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The Latitudinal effect on True Height of the Electron Density Profile in the bottom side of the F2 layer of an equatorial region

Olalekan David Ayokunnu[1], Oluseyi Enitan Ogunsola[2], Jacob Olusegun Adeniyi[3]and Ismail Adekunle Animasaun[4]

[1] Physics Department, The Polytechnic, Ibadan Ibadan, 200284 Nigeria.
[2]Physics Department, University of Ibadan, 200284 Nigeria
[3]Physics Department, Landmark University, Omu-Aran, 240272 Nigeria.
[4]Department of Science Laboratory Technology, The Polytechnic, Ibadan Ibadan 200284 Nigeria

Correspondence to: *Correspondence to*: Ayokunnu, Olalekan D. (davilek@yahoo.com)

Abstract. The latitudinal effect in the variations observed values profile of B_o, h_mF2 and N_mF2 for the F2 layer of the equatorial region during the quiet period at low solar activity was studied. Digisonde data for year 2010, a year of low solar activity from three equatorial stations in the African and Southern American sectors namely; Ilorin, Nigeria (8.5 ^{o}N, 4.5 ^{o}E, -2.96 dip) Fortaleza, Brazil (3 ^{o}S, 38 ^{o}W, -7.03dip) and Jicamarca, Peru (12 ^{o}S, 76.8 ^{o}W, 0.74 dip) were used for the study. During the March equinox; it was observed that the B_o peaks at 1200 hour LT time and the bite-out and the pre-noon peak of N_mF2 were also observed at this same time at Ilorin station. A similar feature was also observed at Fortaleza and at Jicamarca the N_mF2 peaks at 1000 hour LT and B_o peaks at 1500 hour LT. September equinox shows a general deviation from what was observed during the March equinox, at Ilorin and at Fortaleza B_o peaks at 1100 hour LT and at Jicamarca it was observed at 1500 hour LT. During the June solstice at Ilorin, B_o peaks at 1500 hour LT with the bite-out of the N_mF2, and at Fortaleza it was observed at 1200 hour LT with the peak of N_mF2 at 1500 hour LT. There was a shift at Jicamarca, in which two peaks were observed at 1100 and 1500 hour LT respectively. December solstice shows distinct double peaks of B_o at Ilorin and Fortaleza and a different feature was observed at Jicamarca. It was observed that the results from Ilorin and Fortaleza are similar and that of Jicamarca are different from those of other two stations. The peculiarity at Jicamarca is attributed to its closeness to the crest of the equatorial anomaly than these other two stations in the geomagnetic latitude as compared the geographic latitude. This is the second time in our studies that two stations from different latitude will be presented is being having similar profile. These variations observed may be due to effect of the latitudinal differences and the features observed find their explanation in the dynamics of the equatorial ionosphere of the stratospheric-ionospheric couplings.

1 Introduction

The in-depth study of the ionospheric electron density profile *Ne(h)* is an important topic in aeronomy for many practical problems and it contributes significantly to our understanding of the ionosphere, its dynamic nature and characteristics of radio wave for telecommunication (Yu-Jung, 2014). The ionosphere has been described as the part of the space weather environment that plays a crucial role through the modulation of global electrodynamic circuit which enables magnetospheric coupling and a key medium for communication, sounding and navigation (Elias *et. al.*, 2022). The F2 region of the ionosphere has also been identified to be the most important of the region in radio wave propagation due to its presence at all times of the day and seasons. The F2 region is often divided into F1 and F2 layers, which are considered as the bottom side of the ionosphere. The F1 layer is the lowest region and is dominated by photochemical processes, on the other hand the upper F region is dominated by diffussion (Ayokunnu, *et. al.*, 2018; Ayokunnu, *et. al.*, 2020). Generally, the overall structure of the atmosphere-ionosphere system is influenced by both internal and external processes such as internal atmospheric waves from below and magnetospheric, solar and geomagnetic processes from above (Yigit, *et. al.*, 2016). In between these two regions is the F2 layer in which transition from chemical to diffussion takes pre-eminence, investigation of variations in shape of the ionosphere will aid our understanding of the physical processes of the region and will further contribute significantly to our understanding of this important region. The equatorial region of the F2 layer is transversed by both geographic and geomagnetic equator which allows the region to receives maximum solar radiation and set of

https://doi.org/10.5194/egusphere-2023-107
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peculiarities such as: the equatorial ionization anomaly (EIA), possible additional stratification, F3 layer, equatorial spread F (ESF), etc are being observed. These result from the purely horizontal magnetic field along the geomagnetic equator (Abdu, 2020). The vertical plasma drift has been reported to play an important roles in the variations equatorial ionospheric plasma density and composition of the F region and further affect the generation and evolution of plasma structures (Zhang, *et. al.*, 2016; Shume, *et. al.*,). Scholarly work have been done on many analytical functions and emperical modeling techniques and and it has been reported to be used in the study of topside ionospheric parameter, such functions includes: Chapman's function and exponential, parabolic and Epstein function (Booker, 1977; Rawer, *et. al.*, 1988; Rawer, 1998; Di Giovanni, *et. al.*, 1990; Reinisch, et. al., 2001). Most of this works are seem to be concentrated on the high and mid latitude and scanty work on the equatorial region of the low latitude.

In this study, empashis is laid on the B_o parameter of the ionosphere; a parameter that describes the thickness of bottom side of the F2 layer (Adeniyi, and Radicella, 1997). We intend to investigate on the latitudinal effect of the true height of the electron density profile across the African and Southern American sector. The study is on the bottom side parameters of the equatorial region, the height was examined from 100 km up to its peak for seasonal, diurnal, solar cycle and latitudinal variations. Digisonde data for year 2010, a year of low solar activity from three equatorial stations in the African and Southern American sectors were used for the study. Variations from the African and Southern American sectors of the equatorial region were analyzed; also, previous results from this region were confirmed in the study.

1.1 Data and Methodology Subsection

The digisonde data from three equatorial stations namely; Ilorin, Nigeria (8.5ºN, 4.5ºE, -2.96 dip), Fortaleza, Brazil (3ºS, 38ºW, -7.03dip), and Jicamarca, Peru (12ºS, 76.8ºW, 0.74dip) were used for this study. Hourly data obtained from a Digisonde Portable Sounder (DPS-4) located at Ilorin in the form of Standard Archive Output (SAO) files for the year 2010, a year of low solar activity were used. The DPS at Ilorin and Jicamarca are capable of collecting forty-five ionospheric parameters that describe the condition of the ionosphere at a particular point in time for a routine measurement. The instrument is usually set to take measurement at fifteen minutes interval, except for that of Fortaleza, which was set to take the reading at a time interval of ten minutes. A SAO file is an American Standard Code for Information Interchange (ASCII) text file with a maximum length of 120 characters. All the data from the stations were analyzed using individual local time.

The corresponding data used in the analysis for Fortaleza and Jicamarca were obtained online from the Centre for Atmospheric Research, University of Massachusetts, Lowell, United States of America. Good and scalable ionogram files were carefully chosen and days of intense storms were avoided, since the study is about the quiet days. The data was carefully chosen to avoid non-scalable ionogram and edited. The edited SAO file of same hour was copied into a separate file. The edited data is then stored in a separate file and run through a computer programme CARP (Calculated Average Representative Profile). The CARP helps to calculate the average profile of the input data for any given month. The ionograms used for the study and the data for the quiet day were manually scaled using the ARTIST program, (NHPC) to verify the automatic scaled data. The output from the SAO files was run using CARP program to obtain the average profile for a particular month. The Truth table, computer software from the NHPC programme was then run to generate the electron density profiles at a height interval of 10 km (Huang and Reinisch, 1996a; Huang, and Reinisch, 1996b). The average of each of the three months (November, December and January) was used to represent December Solstice; (February, March and April) March equinox; (May, June and July) June Solstice; and (August, September and October) September Equinox respectively.

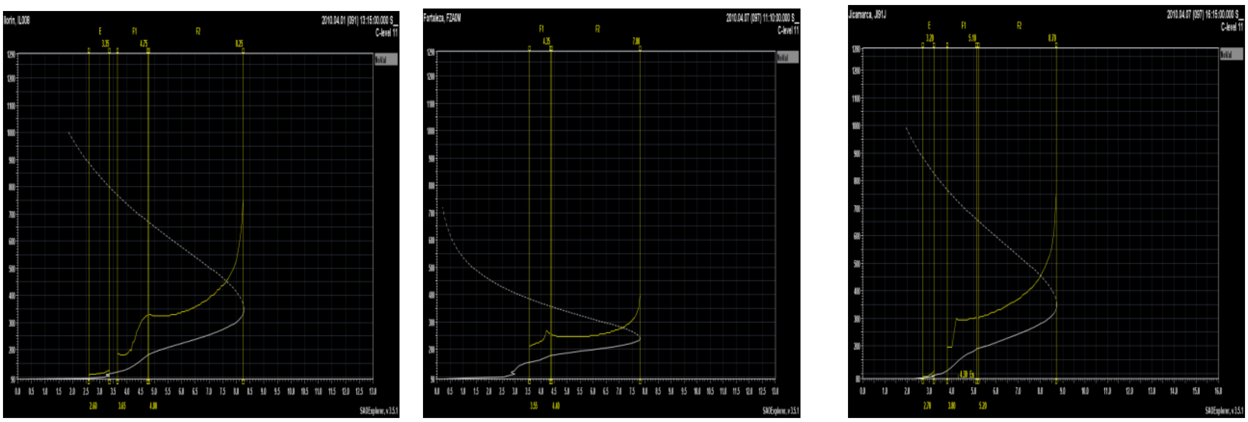
1.1.1 RESULTS AND DISCUSSION

The data source is as presented in table 1 and typical day and night profiles of the electron density of the stations used are presented in figures1 and 2 respectively. Figure 3 is a typical ionization characteristic of the equatorial region, which makes the region peculiar and figure 4, is a plot of geographic and geomagnetic plots with the electron density, showing the positions of the stations under study in the crest and trough of the equatorial. The result is as presented in figures 5 and 6. During the March equinox; it was observed that the B_o peaks at 1200 hour LT time with the bite-out and the pre-noon

https://doi.org/10.5194/egusphere-2023-107
Preprint. Discussion started: 21 February 2023

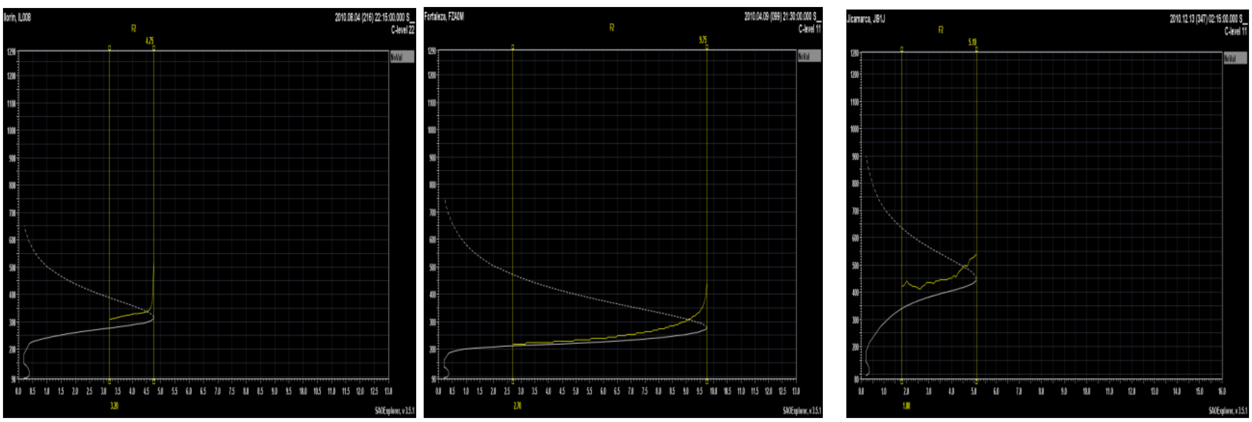
Table 1.0: Data Source

Geograhic Coordinate	Geomagnetic coordinate
Ilorin, Nigeria(8.5°N, 4.5°E)	(-1.82, 76.80, -2.96 dip)
Fortaleza, Brazil (3°S, 38°W)	(-3.64, 34.21,-7.03dip)
Jicamarca, Peru (12°S, 76.8°W)	(0.77, 354.33, 0.74dip)



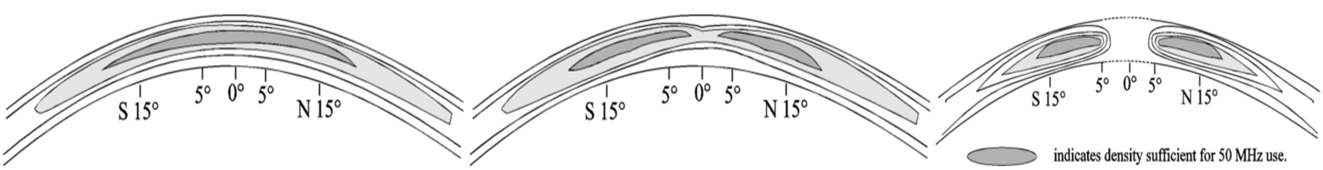
(a) (b) (c)

Fig. 1: Typical Daytime profile (a) Ilorin, Nigeria (b) Fortaleza, Brazil (c) Jicamarca, Peru



(a) (b) (c)

Fig. 2: Typical Night time profile (a) Ilorin, Nigeria (b) Fortaleza, Brazil (c) Jicamarca, Peru



(a) (b) (c)

Figure 3. Typical ionization of the F region (a) Before noon (b) At noon(c) After noon (Adeniyi, et. al, 2012).

https://doi.org/10.5194/egusphere-2023-107
Preprint. Discussion started: 21 February 2023

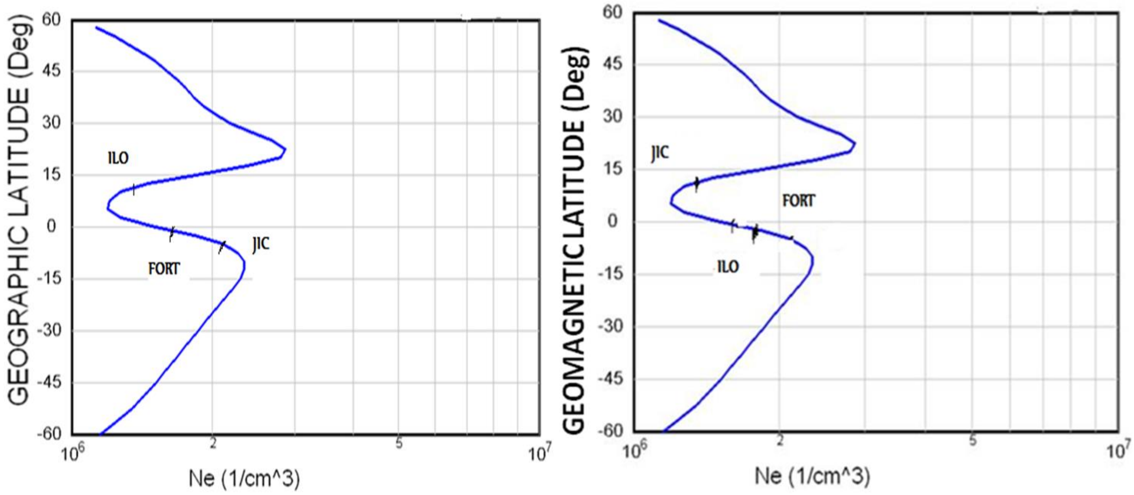
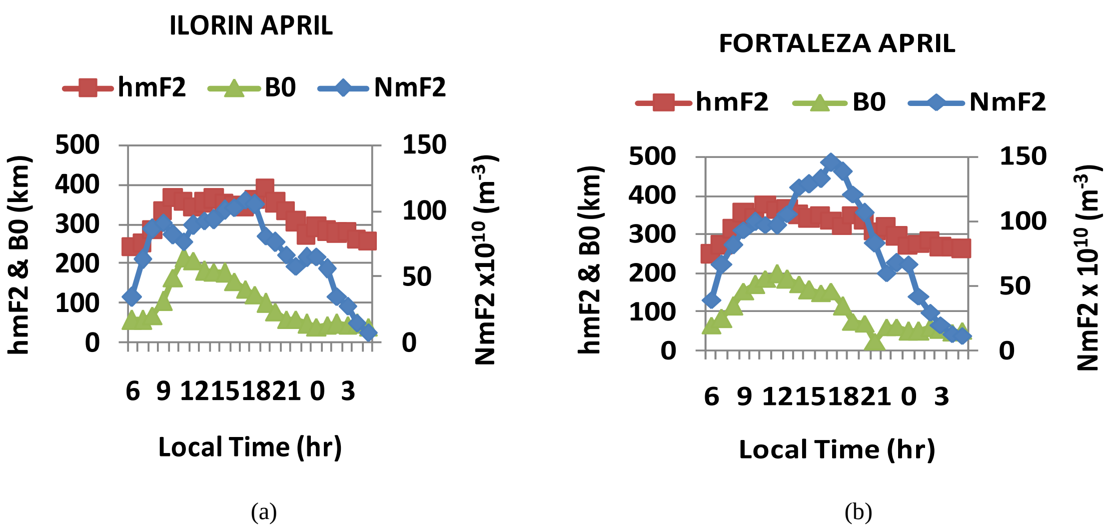
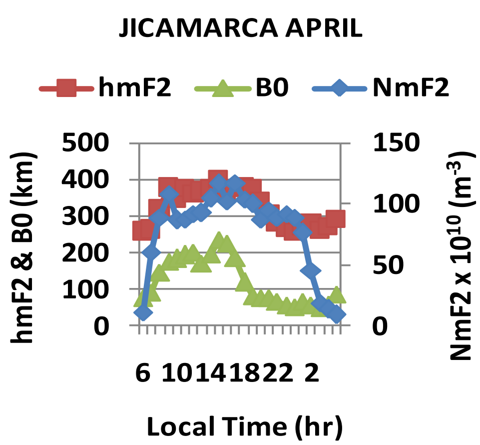


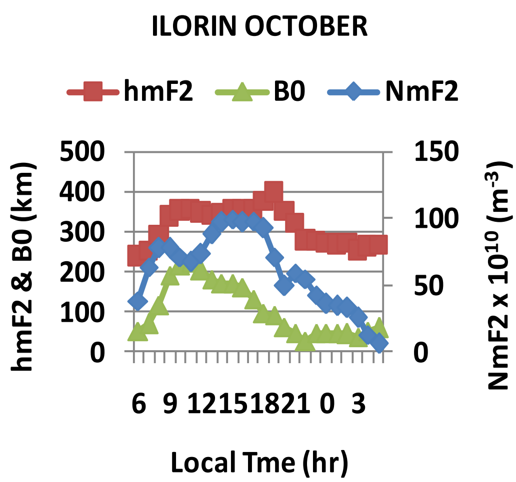
Fig. 4: Geographic and Geomagnetic Latitude Plots of the stations studied in the Equatorial trough and crest of ionization (Adeniyi, et. al, 2012).



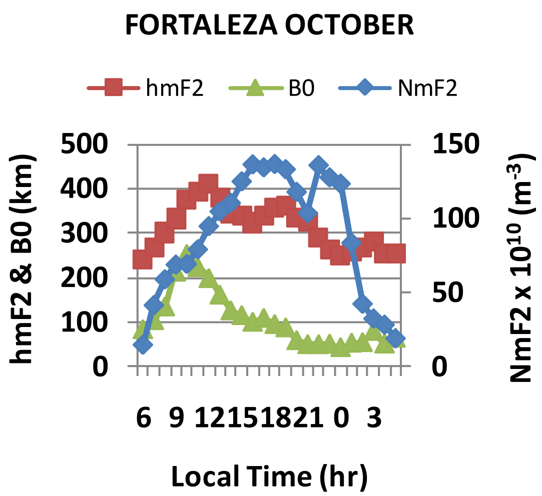
https://doi.org/10.5194/egusphere-2023-107
Preprint. Discussion started: 21 February 2023



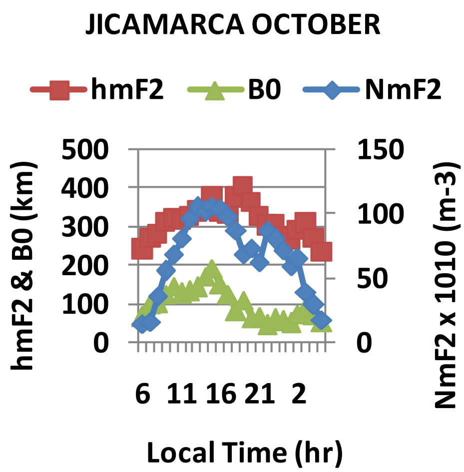
(c)



(d)



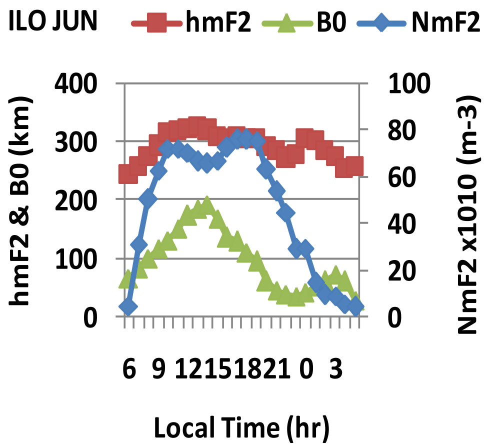
(e)



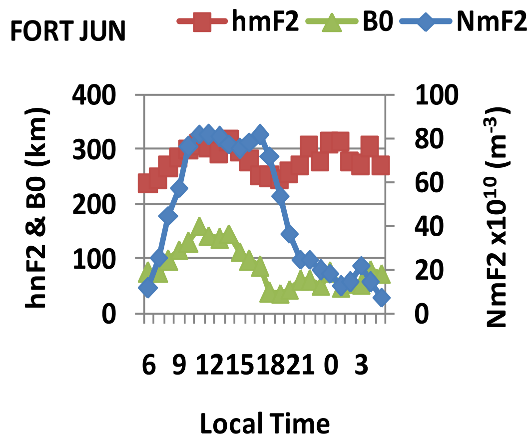
(f)

Fig. 5: Average Plot for March and September Equinox (a & d) Ilorin (b & e) Fortaleza (c & f) Jicamarca respectively.

https://doi.org/10.5194/egusphere-2023-107
Preprint. Discussion started: 21 February 2023



(a)



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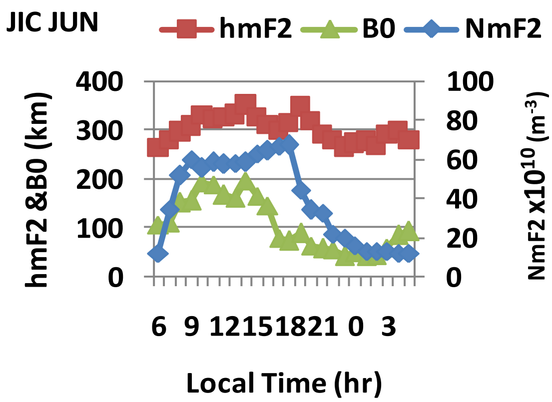
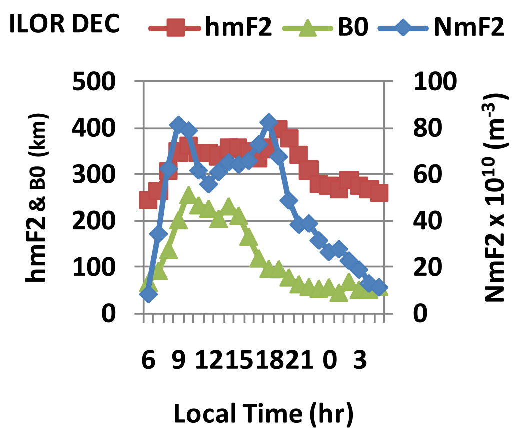
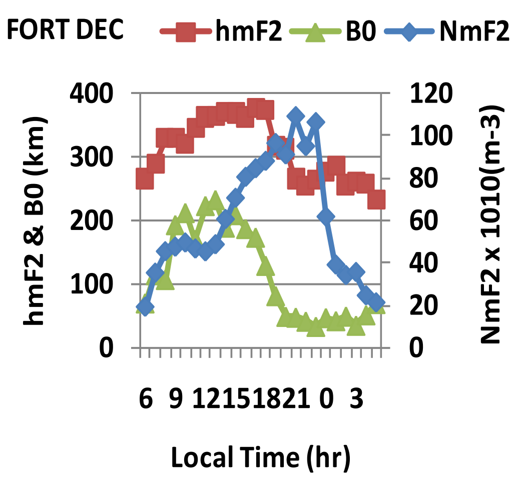


(c)

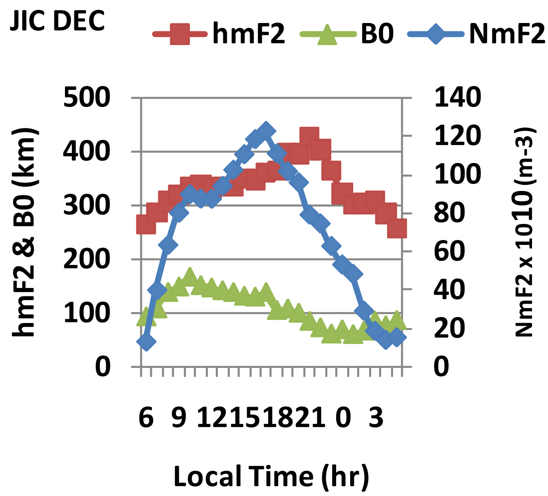


(d)

https://doi.org/10.5194/egusphere-2023-107
Preprint. Discussion started: 21 February 2023



(e)



(f)

Fig. 6: Average Plot for June and December Solstice (a & d) Ilorin (b & e) Fortaleza (c & f) Jicamarca respectively.

peak of N_mF2 were also observed at this same time. A similar feature was also observed at Fortaleza, at Jicamarca the N_mF2 peaks at 1000 hour LT and B_o peaks at 1500 hour LT. September equinox shows a general deviation from what was observed during the March equinox, at Ilorin and Fortaleza B_o peaks at 1100 hour LT and Jicamarca at 1500 hour LT. During the June solstice at Ilorin, B_o peaks at 1500 hour LT with the bite-out of the N_mF2, at Fortaleza it was observed at 1200 hour LT with the peak of N_mF2 at 1500 hour LT. There was a shift at Jicamarca, in which two peaks were observed at 1100 and 1500 hour LT respectively. December solstice shows distinct double peaks of B_o at Ilorin and Fortaleza and a different feature was observed at Jicamarca. At the low latitude, many special phenomena have been discussed in scholarly published articles (Hanson, and Moffett, 1966; Oyama, et. al., 1997 and Raghavarao, et. al., 1991). One of this special phenomenon is the Equatorial ionization anomaly (EIA) presented in fig. 3. It is due to the horizontal orientation of geomagnetic field at the equator, at which the variation of the electron density exhibit an unexpected large structure around the equator, crests near $\pm 15^o$ magnetic latitudes and crest to trough ratio of about 1.6 in day time peak electron density (Bailey, and Balan, 1996). Fig. 3a, shows the observation during the morning, at the equatorial station when the neutral species has not been ionized; as the solar radiation begins to intereact with the species of the ionosphere (O_2), around the noon time and fig. 3b comes into play, which produces the first peak in the ionization of the species. Another peak is usually being oberved in the region, the post-noon peak is depicted in fig. 3c.

It has been reported that in addition to diffussion of ionospheric species, the upward $\overline{E}\times\overline{B}$ drift of plasma is important cause of the anomalies (Martyn, 1955). Diffusion produces weak anomaly in the morning with the crest around $\pm 10^o$ magnetic equator due to large plasma pressure gradient between the equator and higher latitudes, and the anomaly becomes weaker with time and disappears before noon when the gradient pressure is small (Balan, et. al., 2018). The EIA is formed mainly from the removal of plasma from around the equator by the upward $\overline{E}\times\overline{B}$ drift creating the trough and consequently the crest with small accumulation at the crests as long as the crests are at lower latitudes. The upward movement of the drift and other dynamics in the ionosphere may be the cause of the latitudunal effect on the true height of the electron density profile in the both of the F2 layer of an equatorial region.

1.1.2 Conclusion

The main result of the latitudinal effect on true height of the electron density profile in the bottom side of the F2 layer of an

https://doi.org/10.5194/egusphere-2023-107
Preprint. Discussion started: 21 February 2023

equatorial region is as presented:

(i) During the March equinox; it was observed that the B_o peaks at 1200 hour LT time and the bite-out and the pre-noon peak of N_mF2 were also observed at this same time.

(ii) A similar feature was also observed at Fortaleza, at Jicamarca the N_mF2 peaks at 1000 hour LT and Bo peaks at 1500 hour LT.

(iii) September equinox shows a general deviation from what was observed during the March equinox, at Ilorin and Fortaleza B_o peaks at 1100 hour LT and Jicamarca at 1500 hour LT.

(iv) During the June solstice at Ilorin, B_o peaks at 1500 hour LT with the bite-out of the N_mF2, at Fortaleza it was observed at 1200 hour LT with the peak of N_mF2 at 1500 hour LT. There was a shift at Jicamarca, in which two peaks were observed at 1100 and 1500 hour LT respectively.

(iv) December solstice shows distinct double peaks of B_o at Ilorin and Fortaleza and a different feature at Jicamarca.

(v) Previous results from this region were confirmed in the study.

In this study, it was observed that the results from Ilorin and Fortaleza are similar and that of Jicamarca are different from those of other two stations (fig. 4 and table 1.0), considering the geomagnetic coordinate. The peculiarity at Jicamarca is attributed to its closeness to the crest of the equatorial anomaly than these other two stations. This is the second time in our studies that two stations from different latitude will be presented as being having similar profile. The features observed find their explanation in the dynamics of the equatorial ionosphere of the stratospheric-ionospheric couplings.

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