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Modeling of Electron Density of the Equatorial F1 Layer in the Low Latitude Region

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Abstract

The electron density of the equatorial F1 layer (±30°) of the low latitude region is modeled in this work. The digisonde data used is of the year 2016, a year of low solar activity with sunspot number, Rz (20) of 30. The data used is from seven (7) stations North and South of the region of the low latitude. The stations used are: Guam (13.4°N, 144.5°S dip 12.8°), America; Sanya (18.3°N, 109.5°S dip 25.0°) China; Boa Vista (16.1°N, 22.8°S dip 22.1°) Cape Verde; Campo Grande (20.5°S, 54.6°W dip 22.3°); Cachoeira (12.6°S, 39°W dip -28.0°); Fortaleza (3°S, 38.6°W dip -15.8°) all in Brazil and Jicamarca (12.0°S, 76.9°W dip -0.5°) Peru. The F1 layer was observed in each of the stations used and found to be present between 0700-1800 local time. The percentage occurrence of the layer at 0700 and 1800 local time is 1 and 3% respectively, while that of 0900-1700 local time exceeds 85%. The solar dependency of the layer is characterized and latitudinal variability of the layer is also observed. The index 'n' was observed to be in the region of $n = \pm 0.2$ during the Equinox months and $n = \pm 0.1$ during the Solstice months. The prediction from this new model was found to be of order $10^{-4} / 10^{-5}$ for the minimum error and 10^{-2} for the maximum error and found quite close to the observed value at the various stations in the low latitude region.

Keywords

Electron Density, Equatorial Ionosphere, Low Latitude and Low Solar Activity

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1. Introduction

Modeling of the F1 layer is not as common as the other layers of the ionosphere because it requires very well specified input parameters. The F1 layer is not always present in the ionosphere due to its solar activity dependence. It is not observed during high solar activities and often when present it is usually represented as ledge [1].

Generally, several studies have been done on both the high and low latitudes, while we have scanty studies on the equatorial region of the ionosphere. Also, studies on the F1 region are often less than those of the F2 region. Production of good ionospheric model that will give an accurate picture of the ionosphere requires well-defined characteristic properties of the F1 region [2]. Also for adequate prediction of the space weather, the F1 region should be put into consideration [3]. It has been observed that the study of space climate needs accurate prediction of the parameters of the ionosphere, F1 layer inclusive.

Scholarly work such as [4-7], has shown that the results in all this work lack adequate prediction for modeling the electron density of the F1 layer of the low latitude region, especially the equatorial region.

X-ray is the most important wavelength band for ionization

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species of the air molecule present in the altitude range of the F1 layer. The photo ionized O_2, N_2O and to lesser degree NO is the primary ionization product which has sufficient energy to produce the secondary ionization.

In a previous report in which a numerical model for the F-layer in the ionospheric region was put up, it was based on the solution of continuity and momentum equations for O^+, N^{2+}, O^{2+}, and NO^+; considering photo-ionization, recombination, thermospheric wind, and electromagnetic drifts [8]. They reported that this kind of model helps in having a clue into the physical processes of the activities driven by the solar processes in the ionosphere [9]. Moreover, despite that their model was utilized in stimulating some of the ionospheric profile, however, results obtained showed that stable ions species alone would not be enough to bring about the F1 ledge. They demonstrated in the research work that metastable ion containing singly positively charged atomic oxygen; particularly O^+ (2d-orbital) and O^+ (2p-orbital) species are important in the production of the F1 ledge. They also iterated that transport produced by wind for all the ionization under consideration is also an essential factor for the formation of the F1 ledge.

In another report, a version of the numerical model was used to investigate the occurrence and evolution of the F1 ledge [10]. Their results showed that the development of the F1 ledge can be explained with the use of variations which occurs in the magnitude of the ratio of the mass of atomic oxygen (O) compared to the mass of neutral molecules (M) and the transition height where the concentration of atomic oxygen is equal to that of neutral molecules. They however reported that when numerical values of critical frequency (f_oF1) alone are used in modeling the F1 layer, the availability of that kind of electron density ledge is completely omitted. This partly accounts for the lack of agreement between the profiles of the IRI model and observed profiles mentioned earlier on. In order to improve the modeling of ionospheric profile in the F1 region, attempts were made to introduce other parameters. Some of these studies include those of [11-13]. Ultimately, their studies were carried-out for the low-latitude and mid-latitude regions.

Also, the change in the dominant ions during the geomagnetic storm has been reported to play neither any role or affect only the upper part of the E-F1 region system [14]. The electron density of the F1 region maximum usually occurs between the height of 150 km and 180 km [15] and photochemistry dominates the region. The region is thought to be created by the part of the extreme ultraviolet (EUV) section, which is most heavily absorbed by the solar radiation of wavelength between 500-600°A, reaching the unit optical depth at about 160 km contributes to the ionization of the region [16].

The f_oF1 has been found to vary as $(Cos\ \chi)^n$ and is theoretically close to $\alpha -$ Chapman behaviour. The height of the F1 layer (h_mF1) does not vary like the height of the peak of $\alpha -$ Chapman layer; it increases towards the dawn as expected. Its value is higher in the winter at low latitude than at middle latitude; which certainly contradicts what happens at the $\alpha -$ Chapman layer [17]. The f_oF1 which exists in the ionospheric layers characterizes the electron density of the layers and it is an essential parameter for observing the ionosphere [18]. The values of critical frequency of the E layer (f_oE) of the ionosphere given at Chumphon (10.72°N, 99.37°E), Thailand ionospheric observatory station, between the year 2007-2012 were implemented to investigate the variations of f_oF1 over the geomagnetic equatorial region during the solar cycle 24. The investigation, including variations with local time, days, seasons and solar cycle, and the result was found to be in agreement with the observed values. A comparison between the observation data and International Reference Ionosphere (IRI) 2012 model has also been made [19]. The IRI 2012 model underestimates f_oF1 especially during the period of 7000-1100 LT and after 1800 LT for each day and all seasons. Combining with previous investigations, they suggested that under-estimation of ionospheric f_oF1 by IRI 2012 model was very useful for the correction of IRI model in an equatorial Asia region.

The analysis of the annual ionospheric variations of f_oF1 at the equatorial stations during the solar minima were found to be essential distinctions between the global TEC (Total Electron Content) and f_oF1 annual variations during the last two solar minima. Many authors concluded that the annual means of f_oF1 and the global TEC were reduced, while other investigations found essential variations as compared with the previous solar minimum.

The study for mid-latitude and an equatorial station in the American region reveals that electron density at a particular set height of 170 km has a day-to-day variability which is not up to 10% [20]. In this study for Ouagadougou station, the height, hF1 has an average value given as 166 km. The value arrived at for Ibadan from the comparison done in this study was about 6 km short of the value for Ouagadougou. The magnitude of this difference drops within the range of the standard deviations gotten for hF1, hence the difference might not be so pronounced. The discrepancy detected in the electron density (NF1) between these two stations was assumed to be due to the dependence of NF1 on solar activity.

Three equatorial stations in the African sector, Korhogo (9.3°N 5.4°W), Cote d'Ivore, 1995, Ouagadougou, Burkinafaso, (12.4°N, 1.5°W) 1994 and 1995 and Ilorin (8.5°N, 4.5°E), Nigeria, 2010 were studied in another work.

It was reported that the occurrence frequency observed for the solstice months differ slightly from that of the equinox months and observed that IRI over-predicted the value of h_mF1 at all seasons and diurnal occurrence is not also accurately predicted claiming that a minimum of two hours was observed in the late appearance of the layer and one hour in its early disappearance [21]. Furthermore, this work on equatorial region used the height of F1 layer in its model and it was quite in agreement with the observed values at some equatorial stations. He therefore recommended that the model can serve as a guide to equatorial stations where the digisonde portable sounder is not available. It is not adequate because only three stations were used in the work and the usual discrepancies in the height of the F1 layer were observed. He also recommended that further research into the model to determine the electron density of the F1 layer be carried out in order to test its variability and viability in other available equatorial regions of the world [21].

This study tends to validate this existing model in the prediction using the electron density (N_mF1) of F1 layer of the low latitude of the equatorial region and how well the international reference ionosphere (IRI) predicts the F1 region peak ionization density (N_mF1) of the same region. The method used in this research work, including the variations with local time, diurnal and seasonal variations and solar cycle in consonance with the observed values of the f_oF1. In this study, we used the $\alpha-$ Chapman theory to model the electron density of the region, using the critical frequency of (f_oF1) of seven low latitude stations, North and South of the region as an input data. $\alpha-$ Chapman theory predicts $f_oF1\ \alpha\ (\cos\ \chi)^n$; since 'χ' is a factor that is solar dependent. Hence, the model has included the variations due to local time, diurnal and seasonal variation and solar cycle into consideration.

2. Data and Method

The digisonde DPS-4 data used in this study are the average hourly values of the critical frequency (f_oF1) from Guam (13.4°N, 144.5°S, dip 12.8°), America; Sanya (18.3°N, 109.5°S, dip 25.0°) China; Boa Vista (16.1°N, 22.8°S, dip 22.1°) Cape Verde; Campo Grande (20.5°S, 54.6°W, dip 22.3°); Cachoeira (12.6°S, 39°W, dip - 28.0°), Fortaleza (3°S, 38.6°W, dip - 15.8°) all in Brazil and Jicamarca (12.0°S, 76.9°W, dip - 0.5°) Peru. They were obtained online from the Global Ionospheric Radio Observatory (GIRO) on the web portal (http://giro.uml.edu/didbase/scaled.php). Data were collected for the year 2016, a year of low solar activities with sunspot number Rz (20) of 30. The representative months were arbitrarily chosen, and months used are March, April and May (March Equinox), July and August (June Solstice), September and October (September Equinox), November and December (December Solstice).

Records from each day of these months were picked for this study with ionograms good enough to be scaled and magnetic storm days avoided. The POLAN technique [17] was used to invert the ionogram. The data was semi automatically scaled to check for the correctness of the input parameters. The data collected from each of the stations were stored in Standard Archive Output (SAO) explorer, which were edited and converted to binary form to serve as input to Octave (GNU). The Octave (GNU) software which utilizes a compatible programming language with MATLAB was used in solving both the linear and non-linear problems numerically.

Equation (1) is from $\alpha-$Chapman theory and equation (2) connects critical frequency with the electron density.

$$foF1\,\alpha(\cos\chi)^n \tag{1}$$

$$NF1=\frac{(foF1)^2}{80.5} \tag{2}$$

Equation (3) is an expression of the solar zenith angle, ϕ is the hour angle and δ is the angle of declination of the station

$$\cos\chi=\sin\delta\sin\varphi+\cos\delta\cos\varphi \tag{3}$$

The absolute error is calculated from equation (4)

$$\psi=\frac{1}{n}\sqrt{\left|X^{1}-X\right|^{2}} \tag{4}$$

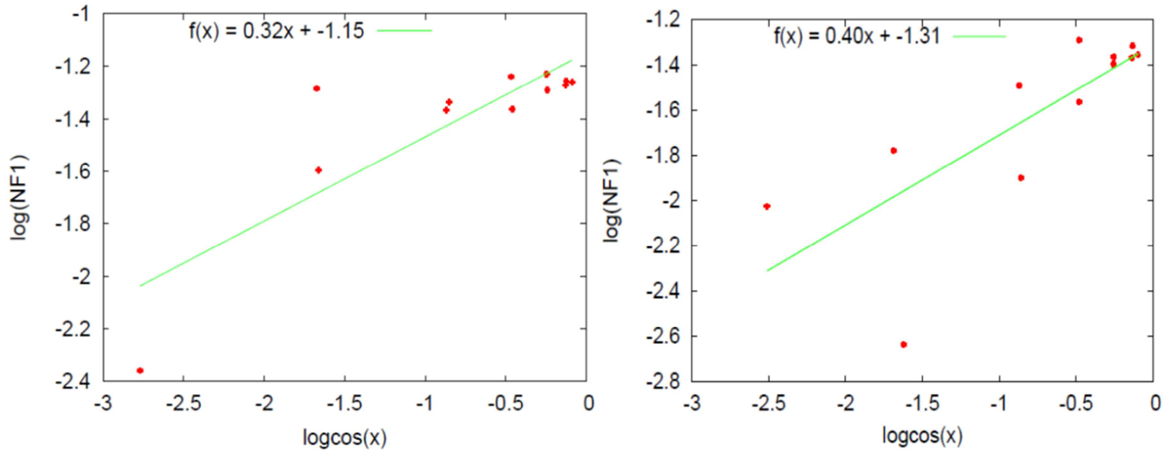
Where n = Total number of points available per plot and ψ is the absolute error; ψ_1,ψ_2 is the minimum and maximum errors respectively.

3. Results and Discussion

Table 1. A table showing the result obtained from the stations used.

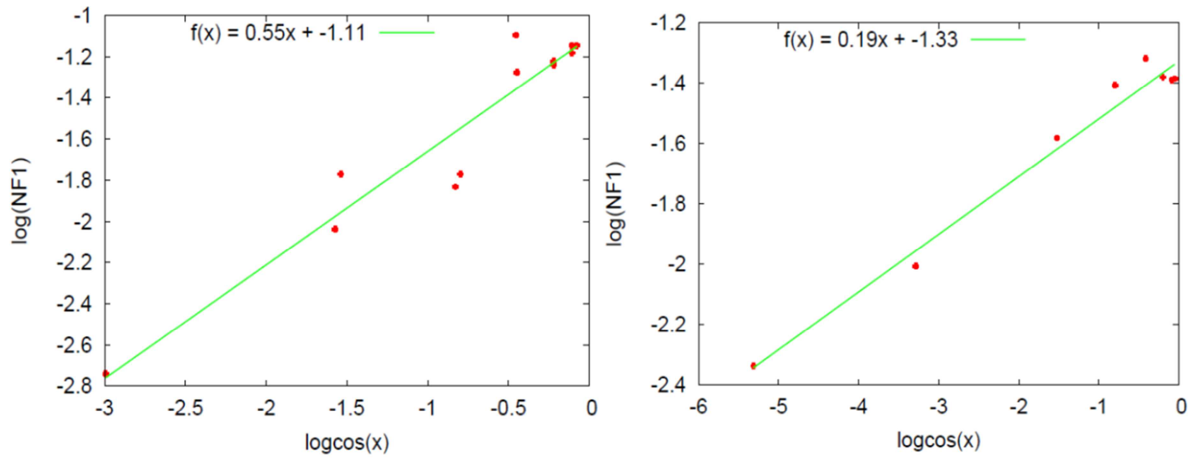
Station Used	The Modeled hourly solar cycle change 'n'											
Local Time	**0700**	**0800**	**0900**	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**
GUAM (13.4°N, 144.8°E dip 12.8°)	0.51	0.55	0.48	0.46	0.34	0.36	0.35	0.37	0.36	0.36	0.32	0.32
SANYA (18.3°N, 109.5°W dip 25.0°)	0.17	0.11	0.14	0.18	0.18	0.17	0.16	0.14	0.18	0.18	0.18	0.18
BOA VISTA (16.1°N, 22.8°W dip 22.1°)	0.41	0.44	0.28	0.32	0.31	0.41	0.41	0.30	0.36	0.32	0.24	0.38
FORTALEZA (3.7°S, 38.6°W dip -15.8°)	0.31	0.24	0.39	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28

Station Used	The Modeled hourly solar cycle change ‘n’											
Local Time	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800
CACHOEIRA (12.6°S. 39°W dip -28.0°)	0.21	0.14	0.21	0.13	0.15	0.19	0.31	0.31	0.31	0.31	0.31	0.31
CAMPO GRANDE (20.5°S, 54.6°W dip 22.3°)	0.34	0.50	0.40	0.35	0.28	0.21	0.16	0.33	0.22	0.24	0.14	0.11
JICAMARCA (12.0°S, 76.9°W dip -0.5°)	0.14	0.16	0.17	0.18	0.17	0.16	0.15	0.14	0.14	0.14	0.14	0.14



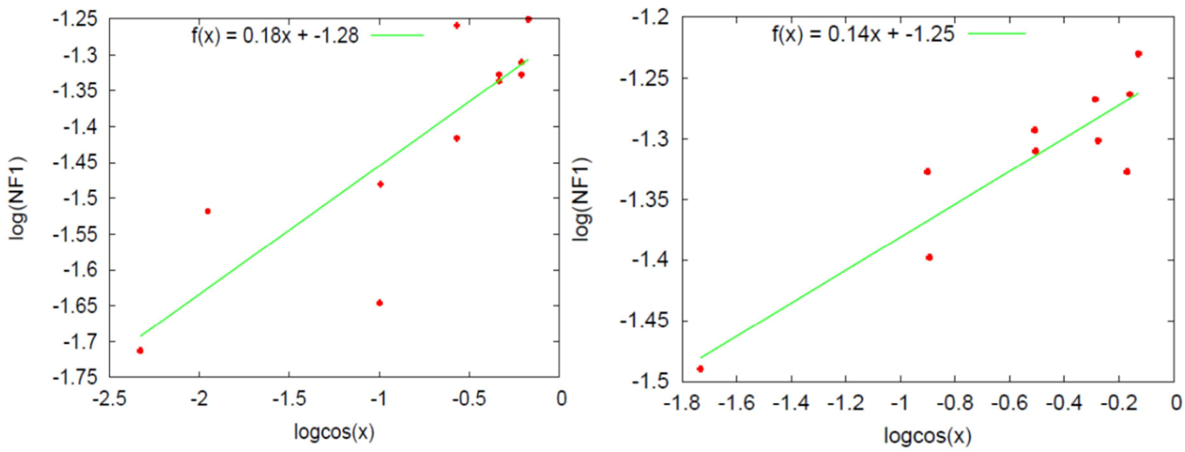
(a) (b)

Figure 1. Average 0900hourLocal Time Plot for (a) Boa Vista (b) Campo Grade.



(a) (b)

Figure 2. Average 1100 hour time local Plot for (a) Guam (b) Cachoeira.



(a) (b)

Figure 3. Average 1600 hour local time Plot for (a) Sanya (b) Jicamarca.

Table 2. A table showing the result absolute error from modeled of selected stations.

Station	LT	Minimum error (ψ_1)	Maximum error (ψ_2)
Boa Vista	0700	0.00025	0.034
	1200	0.00058	0.02
	1800	0.00017	0.071
Campo Grande	0700	0.00025	0.04
	1200	0.00025	0.081
	1800	0.000083	0.071
Sanya	0800	0.00045	0.018
	1200	0.00091	0.020
	1800	0.000727	0.0169
Cachoeira	0700	0.000154	0.015
	1100	0.000846	0.023

The average hourly plots for each of the stations in local time are as shown in figures 1 to 3 respectively. It shows the diurnal variation of electron density (NF1) with the solar zenith angle χ .

The observed occurrence statistics of F1 layer shows that the layer is present between 0700-1800 hour local time (LT). The percentage occurrences are 1 and 3% for 0700-1800 LT respectively and for 0900-1700 LT, it exceeds 85%, which is in agreement with previous works and shows a disagreement with the IRI-2012 model in which the model did not observed the layer until around 0900 LT. The presence of F1 layer is well represented throughout the observed months. It was observed that in the equinox months a regular pattern was followed with an increase in the occurrence frequency of the F1 layer until it gets to 1200-1300 LT; at these hours, occurrence frequency starts to decrease until 1800 LT when the layer disappeared. The occurrence frequency observed for the solstice months differs slightly from those of the equinox months.

4. Conclusion

The modeling of electron density of the equatorial F1 layer using the average hourly values of the critical frequency (f_oF1) of seven equatorial stations: Guam (13.4°N, 144.5°S, dip 12.8°), America; Sanya (18.3°N, 109.5°S, dip 25.0°) China; Boa Vista (16.1°N, 22.8°S, dip 22.1°) Cape Verde; Campo Grande (20.5°S, 54.6°W, dip 22.3°); Cachoeira (12.6°S, 39°W, dip -28.0°), Fortaleza (3°S, 38.6°W, dip -15.8°) all in Brazil and Jicamarca (12.0°S, 76.9°W, dip -0.5°) Peru is presented. The index parameter is ± 0.2 for the equinox months and ± 0.1 for those of the solstice. It has been observed that:

(i) F1 layer are present in all the stations for this work from 0700-1800 local time (LT) as presented in Table 1.

(ii) The layer is observed 0700 and 1800 LT in the percentage occurrence of 1 and 3% while those of 0900-1700 LT exceeds 85%

(iii) The solar dependency of the layer was also characterized

(iv) Latitudinal variability of the layer was observed

(v) The absolute error in the model was found to be of order $10^{-4}/10^{-5}$ for the minimum error and 10^{-2} for the maximum erroras presented in Table 2. This is observed to be quite close to the observed value at the various stations in the low latitude region.

References

[1] Adeniyi, J. O (1997). Equatorial F1characteristics and the internationalreference ionosphere model, Radio Science, 31 (4), pp 893-897.

[2] Ducharme, E. D, Petrie, L. E and Eyfring, A. (1973). A methodfor predicting the F1 layer critical frequencybased on Zurichsmooth number, Radio Science, 8 (10), 837-839.

[3] Bilitza, D. (1990). International Reference Ionosphere, National Space science data centre report, 90-92, GreenbeltMaryland.

[4] Titheridge, J. E (1996). Direct allowancefor the effect of photoelectrons in ionospheric modeling, J. Geophys. Res. 101, 357-369.

[5] Solomon, S. C., Bailey, S. M and Woods, (2001). Effect of soft solar X-ray on the lower atmosphere, Geophys. Res. Lett., 28 2149-2152.

[6] Sojka, J. J, Jensen, J., David, M., Schunk, R. W., Wood, T andEparvier, F (2013). Modeling the Eand F1 regions: using observations as the solar irradiance driver, Journal of Geophysical research: Space physics, 118, 5379-5391, doi:10.1002/jgra.50480.

[7] Somoye, E. O, Eugene, O. O, Ogungbe, A. S, Ogabi, C. O, Ogwala, A., Ometan, O. O, Adeniji-Adele, R. A, Iheonu, E. E, Oluyo, K. S and Sode, T. A (2017). Day-to-day variability of critical frequency of F1 layer. American Journalof sustainable development. 2 (4), 30-35.

[8] Zhang, S. R, Huang, X. Y, Yuan-zhi and Radicella, S. M (1993). A Physical model for one dimension and time independent ionosphere, description of the model, Ann. Geophys. 36 (5-6) 105-110.

[9] Zhang, S. R and Huang, X. Y (1995). A numerical study of the ionospheric profile for mid latitudes, Ann. Geophys.13, 551-557.

[10] Zhang, S. R, Shi, J. K, Wang, X, Radicella, S. M (2004). Ionospheric variability at low latitude station: Hainan, China, J. Adv. Space Res. 34, 1860-1868.

[11] Shchepkin, L. A and Vinitsky, A. V (1982). A new parameters of F1 layer, INAG Bull. Boulder Colorado 37, 5-6.

[12] Mosertde Gonzalez, Radicella, S. M, Adeniyi, J. O, Ezquer, R. G and Jadur, C. (1991). Electron density in the intermediate heights for low latitude stations: Observations and models, Ad. Space Res. 27 (1) 13-16.

[13] MosertdeGonzalez and Radicella, S. M (1987). An empirical model of the F1 intermediate layer true-height characteristics, Advances in Space Research, 7 (6) 65.

[14] Lastovicka, J. (2002). Monitoring and forecasting of ionospheric space weather- effect of geomagnetic storm, Journal of Atm. and Solar Terr. Physics, 64, 697-705.

[15] Adeniyi, J. O and Radicella (1998). Electron density and height at F1 region minimum gradient at high solar activity for an equatorial station, radio science, 33 (5), 1387-1393.

[16] Beynon, W. J. G and Brown, G. M (1959). Geomagnetic distortion of E region, Journal of Atm. Ter. 14-50.

[17] Ratclifee, J. A. (1972). An Intoduction to ionosphere andMagnetosphere. Cambridge press London. 55-58.

[18] Akchurin, A. S (2016). Ionospheric radio, IEE electromagnetic waves series 31, London, UK, Peter peregrius Ltd, The Institute of Electrical Engineering, ISBN 0-86341-186-X.

[19] Volland, H. (1984). Atmospheric electrodynamics, Berlin, Springer Verlag, 45 (6) 189-220.

[20] Reinisch, B. W and Haung, X. (1996a). Vertical electron density profile from Digisonde network. Adv. Space Res. 18 (6), 121-129.

[21] Ayokunnu, O. D, Ogunsola, O. E and Adeniyi, J. O (2018). Modeling of the height of occurrence of the low latitude F1 layer, International Journal of trend in research and development, 5 (4), 129-132.