. However, significant disagreements between the model and the observational values of hmF2 were found during 0700-1500 LT at all months. For the observed B0 compared with IRI model, all the model options give a positive and negative deviation from the observational values. The B1 parameter does not exhibit a significant seasonal variability and has small value during the daytime than during the morning and nighttime periods. The IRI model options gave a closer value with the observed B1 result.

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References
[1] Altadill D, Torta J M and Blanch E 2009 Advance Space Research 43(11)1825 doi: 10.1016/j.asr.2008.08.014.
[2] Bilitza D, Radicella S M, Reinisch B W, Adeniyi J O, Mosert Gonzalez M E, Zhang S R and Obrou O 2000 Advance Space Research 25 89
[3] Lee C -C and Reinisch B W 2006 Journal Atmospheric. Solar Terrestrial Physic 68, 2138-2146.
[4] Lee C -C, Reinisch B W, Su S -Y, Chen W S 2008 Journal Atmospheric and Solar Terrestrial Physic 70184
[5] Bello S A, Abdullah M, Hamid N S A, Yoshikawa A, and Olawepo A O 2017 Advance Space Research doi: 10.1016/j.asr.2017.02.003
[6] Kalita B R and Bhuyan P K 2016 Advance Space Research, doi: 10.1016/j.asr.2016.06.041
[7] Gulyaeva T L 1987 Adv. Space Res. 7(6) 39
[8] Maruyama T, Uemoto J, Ishii M, Tsugawa T, Supnithi P, and Komolmis T 2014 J. Geophysical Research Space Physics 119 10595 doi:10.1002/2014JA020215
[9] Panda S K and Haralambous H 2016 Advance Space Research doi:10.1016/j.asr.2016.08.025