

Variations of B0 and B1 with the solar quiet *Sq*-current system and comparison with IRI-2012 model at Ilorin

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Abstract

The ionospheric thickness (B0) and shape (B1) are bottomside profile parameters introduced by the International Reference Ionosphere (IRI) model. We have validated these parameters with the latest version of the IRI-2012 model and compared them with the solar quiet of geomagnetic H-component (SqH). The B0, B1 and SqH are calculated from the measurements obtained from digisonde DPS-4 sounder and the Magnetic Data Acquisition System (MAGDAS) magnetometer, respectively at Ilorin (geo latitude 8.50°N, geo longitude 4.68°E, and Magnetic dip 4.1°S) an equatorial station in the African sector. The study was for the year 2010, a year of low solar activity (with 27-day averaged solar index, F10.7 = 80 sfu). The results show that B0 for the entire months was higher during the daytime than during the night time. On the other hand, the magnitude of B1 during the daytime period is lower than nighttime values and exhibit oscillatory pattern. By comparing the experimental observations of the profile parameters with the IRI-2012 model prediction, we found that B0 was fairly represented by the IRI model options during the nighttime period while discrepancies exist between the model estimates and the experimental values during the morning till midday. A close agreement exists between the observed B1 values and IRI model options. We observed a positive and significant correlation coefficient between B0 and SqH indicating a plausible relationship between these parameters while a weak and negative correlation coefficient between B1 and SqH was observed. We concluded that the difference in the relationship of SqH and the profile parameters B0 and B1 observed can be attributed to their sensitivity to the electric field which is responsible for the $\mathbf{E} \times \mathbf{B}$ drift which in turn modulate the height of the F2.

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1. Introduction

The parameters B0 and B1 were introduced by the IRI model to describe the bottomside ionospheric electron density distribution below the F2 region. The parameter B0

indicates the bottomside thickness of the ionospheric electron density below the F2 region and is calculated as the height different between the peak height of F2 layer (hmF2) and the height where the electron density equals to $0.24 \times \text{NmF2}$ in the absence of F1-layer or the F1 peak height (hmF1) if the latter occur (Altadill et al., 2009). B1 determines the shape of the profile between the two heights from which the B0 parameter is estimated (Bilitza

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et al., 2000). Using the ground-based ionosonde, the variation of B0 and B1 have been studied across different latitudes (e.g. Reinisch and Huang, 1998; Batista and Abdu, 2004; Lee and Reinisch, 2006; Adeniyi et al., 2008; Venkatesh and Fagundes, 2016), while incoherent-scatter measurements have equally been used to study the morphology of the IRI bottomside profile parameters (Mahajan and Kohli, 1987; Sethi and Mahajan, 2002). The longitudinal behavior of the B0 parameter was studied for the first time by Liu et al. (2010) using FORMOSAT-3/COSMIC radio occultation measurements and they observed a wave-like longitudinal pattern which is similar by amplitude to that of seasonal variation.

In the IRI model, the bottomside electron density profile below the ionospheric F-layer is represented by an analytical function (Bilitza et al., 2000) given in Eq. (1);

$$N(h) = NmF2 \frac{\exp^{-X^{B1}}}{\cosh(X)} \quad (1)$$

where

$$X = \frac{hmF2 - h}{B0}$$

NmF2 and hmF2 indicate the maximum electron density and the maximum height of the F2 layer, respectively. B0 indicates the thickness of the bottom-side of the F2 layer while B1 determines the shape of the electron density profile below the height of the maximum electron density of the F2 layer.

In the latest IRI-2012 model, there are three available options for the prediction of B0 and B1 parameters. These options are (1) Bil-2000 option which is based on values obtained from selected ionosondes (Bilitza et al., 2000), (2) the Gul-1987 option based on a formula for the half-density height (h0.5) (Gulyaeva, 1987) and (3) ABT-2009 option which was formulated using Spherical Harmonics Analysis (SHA) techniques with data obtained from twenty-seven ionosondes (Altadill et al., 2009). There have been considerable numbers of validation studies of the various versions of the IRI model over time and comparison with experimental results. In the African equatorial sector, for instance, there have been studies on the comparison of B0 and B1 parameters with previous versions of IRI model. Adeniyi and Radicella (1998a, 1998b) studied the diurnal variation of B0 and B1 profile parameters during high and low solar activity at Ouagadougou, Burkina Faso (latitude 12.4°N, longitude 1.5°W, dip 5.9°N), an equatorial station in Africa using the Gul-1987 option in the IRI-90 model version. They observed discrepancies between IRI model predictions and observational results for both B1 and B0. Using the IRI-2001 model version, Adeniyi et al. (2008) observed a fairly good agreement between the model prediction and the observational results for B1 parameter. They also observed that IRI-2001 model gave a good representation of B0 parameters during the nighttime but an overestimation during the day time. Similarly, studies from the South American sector, specifically, experimental data

obtained from Jicamarca station have been used to validate the performance of IRI-2001 model (Batista and Abdu, 2004; Lee and Reinisch, 2006). The profile parameters B0 and B1 were equally studied at the Indian sector during the periods of low and moderate solar activity and comparison was made with the IRI-2007 model (Sethi et al., 2009a; Zhang et al., 2004). These previous studies reported considerable discrepancies in the earlier versions of the IRI-model predictions and the experimental observation. Thus, comparisons of the latest version of the IRI-2012 model with measurements of an African station within the magnetic equator are an important input for future improvements of the IRI model. The latest version of the IRI-2012 model used in this study reflects changes made to improve the prediction of several ionospheric parameters such as the electron density, electron temperature, ion composition and auroral oval boundaries (Bilitza et al., 2014; Bilitza, 2014). A specific change in the IRI-2012 model in the region below the F-peak is the inclusion of 'ABT-2009' option (Bilitza et al., 2014; Bilitza, 2014) which is a new option added along with the existing 'Gul-1987' and 'Bil-2000' options.

This present study also examined a plausible relationship that may exist between the solar quiet daily variations of geomagnetic H-component (SqH) at Ilorin, a station at the magnetic dip equator with the ionospheric profile parameters B0 and B1. The term Sq has been commonly defined as the daily variation of the geomagnetic field (H-component for this case) at a ground station on a day when there are no solar-terrestrial disturbances (Yamazaki et al., 2010). The Sq variation arises due to electric currents flowing in the dynamo region of the ionosphere at around the 100 km altitude, thus the ionospheric E-region is inferred as the dynamo region (e.g. Onwumechili, 1997; Prölss, 2004). The ionospheric dynamo mechanism is the source of the geomagnetic Sq variation and this mechanism has been well discussed in many previous works (e.g. Richmond, 1989; Onwumechili, 1997), hence briefly summarized herein. At the dip equator, the configuration of the earth's magnetic field **B** is horizontal and northwards. The ionospheric dynamo mechanism resulted from the motion of particles driven by neutral winds across the earth's magnetic field (Richmond et al., 1992), inducing an electromotive force and causes current to flow in the conducting ionosphere (Pedatella et al., 2011). The neutral wind could be generated by the tidal force of gravity or thermal heating of the sun (Onwumechili, 1997) and the dynamo action of this wind have been extensively studied (e.g. Heelis et al., 2012 and reference therein). The initial current flow polarizes the charges and is not divergence-free. The resulting zonal component of the electrostatic polarization field produced by the dynamo mechanism **E_y** is eastward along the magnetic equator. At the dayside of equatorial E-region, the cross fields of this **E_y** and **B** results in an eastward Pedersen current and downward Hall current. However, the Hall current is impeded due to the poor conductivity of the lower (70 km) and upper (130 km)

boundaries of the E-region. Charges accumulate and consequently an upward polarization electric field E_H is created which induces a Hall current in the eastward direction (Schunk and Nagy, 2009). The induced Hall current enhances the former Pedersen current which in turns enhances the conductivity in the eastward electric field direction. According to Hamid et al. (2014), the upper current layer which is essentially Pedersen current is said to correspond to the global Sq while the eastward lower current layer which is mainly of a Hall current, is defined as the equatorial electrojet (EEJ). The greater enhancement of Sq of geomagnetic H-component (SqH) in the narrow region confined within 0–3° dip latitude is attributed to equatorial electrojet (Onwumechili, 1997). The EEJ is responsible for the strong enhancement produce in the H-component magnetic field measured by magnetometers located within $\pm 3^\circ$ flanking the dip equator (Yizengaw et al., 2014). There has been a prior study on the relationship between EEJ and the IRI bottomside profile parameter B0 and B1 in an equatorial station in the African sector (Obrou et al., 2003). In their study, they have used the amplitude of SqH (ΔH) to indicate the strength of EEJ. By taking the monthly mean of SqH centered around the midday, they observed that both B0 parameter and the peak density height of F2-layer (hmF2) have a high positive correlation with SqH. They attributed the positive and high correlation as due to the proportionality between EEJ and zonal electric field E . That, the crossed fields ($E \times B$) creates an upward drift $E \times B/B^2$ during the daytime under magnetic quiet condition. The electrons then move upward and diffuse downward along the geomagnetic field lines under the influence of gravity and pressure gradients. The net effect creates a depletion of electrons at the equatorial region and the F2 peak is moved to higher latitude, the so-called Equatorial Ionospheric Anomaly (EIA). They based the movement of the plasma due to EIA to affect the thickness of the F2-layer. As a consequence, SqH gave a positive and high correlation with hmF2 and B0 parameter. Similarly, they observed that the correlation between B1 and SqH is negative and low. Which suggest that B1 is not sensitive to the electric field E . The morphology of Sq current system is characterized by two vortices in the sunlight side of the Earth centered in each hemisphere: counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere (Hamid et al., 2015 and reference therein). It is also known that the magnitude and shape of the Sq current system vary on various time scales (Yamazaki et al., 2011), having high intensity during solar maximum and lower during solar minimum. The temporal and spatial changes in the Sq current intensities, therefore, push for an in-depth study and its relation with ionospheric profile parameters across different locations and periods. It was shown from past studies that the computation of the Sq in H-component provides the magnitude of the vertical $E \times B$ drift velocity that plays an important role in variability of the F2-region height (e.g., Anderson et al., 2002; Adebessin et al., 2013; Devi and Unnikrishnan, 2014;

Yizengaw et al., 2014). This study aims to add to the existing knowledge on the variations of observed B0 and B1 parameters. Comparisons of the latest version of the IRI-2012 model with the measurement from Ilorin station (geo latitude 8.50°N, geo longitude 4.68°E), an African station at the dip equator are an important input for the improvement of the IRI model. The profile parameters B0 and B1 are correlated with simultaneous magnetometer measurements. This effort could point to a better way of representing these parameters if magnetometer measurements are available and point to interesting possibilities of real-time updating of IRI model in the future.

2. Data analysis

We have used hourly data from vertical incidence ionogram recorded by the DPS-4 digisonde sounder and geomagnetic H-component data obtained from the Magnetic Data Acquisition System (MAGDAS). The DPS-4 digisonde and MAGDAS magnetometer are both installed and co-located at Ilorin, West of Africa (geo latitude 8.50°N, geo longitude 4.68°E, and Magnetic dip 4.1°S). This station is at the magnetic equator and therefore important for the study of the Equatorial Ionospheric anomaly (EIA). The B0 and B1 parameters data for the year 2010 (year of low solar activity with 27-day averaged $F10.7 = 80$ sfu) is accessible from the Digital Ionogram Data Base (DIDBASE) via Ionogram Characteristic - FastChars with a web access at <http://giro.uml.edu/didbase/scaled.php>. The DIDBASE web portal provides access to the Global Ionospheric Radio Observatory (GIRO) which holds more than 13.5 million and (still) counting ionograms across 38 digisondes in different locations (see Reinisch et al., 2005; Reinisch and Galkin, 2011 for complete details of GIRO project). We ensured a quality data control on the ionospheric data obtained from FastChar by removing data having scaling confidence score less than 70%. By using a least-square approach, the B0 and B1 parameters are obtained by best fitting the experimental measurements profile with the analytical function given in Eq. (1). The procedure for obtaining the B0 and B1 parameter was implemented using the SAO-Explore software.

The experimental B0 and B1 values were compared with the ABT-2009, Bil-2000 and Gul-1987 model options in the latest IRI-2012 model. The IRI model is available for public use for free and can be accessed at <http://irimodel.org> (see Bilitza et al., 2014; Bilitza, 2014 for recent updates on the IRI model). Since both the Bil-2000 and Gul-1987 model options used the same B1 model their result would be the same for B1 prediction. To quantify the performance of the IRI model prediction relative to the experimental values, we calculated the Root Mean Square Error (RMSE) using the expression given in the Eq. (2).

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (\beta_{IRI} - \beta_{observed})^2} \quad (2)$$

where β_{IRI} indicates the IRI model options for predicting the bottomside B0 and B1 while $\beta_{observed}$ correspond to the experimental result obtained from the digisonde measurements. The fundamental assumption when computing the RMSE is that the errors are unbiased and follow a normal distribution (Chai and Draxler, 2014). Thus, the complete picture of the error distribution can be observed by utilizing RMSE.

MAGDAS magnetometer record the ambient magnetic field, expressed by northward (H), eastward (D), and vertical (Z) components data every second. We used the minute average of the horizontal components of geomagnetic field from Ilorin MAGDAS station for the year 2010. The magnetometer from this station is part of MAGDAS and Circumpar Pacific Magnetometer Network (MAGDAS/CPMN) (Yumoto and CPMN, 2001). Further details on accessing MAGDAS data can be found on the link at <http://data.icswse.kyushu-u.ac.jp/magdasindex/>. We estimated the daily variation of the ΔH component by subtracting the deviation of the magnitude of geomagnetic H-component from the baseline level. The baseline for each day is defined as the average of the nighttime values (i.e., the value observed between the period 0100 and 0200 and between 2300 and 2400 in the local time). The summation of the ΔH_t (where $t = 1$ to 24 h) gives the SqH value after subtracting the baseline value from the hourly H-component from each day (i.e. $SqH = H_t - \text{Baseline}$).

3. Result and discussion

3.1. Profile parameters B0, B1, and validation with IRI-2012 model

The monthly median results of the experimental B0 and B1 are shown in Figs. 1 and 2. Comparisons were made between the experimental B0 and B1 with the IRI-2012 model for the months of March to November for the year 2010. There is a data gap in the months of December – February due to power failure or some technical issues. We have only used selected days in each month with magnetic activity Ap index less than 26. The experimental B0 results are indicated in Fig. 1 as OBS-B0 and are plotted with error bars for each month. The error bar indicates the percentage standard deviation (or the coefficient of variance, CV), allowing us to estimate the daily relative variability of B0 and B1 parameters. It was calculated as the ratio of standard deviation of the daily values from the monthly mean to the corresponding mean value multiplied by 100. The CV of B0 fluctuates between 30% and 60% during the pre-noon time at about 0000–0600 UT (where $LT = UT + 1$ for Ilorin station) for all the months while outside this period, deviations are generally less than 40%. The maximum B0 occurred around noontime, generally between the periods between 1100 and 1200 UT. B0 gradually decreases during the nighttime and reaches a minimum value between 0500 and 0600 UT. The minimum nighttime B0 values are as a result of lower hmF2, reduced

production rate, and greater loss rate on the equator (Lee and Reinisch, 2006). The months of March, April, August, and September (Fig. 1a–b and f–h) represent the equinoctial months while the month of May, June, and July (Fig. 1c–e) represent the summer months. The month of November is the only month that is available in the winter season due to data gap in the month of December to February as earlier explained. We observed that midday peak of the B0 is highest in the month of July compared to the rest of the months. In general, the midday peak of the B0 values during the equinoctial months is slightly similar to of the summer months.

Comparison was made between the experimental B0 values (OBS-B0) with the three options (Bil-2000, ABT-2009 and GUL-1987) of the IRI-2012 model. The results indicated the ABT-2009 and GUL-1987 options represent the model value with a similar trend of the observation. The options equally exhibit a midday peak values with the exception of Bil-2000 option. Using the three options in predicting B0 and B1 values in the IRI-2012 model, the RMSE were computed in each case and are given in Tables 1 and 2. We have grouped the calculated RMSE for the IRI model options (ABT-2009, GUL-1987 and Bil-2000) into three periods in order to have a better perception of the performance of the IRI model prediction around different time of the day; 0600–0900 UT, 1000–1600 UT and 1700–0500 UT. From Table 1, the largest deviation observed between the IRI model options and the experimental observed values occur at 0600–0900 UT while the lowest deviation is around the period between 1700 and 0500 UT. Observe that the ABT-2009 and GUL-1987 options follow closely in their prediction of B0 value during the period of 0600–0900 UT for all the months while Bil-2000 has the highest RMSE value for the month of March and April at that period while outside this time RMSE value for Bil-2000 is below ~50 km. However, the GUL-1987 option gave a better prediction for the rest of hours in the day as compared to the ABT-2009 and Bil-2000. In general, we observed discrepancies between the three options of the IRI model and the experimental B0 value during the morning and noon time period. While at nighttime, all the three options gave predictions which closely follow those of the experimental B0 value. The validated data presented in this current study is that of the year 2010, which was a year that followed the unusually low and extended solar minimum in the year 2008/2009. This could be the reason for IRI overestimating (high RMSE values) the experimental results. Adeniyi (1997) compared the electron density profile, $N(h)$ during the period centered around the midday with IRI-90 model. He observed that IRI gave a close prediction to the experimental observations from the F2 peak to about the height where the electron density is half of the F2 peak density. A major difference occurs around the F1-region, where the model gave a lower electron density than the experimental results. The absence of F1 layer in the IRI model predictions might also contribute to the differential in the model and experi-

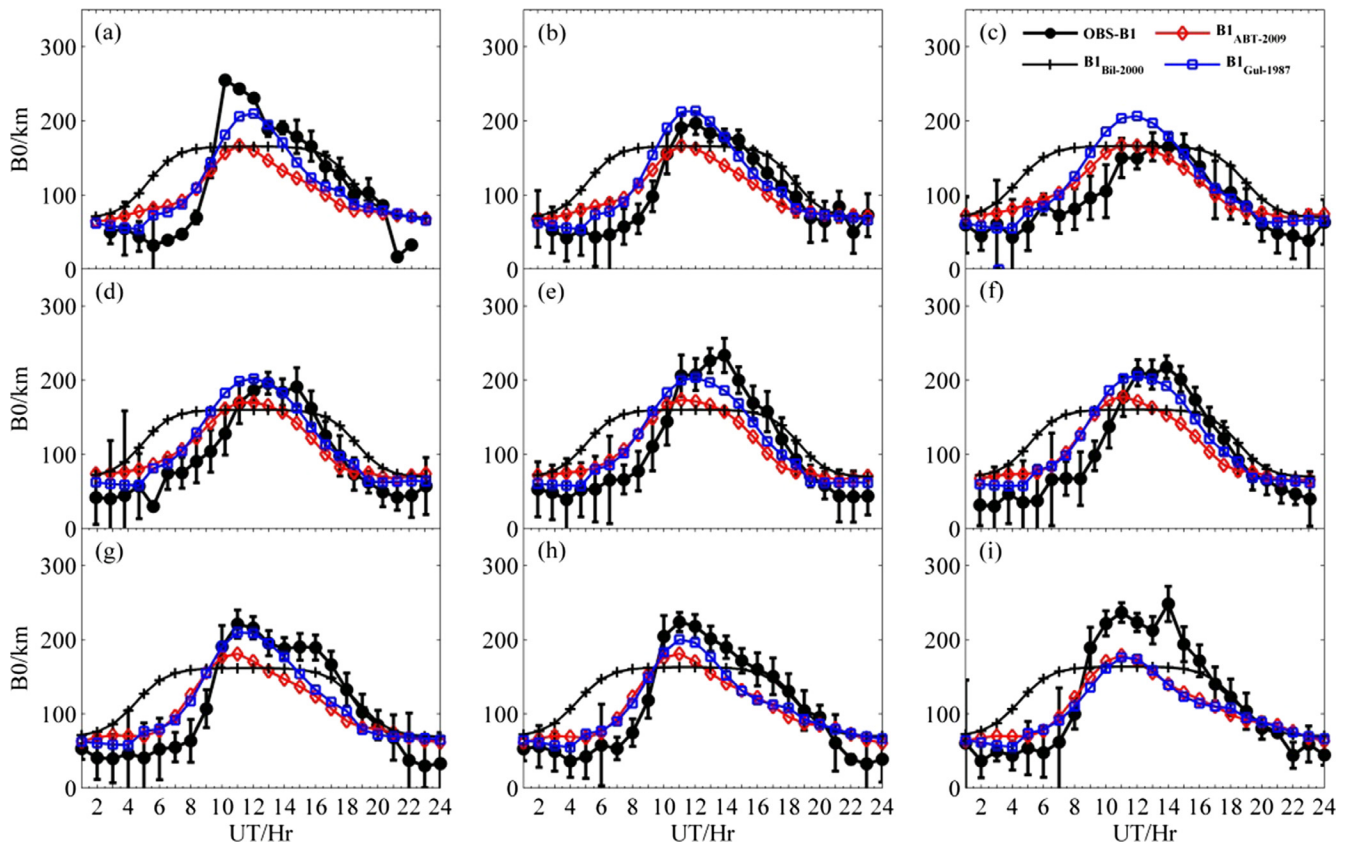


Fig. 1. Diurnal variations of B0 parameter from ionosonde measurements at Ilorin (geo latitude 8.50°N, geo longitude 4.68°E, dip lat. 2.95°) and prediction from the IRI-2012 model using the three different options (Gul-1987, Bil-2000 and ABT-2009) for the month March–November (a–i) 2010.

mental results presented in Table 1. If IRI predicts an F1-layer but the ionogram does not show an F1-layer, IRI model will underestimate B0 and vice versa for the reverse case. Similar observation reported by Venkatesh and Fagundes (2016), where they have compared experimental results obtained from ionosonde measurement in the Brazilian sector from two stations: Fortaleza station, an equatorial station and a low latitude station, Cachoeira Paulista for a two year period from 2010 to 2011 and the latest version of the IRI-2012 model. They observed that midday maximum values of B0 between the experimental observations and the three options in the IRI-2012 model show that Gul-1987 gave a better representation of the seasonal variations in B0. Several previous studies have reported similar findings such as Zhang et al. (2004) using IRI-2001 model over a low latitude at Hainan station and the study made by Lee and Reinisch (2006) over Jicamarca station using IRI-2007 model. Both studies reported that the B0 values from the Gulyaeva-1987 model are closer to the measured values than those from the B0-Table (update option of the B0-Table is referred now to as Bil-2000 in the IRI-2012). The present study shows that during the low solar activity the greatest discrepancies between the model and the experimental results occurred during the midday. The present study shows that at the low solar activity, the greatest discrepancies between the model and the experimental results occurred during the

midday and outside this period the IRI model options fairly represent the experimental values. The present study shows that at the low solar activity, the greatest discrepancies between the model and the experimental results occurred during the midday and outside this period the IRI model options fairly represent the experimental values.

The monthly median values of experimental B1 with the IRI-2012 model are illustrated in Fig. 2. The Bil-2000 and GUL-1987 options use the same B1 model and therefore show identical values. The coefficient of variance (CV) of B1 is lowest during the daytime than nighttime. For all the months considered, the deviations are observed to be less than 30% during daytime around the period between 0700 and 1600 UT, while outside this time period, B1 fluctuates between 20% and 60%. Similar observations were reported in the study made by Sethi et al. (2009b) at a low-middle latitude station in New Delhi, India. Generally, the experimental B1 values are lower during the daytime than during the nighttime. The magnitude of the observed B1 between the periods 0800–1700 UT for all the months is centered about 2.0 while outside this period, the magnitude is between 1.7 and 2.95. The value of B1 in the new IRI model takes a value of 1.9 during the day time and 2.6 during the nighttime (Bilitza et al., 2000). Adeniyi and Radicella (1998b) studied the variation of B1 at Ouagadougou station and observed that B1 value is between 1.7 and 3.5 around the period between 1800 and 0700 LT

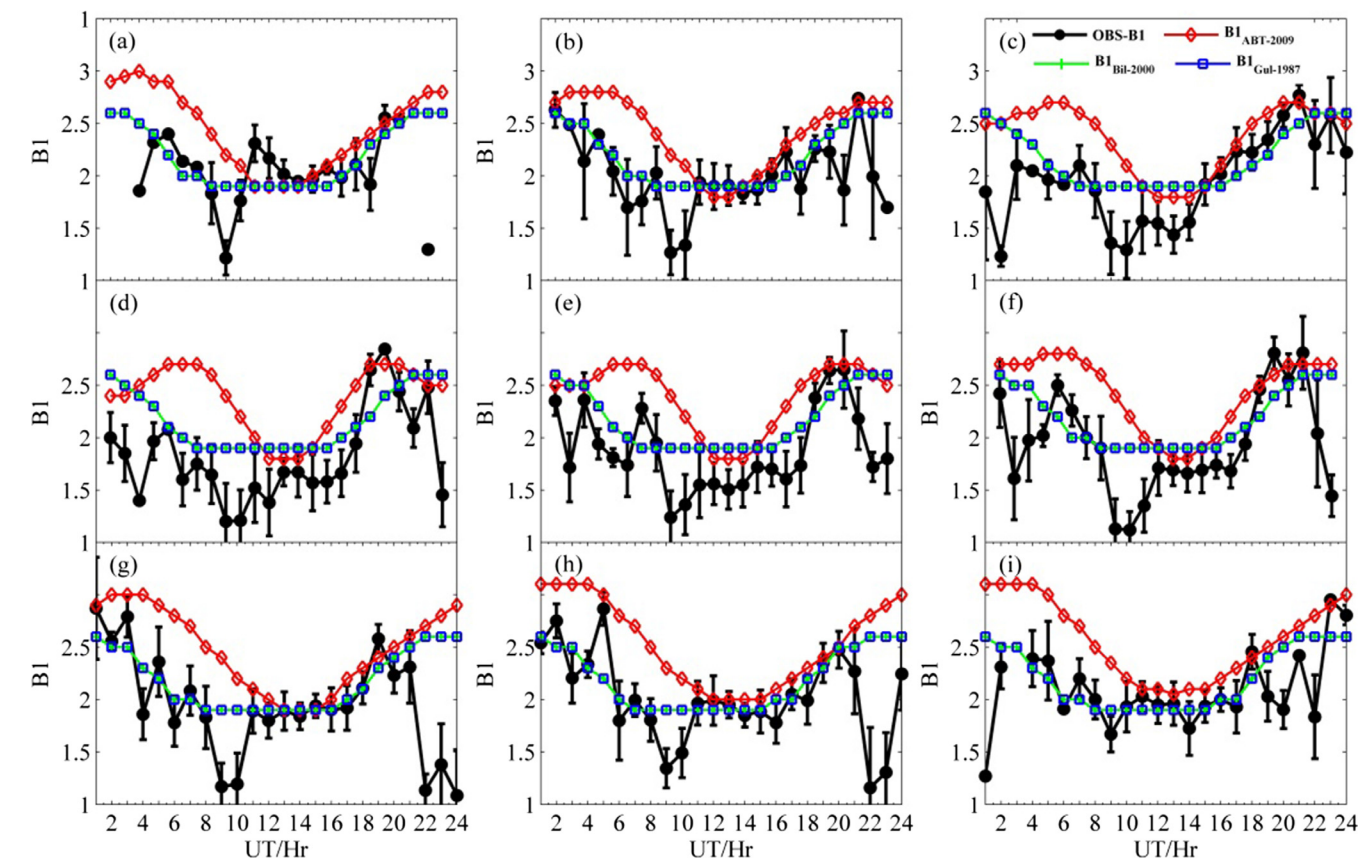


Fig. 2. Diurnal variations of B1 parameter of the F2 layer.

Table 1
Root Mean Square Error (RMSE) of the IRI B0 values from the experimental B0 values.

Months/h	0600–0900 UT			1000–1600 UT			1700–0500 UT		
	ABT	BIL	GUL	ABT	BIL	GUL	ABT	BIL	GUL
March	37.38	90.57	34.12	66.74	53.21	39.07	34.58	41.45	27.84
April	39.98	92.42	43.21	32.62	18.55	21.25	22.37	34.94	13.74
May	31.14	76.18	39.91	25.35	25.98	44.50	22.62	40.06	13.11
June	31.46	69.23	36.69	31.51	26.04	28.18	27.67	44.38	19.67
July	39.29	75.69	39.98	49.80	48.19	30.06	28.47	35.90	18.47
August	45.61	79.89	45.35	45.97	39.47	27.01	28.95	40.40	20.92
September	46.41	87.41	42.49	44.80	40.02	26.41	30.42	38.39	27.31
October	37.10	83.43	32.40	42.15	39.44	31.23	25.84	37.71	23.78
November	31.83	76.50	34.56	66.04	57.74	68.50	20.66	33.41	17.79

Table 2
Root Mean Square Error (RMSE) of the IRI B1 values from the experimental B1 values.

Months/h	0600–0900 UT			1000–1600 UT			1700–0500 UT		
	ABT	BIL	GUL	ABT	BIL	GUL	ABT	BIL	GUL
March	0.68	0.35	0.35	0.23	0.21	0.21	0.70	0.51	0.51
April	0.82	0.37	0.37	0.30	0.22	0.22	0.54	0.38	0.38
May	0.73	0.29	0.29	0.38	0.37	0.37	0.51	0.46	0.46
June	1.06	0.43	0.43	0.51	0.42	0.42	0.60	0.56	0.56
July	0.85	0.40	0.40	0.43	0.35	0.35	0.59	0.47	0.47
August	0.85	0.41	0.41	0.50	0.40	0.40	0.62	0.51	0.51
September	0.92	0.39	0.39	0.40	0.27	0.27	0.87	0.70	0.70
October	0.85	0.30	0.30	0.31	0.18	0.18	0.78	0.59	0.59
November	0.66	0.17	0.17	0.21	0.09	0.09	0.75	0.52	0.52

while outside this period the value of B1 is less than 2.0. We observed that all the three options of the IRI model show fairly good agreement with the experimental B1 result for all the months. The oscillatory pattern of B1 observed in

the experimental result is similar to all the three options of the IRI- 2012 model. The RMSE estimate given in Table 2 indicate that the three options in the IRI model gave predictions that are close to the experimental B1 results.

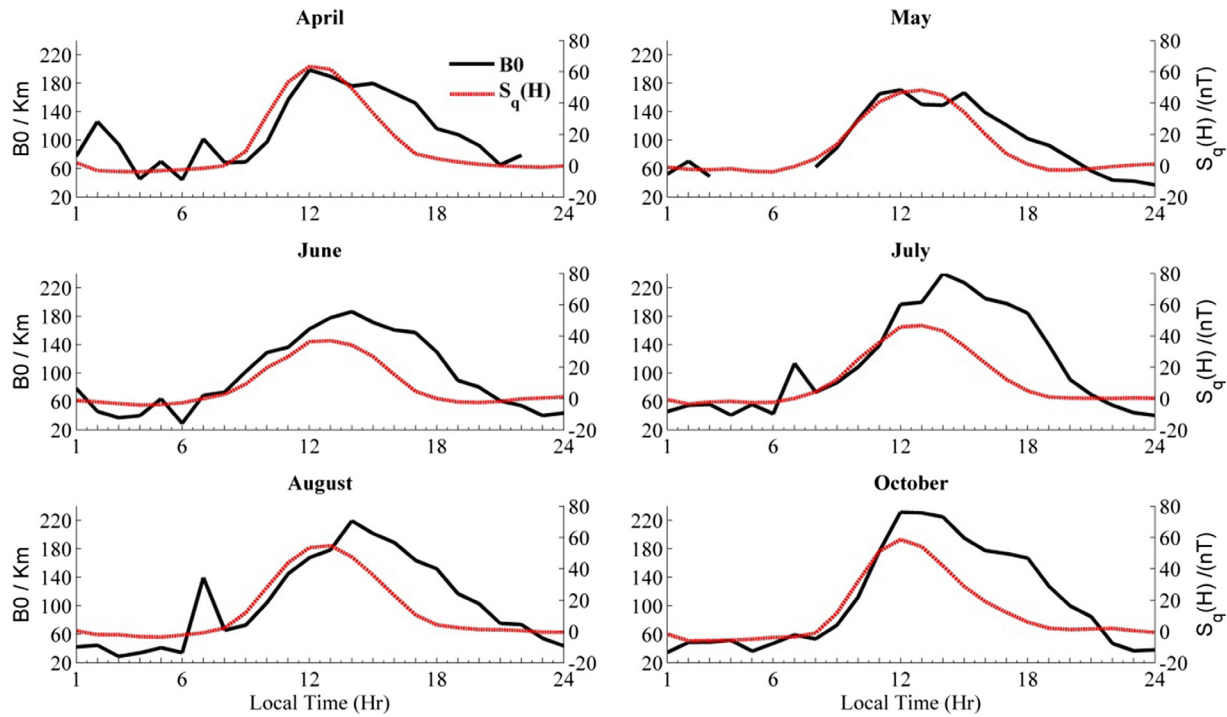


Fig. 3a. Simultaneous diurnal variations of B0 and SqH in each month for the year 2010.

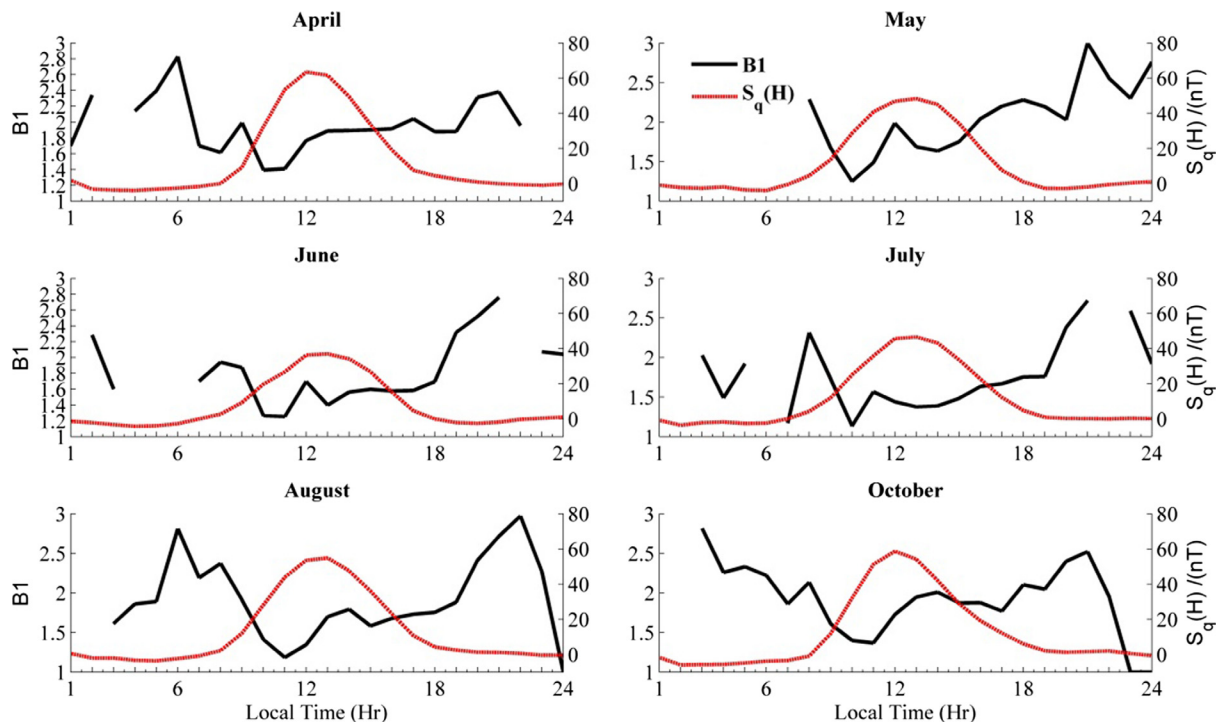


Fig. 3b. Simultaneous diurnal variations of B1 and SqH.

3.2. Relationship between B_0 , B_1 , and SqH

Studies of the simultaneous ten quietest days values from each month of SqH and ionospheric profile parameters B_0 and B_1 are presented in Figs. 3a and 3b. Largely due to the paucity of data only the results of the month of April–August and October are presented. Each of these months has data for the ten quietest days in each month except the month of August with seven quietest days data. The quietest days period are obtained from the International Quiet Days (IQDs) provided by the Geoscience Australia website available on the web link at <http://www.ga.gov.au>. The simultaneous variation of SqH and B_0 values are presented in Fig. 3a. The diurnal variation of SqH is observed to increase with sunrise with maximum field strength around 1200 LT. The magnitude of the SqH began to increase around 0800 LT for all the months and reduces to the baseline level between 1900 LT and 0600 LT. This increase is due to the heated tidal wind conducting over the ionosphere during its progression in the E-region (Bolaji et al., 2013). Consequently, the strength of SqH increases steadily during sunrise and reaching its peak value around midday after which it began to decrease toward the base level by sunset. The dominant factors that control the structure and strength of the SqH current system during the day are the neutral tidal winds and the local conductivities in the ionospheric dynamo E-region (Pedatella et al., 2011).

From Fig. 3a, we observe that B_0 values are lowest around pre-sunrise (0100–0600 LT) and during the nighttime between 2100 and 2400 LT for all the months coinciding with the period where the magnitude of SqH reaches its baseline level. In general, the variation of SqH follows closely that of B_0 value and both exhibit midday peak around noon time (1100–1300 LT). However, there is a time lag between the peaks of SqH and B_0 . The lag can be attributed to the delay in-between the EEJ current and plasma drift and varies in different seasons (Adebesin et al., 2013). During the daytime hour, the cross-field of east-west electric field (zonal electric field) and the horizontal northward geomagnetic field around the equatorial region result to an upward transport of plasma electrodynamics ($E \times B$) drift. Bolaji et al. (2013) explained that the orthogonality of E and B at the equator causes abnormal large conductivities within the ionospheric dynamo region (E-region altitude). The SqH current system in the E-region is due to the effect of the neutral wind and variation in the tidal component in the atmosphere and thus resulted in current flowing at E-region (Anderson et al., 2004). The current system resulted in the equatorward electric field that increases in strength toward the east and is responsible for the upward $E \times B$ drift velocities (e.g. Schunk and Nagy, 2009). Consequentially, an enhanced eastward current flow within a narrow band at $\pm 2^\circ$ and peak at of 107 ± 2 km and 136 ± 8 km, respectively (Hamid et al., 2014). This current has been earlier defined as EEJ. The eastward electric fields that are generated by

the E-region dynamo are then mapped onto the ionospheric F region altitudes along the equipotential geomagnetic field lines and cause an $E \times B$ drift (Anderson et al., 2002) resulting in the change of vertical ionospheric electron density profile. The drift allows the electron density to rise until the pressure forces are high enough that it starts to slide down the magnetic field lines, assisted by gravity and pressure (Anderson et al., 2002). Hence, the electron density is distributed on either side of the magnetic equator at ± 15 to 18° dip latitude, known as the equatorial ionospheric anomaly (EIA). Obrou et al. (2003) studied the relationship between hmF_2 and B_0 with SqH and observed that the movement of the plasma affects the thickness of the bottomside electron density below the F2-layer. By using the daily averages of the observed values of SqH and B_0 for the six months we considered, the correlation coefficient (r -value) between SqH and B_0 is 0.72 as shown in Fig. 4a. The positive and significant r -value indicates a plausible relationship between SqH and B_0 . The daily value of SqH is said to be the overhead ionospheric electric

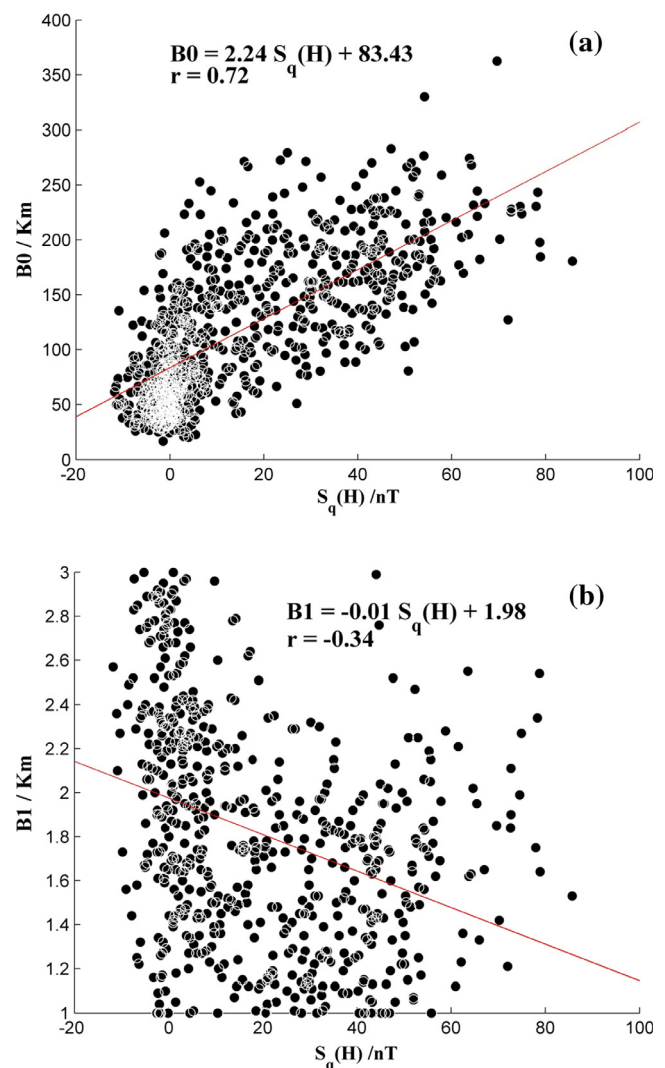


Fig. 4. (a–b) Shows the regression line for B_0 , B_1 against SqH , respectively.

field at the EEJ-trough (Bolaji et al., 2013), hence the EEJ is proportional to the electric field E . This suggests that, the morphology of the electron density profile below the F2-layer depends primarily on peak density $hmF2$ and $B0$ and are greatly influenced by the electric field whose strength can be indicated by SqH at the equatorial region Obrou et al. (2003).

On the other hand, Fig. 3b shows that the diurnal variation of SqH and $B1$. We observed that $B1$ exhibit two peaks; one in the morning and another at nighttime. During the daytime hour, $B1$ is lowest while the strength of SqH is highest around the midday. The correlation coefficient between SqH and $B1$ is found to be weak and negative ($r = -0.33$) and the linear relation is illustrated in Fig. 4b. The low correlation coefficient indicates that there is no clear relationship between the profile shape parameter $B1$ and SqH . Our result is similar to the result of Obrou et al. (2003) who used ionosonde and magnetometer data from Korhogo in Côte-d'Ivoire (Lat. $9.3^{\circ}N$, Lon $5.4^{\circ}W$, Dip $0.67^{\circ}S$) from 1993 to 1994. They obtained a strong and positive correlation coefficient (0.88) between $B0$ and the amplitude of geomagnetic H-component, ΔH (SqH in our study) and a negative correlation coefficient value of 0.57 between the $B1$ and SqH . It appears that shape parameter, $B1$ of the electron density profile at the bottom-side of the F2 region is not influenced by the SqH current and that was why the r -value is weak and negative. This indicates that $B1$ is not sensitive to the electric field in the correlation coefficient estimate.

4. Conclusion

Digisonde measurements obtained from Ilorin station during the period 2010, a year of low solar activity were used to characterize the bottom-side profile parameters $B0$ and $B1$. These profile parameters were used to validate the updated IRI-2012 model. The experimental $B0$ values were observed to be higher during the daytime than during the night. The shape parameter $B1$ does have smaller values during the day than at night. Comparative analysis presented in this study reveals that Gulyaeva-1987 option agrees better with the measured $B0$ value as compared to the rest of the other options in the IRI-2012 model. The shape parameter $B1$ was observed to exhibit oscillating pattern with a close trend to that of the IRI model options. The study also shows a positive and significant correlation between $B0$ and the SqH current while a negative and weak correlation exist between $B1$ and SqH . The regression equation obtained is a step toward the development of a regional model for the prediction of the profile parameters that can possibly be incorporated into the IRI model for better prediction in the nearer future.

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