Volume 4, Issue 1, 2021 ISSN: 2664-0821
DOI: https://doi.org/10.31058/j.ap.2021.41001

Seasonal Response of Peak Electron Density of F_2-Layer in the African and American Sectors during Low Solar Activity Period of Cycle 24

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Received: 12 September 2020**;** **Accepted:** 27 October 2020**;** **Published:** 27 November 2020

Abstract:

This paper presents the seasonal response of the peak electron density of the, F_2-layer N_mF_2 from two equatorial stations: Ilorin with geographical coordinates (latitude 8.48^{0}N and longitude 4.54^{0}E) in the African sector and Jicamarca with geographical coordinates (latitude 11.95^{0}S and longitude 76.87^{0}W) in the American sector during low solar activity (LSA) year 2010 of solar cycle (SC) 24. The data used for this work are N_mF_2 peak values derived from f_oF_2 data obtained at the local time of these stations from the Space Physics Interactive Data Resources (SPIDR). Seasonal analysis was done by combining the hourly mean monthly values of N_mF_2 for all days of the months in each of the seasons considered. Annual analysis was carried out by averaging all the N_mF_2 values for the year at each hour for the two stations considered. Diurnal analysis from the plots revealed that equatorial N_mF_2 respond more to solar activity at daytime than at nighttime at these stations with two characteristics peaks: pre-noon peak and post-noon peak bordered a trough (depletion) called noon bite-out (NBO). This depletion is more noticeable at Ilorin than at Jicamarca. The pre-noon highest peaks at Ilorin and Jicamarca were 79 x 10^{10} e/m^3 and 103 x 10^{10}e/m^2 respectively, while the post-noon highest peaks at Ilorin and Jicamarca were 94 x 10^{10} e/m^2 and 113 x 10^{10} e/m^2, respectively. Seasonally, the highest peak value was recorded in September equinox and December solstice at Ilorin and Jicamarca, respectively and the lowest peak value were recorded in June solstice at both stations. Annually, the N_mF_2 ionisation at the two stations are closely related in values at all hours except at 16:00 – 18:00 hours where it is slightly higher at Ilorin. Overall, Peak N_mF_2 ionisation is higher at Jicamarca when compared with that at Ilorin.

Keywords:

Peak Electron Density, Ionisation, F_2-layer, Low Solar Activity

1. Introduction

The ionosphere is the ionized part of the upper atmosphere that is approximately 50 km above the earth surface. It is the region of the earth atmosphere where charged ions and electrons are present in quantity sufficient to cause the propagation of radio waves. These charged particles are usually caused by the infiltration of ultraviolet radiation from the sun on neutral atoms or molecules. The electron density of the ionosphere is the quantitative measure of the amount of electrons present in an ionospheric layer. It can also be said to be a representation of the probability of finding an electron in a specific location around an atom.

The F_2-layer is the farthermost layer from the earth surface and it is the most important layer of the ionosphere because it is the layer that is active throughout the 24 hours of the day unlike other ionospheric layers that are not present of active at night. More so, it is the layer with the highest height and highest electron density. This is so because electron density increases as one moves away from the earth surface towards the upper part of the atmosphere. The maximum electron density of the F_2-layer (N_mF_2) is the quantitative measure of the electron at the highest attainable point in the F_2-layer. The ionospheric F_2-layer maximum electron density (N_mF_2) depends strongly on solar activity, it suffers temporal and spatial variations. It is related to the critical frequency of the F_2-layer by the relation shown in section two of this paper.

A number of literatures have been made to show certain trends of these F_2-layer characteristics as a function of local time, season, and solar/geomagnetic activity. Some of these studies include those of [1,2,3,4,5,6,7,8,9,10] had investigated ionospheric variability of the F_2-layer critical frequency (f_oF_2) at equatorial and low latitude during high, moderate and low solar activity periods. They reported that equatorial f_oF_2 variability increases with decreasing solar activity. [11,12,13,5,14,7,15,16,17,18,8,19,15] had examined ionospheric parameters (f_oF_2, hmF_2 and N_mF_2) in correlation with solar indices and their results documented. In most of the work N_mF_2 /f_oF_2 show strong dependence on solar indices like sunspot number (Rz) and solar radio flux on 10.7 cm wavelength (F10.7 cm) used as solar proxy. In this present work the Zurich sunspot number (Rz) was used as solar proxy because it has direct relation with the level of solar activity.

The aim of this study is to compare the response of maximum electron density of F_2 -layer (N_mF_2) in the African and American longitudinal sectors during minimum solar activity period of cycle 24.

2. Materials and Methods

The data used for this work are N_mF_2 peak values derived from f_oF_2 data observed at Ilorin with geographical latitude 8.48^{0}N and longitude 4.54^{0}E in the African sector and Jicamarca with geographical latitude 11.95^{0}S and longitude 76.87^{0}W in the American sector during low solar activity LSA (2010) of cycle 24, with average annual sunspot number Rz = 16.5. All the available f_oF_2 data for this study were obtained at the local time of these stations from the Space Physics Interactive Data Resources (SPIDR) (https://spidr.ngdc.noaa.gov) last access 2017.

The N_mF_2 values were obtained from f_oF_2 using the relation below.

$$N_m = 1.24 \times 10^{12} (f_oF_2)^2 \tag{1}$$

where N_mF_2 is in e/m^3 and f_oF_2 is in MHz

Seasonal grouping was done by combining the hourly mean monthly values of N_mF_2 for all days of the months of November, December and January (December Solstice); May, June and July (June solstice); and August, September and October (September equinox). February, March and April (March equinox) was not observed due to missing data at Ilorin for the three months. Furthermore, annual response was carried out by averaging all the N_mF_2 values for the year at each hour for the two stations considered. Thereafter, both the seasonal and annual values obtained were plotted against local time (LT) to investigate seasonal and annual response at the two sectors (stations) respectively.

3. Results and Discussion

Figure 1 and Figure 2 show the diurnal and seasonal variation of maximum electron density of the F_2-layer (N_mF_2) values for December Solstice, June Solstice and September Equinox at Ilorin during low solar activity year LSA (2010). From Figures 1 and 2, diurnal and seasonal variation of N_mF_2 values increase from sunrise around 6:00 Local Time (LT) and reach their first peak before noon. The highest pre-noon peak values of about 79 x 10^{10} e/m^3 was observed in September equinox, while the lowest pre-noon peak value of 66 x 10^{10}e/m^2 was observed in June and December solstice at Ilorin from Figure 1. In Figure 2 on the other hand, the highest pre-noon peak values of 103 x 10^{10}e/m^2 was observed in December solstice and the least pre-noon peak values of 54 x 10^{10} e/m^2 in June solstice at Jicamarca. In Figure 1 and Figure 2, a depletion known as noon bite out (NBO) was noticed around noon (between 11:00 and 14:00 LT). This depletion was noticed more at Ilorin than at Jicamarca. This NBO is caused by the fountain effect whereby, an eastward electric field at the equator gives rise to an upward **E**×**B** drift at daytime, indicating the presence of equatorial electrojet (EEJ) strength [20,21,22,23].

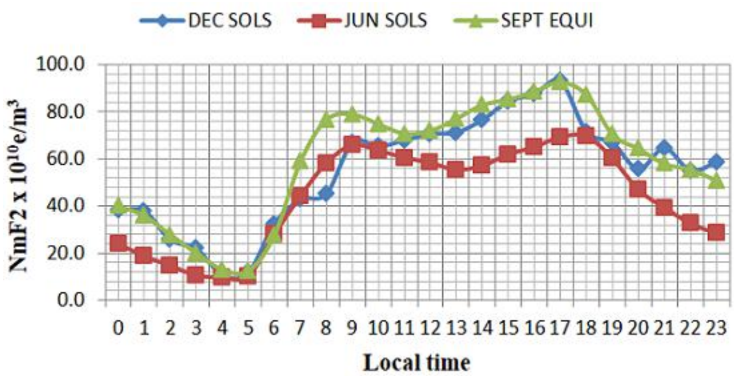


Figure 1. *Diurnal and seasonal variation of equatorial N_mF_2 values for December Solstice, June Solstice and September Equinox at Ilorin during low solar activity year (2010).*

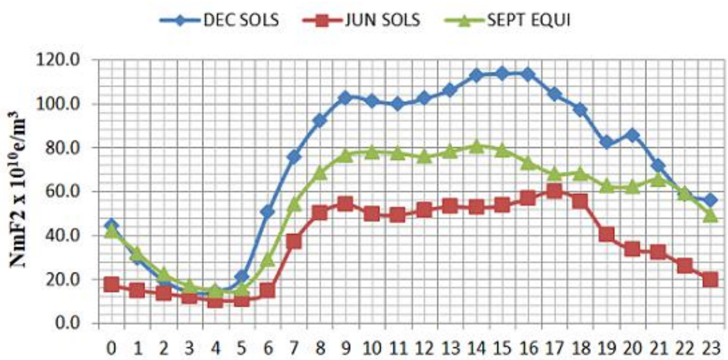


Figure 2. *Diurnal and seasonal variation of equatorial N_mF_2 values for Dec solstice, June Solstice and Sept Equinox at Jicamarca during low solar activity year (2010).*

At high and mid-latitudes, vertical transport is approximately along magnetic field lines and particles will tend to diffuse upward or downward according to their mass and because the ions and electrons are electrically coupled, ambipolar diffusion must be consider. But at the equator or near the equator, vertical transport is impeded by magnetic fields lines. At daytime, however, due to electrodynamic effect (**E**×**B** drift) ionisation is transported upwards at the magnetic equator which subsequently diffuses down magnetic fields lines in form of a fountain at $\pm 15^0$ on both sides of magnetic latitude. This results in the depletion of ions at the equator (NBO) also known as Appleton anomaly.

The difference in the level of depletion observed between these two stations may be due to difference in their latitudinal and longitudinal locations at the equatorial region. The latter (Jicamarca) is geographically located at the southern hemisphere of equatorial ionisation anomaly (EIA) (Lat. 11.95°S) while the former (Ilorin) is located at the northern hemisphere of equatorial ionisation anomaly (EIA) (Lat. 8.48°N). Longitudinally, Ilorin is located to the east of Greenwich meridian (Long. 4.54 °E) while Jicamarca on the other hand is located to the west of Greenwich meridian (Long. 76.87°W). This clearly indicates that the two stations are far apart and in different sector of the globe, thus experiencing different time duration of solar ionisation of N_mF_2 (longitudinal variation). [24], reported similar observation and stated that the difference of major peak locations between the two stations may be due to longitudinal variation of F_2-layer critical frequency. Furthermore, a steady decrease was noticed after 18:00 LT at both stations because at this period the sun was setting and there was no more solar radiation. Hence, ionisation decreases.

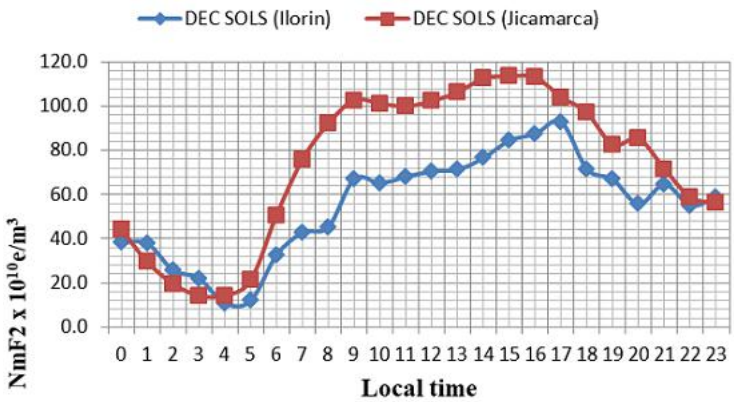
A second peak (i.e. the post-noon peak) was observed between 14:00 and 18:00 LT for the two stations. The magnitude of the post-noon peaks was highest in December solstice and September equinox at Ilorin with a values of 94×10^{10} (Figure 1). It was also highest in December solstice with a value of about 113×10^{10} e/m^3 at Jicamarca (Figure 2). The least values of the electron density of about 70×10^{10} e/m^3, occurred in June solstice around 18:00 LT at Ilorin and 60×10^{10} e/m^3 in the same season around 17:00 LT at Jicamarca from Figures 1 and 2 respectively. The characteristic trend of the ionosphere over the two stations showed that the ionosphere commences building up at sunrise, completely around noon and decreases afterward. This trend is attributed to the fact that the formation of the ionosphere is largely due to photo-ionisation of the neutral atoms in the upper atmosphere by solar radiation. Although, some other factors like solar winds, geomagnetic, and metreological effects contribute to the modification of the ionosphere, photo-ionisation is a notable factor at daytime [17].

All these effects are reliant on local time, latitude and season [25]. Highest values of N_mF_2 are recorded in December solstices (winter) than the June solstices (summer). This indicates the presence of the December anomaly or winter anomaly characterized by f_oF_2 and N_mF_2 values systematically higher all over the world in the ionosphere winter season (November, December and January) than in the ionosphere summer season (May, June and July). Highest peak values observed in equinoxes show that semiannual anomaly exist in the N_mF_2 response. This is because semiannual anomalies are characterized by f_oF_2 and N_mF_2 values usually high at ionospheric equinoxes (February, March, April, August, September and October) than solstices (November, December, January, May, June and July) from documented studies. [26].

Figure 3, Figure 4 and Figure 5 are similar to Figures 1 and 2 discussed above. Only that the plots are used to show a clearer seasonal comparison of N_mF_2 variations in each season between the two stations (Ilorin and Jicamarca). And just like in Figure 1 and Figure 2, reduction of N_mF_2 ionisation occurs after 18:00 LT due to reduced solar radiation.

Volume 4, Issue 1, 2021 ISSN: 2664-0821
DOI: https://doi.org/10.31058/j.ap.2021.41001

Jicamarca was observed to be more depleted of ionisation than Ilorin in June solstice and September equinox immediately after 18:00 LT (nighttime period), except in December solstice when the reversed was the case with Ilorin. This loss of ionisation at nighttime period (18:00 – 05:00 LT) is attributed to the fact that the nighttime ionosphere in this region was mainly under the control of transport and loss processes. So the recombination rate at which ions recombine with the neutral molecules at nighttime determines the loss rate of ionisation in any season. This is in agreement with the report of [27], who reported that around local noon, the F_2 ionosphere had reached a dynamic stability with respect to losses by recombination and production by solar radiation. Implying that after this stability period (after noon) there is gradual loss of ionisation.



Figures 3. *Seasonal variation of N_mF_2 at Ilorin and Jicamarca in December solstice.*

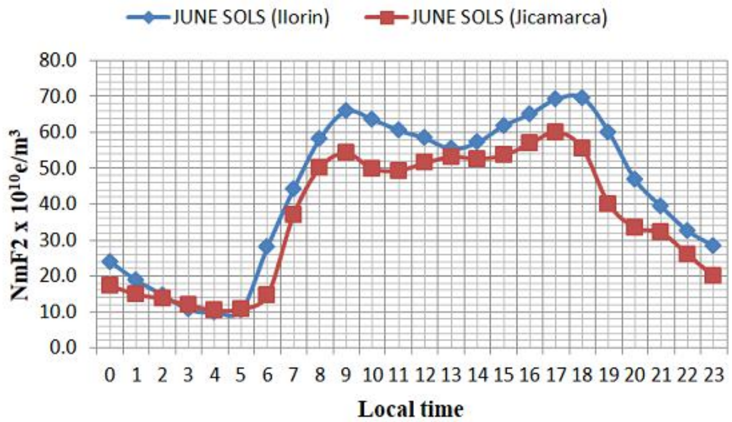


Figure 4. *Seasonal variation of N_mF_2 at Ilorin and Jicamarca in June solstice.*

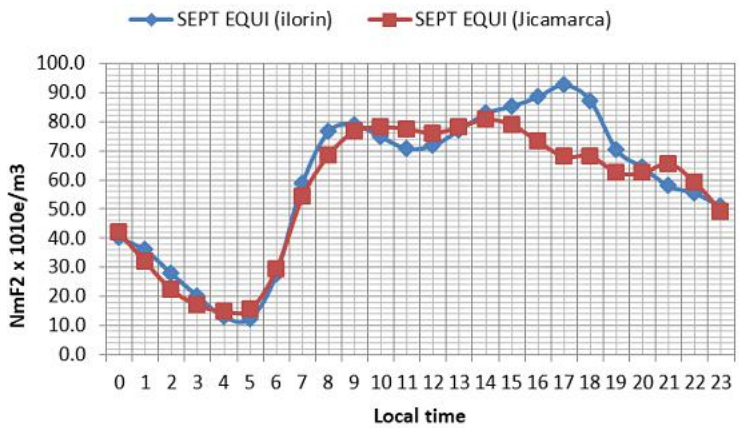


Figure 5. *Seasonal variation of N_mF_2 at Ilorin and Jicamarca in September Equinox against local time.*

In almost all the plots in this study post-noon peak is higher than the pre-noon peak during LSA. This is in agreement with [28], who reported similar observation during LSA and the reverse during high solar activity (HSA). They ascribed the decrease in N_mF_2 post-noon during HSA to faster increase in the recombination efficiency relative to the plasmaspheric flux increase [29].

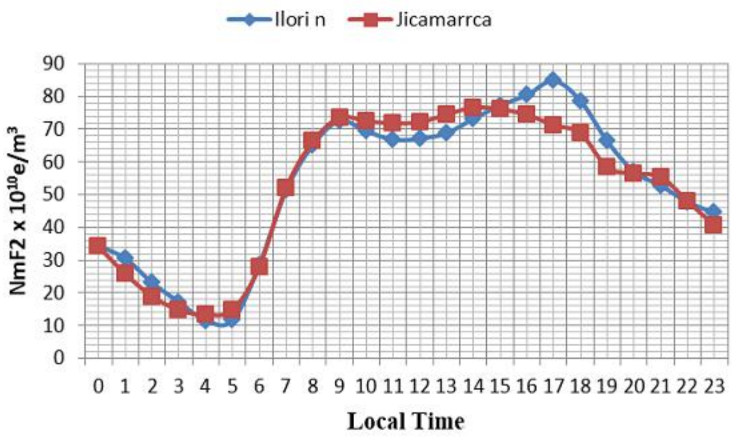


Figure 6. *Annual variation of N_mF_2 at Ilorin and Jicamarca against local time.*

Depicted in Figure 6 is the annual variation of N_mF_2 at Ilorin and Jicamarca against local time. Observations here show that the pre-noon peak electron density at Ilorin and Jicamarca are almost of equal values. The magnitude of the pre-noon peak electron density of 74 x 10^{10} e/m^3 and 73.5 x 10^{10}e/m^3 were recorded at Jicamarca and Ilorin respectively. A second peak (i.e. the post-noon peak) was observed around 14:00 and 18:00 LT for the two stations. The magnitude of the post-noon peak electron density at Ilorin from Figure 6 was 85 x 10^{10} e/m^3 and that at Jicamarca was 77 x 10^{10}e/m^3, indicating a higher value of N_mF_2 ionisation at Ilorin at nighttime.

The pre-noon peak, post-noon peak, and noon bite-out (NBO) characteristics, observed in electron density values at the F_2-layer were attributed to the vertical drift of ionisation caused by variations of upward $\boldsymbol{E} \times \boldsymbol{B}$ plasma drifts, the rapid filling up of the magnetic field tube at sunrise due to solar extreme ultraviolet (EUV) ionisation and neutral winds effect on the plasma at the equatorial anomaly region [30,2,31,7]. At daytime, an eastward electric field at the equator causes plasma to be lifted to greater heights. This dynamo-generated eastward electric field combined with the northward geomagnetic field ($\boldsymbol{E} \times \boldsymbol{B}$) lifts the equatorial ionosphere from 700 km to about 1000 km, resulting in further ionisation [32,33]. After Sunset and due to low thermospheric temperature and Rayleigh–Taylor instability (RTI), the magnetic field tubes collapse giving rise to the minimum N_mF_2 values after sunset [34].

Furthermore, observation from almost all the figures show that the pre-midnight (18:00 – 23:00 LT) values of N_mF_2 are higher than post-midnight (00:00–05:00 LT) N_mF_2 values during the LSA periods. This may be ascribed to the slow recombination rate of ions at the pre-midnight hours, Since the nighttime ionosphere in this region was mainly under the control of transport and loss processes, the recombination rate at which ions recombine with the neutral molecules at pre-midnight hours (18:00 – 23:00 LT) is slower than that at post-midnight hours (00:00 – 05:00 LT). Also, superimposition of spread F which is responsible for the reshaping of the ionosphere plasma immediately after sunset contributes to this pre-midnight enhancement. Pre-reversal enhancement (PRE) and gravity waves are also believe to be responsible for this higher pre-midnight values. This same result was observed by [35,33], whose work on total electron content (TEC) in the equatorial and low latitude ionosphere reported higher pre-midnight TEC values than post-midnight TEC values in the Indian and African sectors, respectively.

4. Conclusions

Diurnal analysis revealed that equatorial N_mF_2 respond more to solar activity at day time than at nighttime at these stations with two characteristics peaks (pre-noon peak and post-noon peak) bordered about a depletion called noon bite-out (NBO). This depletion is more noticeable at Ilorin than at Jicamarca. The pre-noon highest peaks at Ilorin and Jicamarca were 79 x 10^{10} e/m^3 and 103 x 10^{10}e/m^2 respectively, while the pre-noon lowest peak for the two stations are 66 x 10^{10}e/m^2 and 54 x 10^{10} e/m$^{2.}$ respectively. The post-noon highest peaks at Ilorin and Jicamarca were 94 x 10^{10} e/m^2 and 113 x 10^{10} e/m^2, while the post-noon lowest peaks at the two stations were 70 x 10^{10} e/m^3 and 60 x 10^{10} e/m^3 respectively.

Seasonally, the highest peak values were recorded at post-noon period from Figures 1 and 2 with a values of 94 x 10^{10} and 113 x 10^{10} e/m^3 in December solstice at Ilorin and Jicamarca respectively while the lowest peak values for both stations were recorded in June solstice

Annually, the highest N_mF_2 peak values of 85 x 10^{10} e/m^3 and 77 x 10^{10}e/m3 were recorded at Ilorin and Jicamarca respectively (Figure 6), while the lowest peak values were recorded as 74 x 10^{10}e/m^3 at both stations. Overall, N_mF_2 ionisation is much higher at Ilorin in the African longitudinal sector than at Jicamarca in the American longitudinal sector for all seasons except in December solstice.

Conflicts of Interest

The authors have declared that there is no conflict of interest regarding the publication of this article

Authors Contribution

Conceptualization: O.E.O.; O.S.; Methodology: O.E.O.; A.R.A.; Software: O.E.O.; O.O.O.; Validation: S.E.O.; O.A.S.; Formal analysis: O.E.O.; Investigation: O.E.O.; A.R.A.; Resources: O.E.O.; S.E.O.; O.A.; Data Curation: O.E.O.; S.E.O.; O.A.; Writing – original draft preparation: O.E.O.; O.S.; Writing – review and editing: O.A.S.; O.O.O.; O.A.; O.C.O.; Visualization: O.E.O.; S.E.O.; Supervision: S.E.O.; Project administration: S.E.O.; Funding acquisition: O.E.O.; O.A.S.; O.C.O.; O.O.O.; A.R.A.

Acknowledgments

The authors would like to acknowledge Space Physics Interactive Data Resource (SPIDR) website (http://ngdc.noaa.gov/) for providing the data of ionospheric parameters (foF2 values) for the duration under consideration of the present study.

References

[1] Jayachandran, B.; Balachandran, N.R.; Balan, N.; Rao, P.B. Short time variability of the ionospheric electron content and peak electron density during solar cycles for a low latitude station. *J. Atmos. Sol. Terr. Phys.* 1995, 52, 1599-1605.

[2] Fejer, B.G.; de Paula, E.R.; Heelis, R.A.; Hanson, W.B. Global equatorial ionosphere vertical plasma drifts measured by the AE-E Satellite. *J. Geophys. Res.* 1995, 100, 5769-5776.

[3] Rishbeth, H.; Mendillo, M. Patterns of F_2-layer variability. *Journal of Atmospheric Solar Terrestrial Physics,* 2001, 63, 1661-1680.

[4] Kouris, S.S.; Fotiadis, D.N. Ionospheric variability: A comparative statistical study. *Adv. Space Res.* 2002, 29(6), 977-985.

[5] Adeniyi, J.O.; Oladipo, O.A.; Radicella, S.M. Variability of f_oF_2 for an equatorial station and comparison with the f_oF_2 maps in IRI model. *J. Atmos. Sol. Terr. Phys.* 2007, 69, 721-733.

[6] Akala, A.O.; Oyeyemi, E.O.; Somoye, E.O.; Adeloye, A.B.; Adewale, A.O. Variability of f_oF_2 in the African equatorial ionosphere. *Adv. Space Res.* 2010, 45, 1311-1314.

[7] Adebesin, B.O.; Adeniyi, J.O.; Adimula, I.A.; Reinisc, B.W.; Yumoto, K. F_2-layer characteristics and electrojet strength over an Equatorial station. *Advances in Space Research,* 2013, 52(5), 791 - 800.

[8] Onori, E.O.; Somoye, E.O.; Ogungbe, A.S.; Ogwala, A. Longitudinal Influence of N_mF_2 Variability on the Equatorial Ionosphere During High Solar Activity. *Physics Journal,* 2015, 3(2), 388-392.

[9] Onori, E.O.; Somoye, E.O.; Ogungbe, A.S.; Ogwala, A.; et al. Comparison of Absolute and Relative variability of F_2 Layer Critical Frequency in West Africa Using Ionosonde Station at Ibadan. *American Journal of Environment and Sustainable Development,* 2018, 3(1), 15.

[10] Somoye, E.O.; Onori, E.O.; Akala, A.O.; Ogabi, C.O.; Ogungbe, A.S.; Ometan, O.O.; Ogwala, A. Day- to- day variability of the critical frequency of F_1-layer. *American Journal of Environment and Sustainable Development,* 2018, 2(1), 430-435.

[11] Özgüç A.; Ataç T.; Pectaş R. Examination of the solar cycle variation of f_oF_2 for cycles 22 and 23. *Journal of Atmospheric and Solar-Terrestial Physics,* 2008, 70, 268-76.

[12] Liu, L.; Wan W.; Chen, Y.; Le, H. Solar activity effects of the ionosphere: A brief review. *Chin Sci Bull (China),* 2011, 56(12), 1202-1211.

[13] Ma, R.; Xu J.; Wang W.; Yuan W. Seasonal and latitudinal differences of the saturation effect between ionospheric N_mF_2 and solar activity indices. *J. Geophys. Res.* 2009, 114, 1- 8.

[14] Ikubanni, S.O.; Adeniyi J.O. On the Dependence of F_2-Layer Critical Frequency on F10.7 Solar Flux at an Equatorial Station. *World J. of Engineering and Applied Sci.,* 2012, 2(3), 85-91.

[15] Ikubanni, S.O.; Adeniyi, J.O. Relationship between ionospheric F_2-layer critical frequency, F10.7, and F10.7P around African EIA trough. *Advances in Space Research,* 2017, 59(4), 1014–1022.

[16] Somoye, E.O.; Akala A.O.; Adeniji-Adele R.A.; Iheonu E.E.; Onori E.O.; Ogwala A. Equatorial F_2 characteristic variability: A review of recent observations. *Advances in Space Research,* 2013, 52, 1261-1266.

[17] Adebesin, B.O.; Adekoya, B.J.; Ikubanni, S.O.; Adebiyi, S.J.; Adebesin, O.A.; Joshua, B.W.; Olonade, K.O. Ionospheric f_oF_2 morphology and response of F_2-layer height over Jicamarca during different solar epochs and comparison with IRI-2012 model. *J. Earth Syst. Sci.* 2014b, 123(4), 751-765.

[18] Bhawre, P.; Kishore, K.; Dogra, S.K.; Purohit, P.K.; Waheed, M.A.; Khatarkar, P.; Atulkar R. Characteristic of Ionospheric f_oF_2 and Solar Indices during the 23rd Solar

Cycle over High Latitude Station, Syowa, Antarctica. *American Journal of Climate Change,* 2015, 408-416.

[19] Ogwala, A.; Somoye, E.O.; Onori, E.O.; Adeniji-Adele, R.A. Characterizing the Maximum Electron Density of the F_2-Layer (N_mF_2) in the Equatorial Ionosphere. *Physics Journal,* 2015, 2(1), 137-152.

[20] Rajaram, G.; Rastogi, R.G. Equatorial electron densities – Seasonal and solar cycle changes. *J. Atmos. Terr. Phys.* 1977, 39, 1175-1182.

[21] Yeh, K.C.; Franke, S.J.; Andreeva, E. S., and Kunitsyn, V. E. An investigation of motions of the equatorial anomaly crest. *Geophys. Res. Lett.* 2001, 28, 4517-4520.

[22] Quattara, F. IRI-2007 f_oF_2 Predictions at Ouagadougou Station during Quiet Time Periods from 1985 to 1995. *Archives of Physics Research,* 2013, 4, 12-18.

[23] Eyelade V.A.; Adewale, A.O.; Akala, A.O.; Bolaji S.O.; Rabiu, A.B. Studying the variability in the diurnal and seasonal variations in GPS total electron content over Nigeria. *Ann. Geophys.* 2017, 35, 701-710.

[24] Quattara, F.; Gnabahou, D.A.; Amory-Mazaudier, C. Seasonal, Diurnal and Solar-Cycle Variation of Electron Density at Two West Africa Equatorial ionisation Anomaly Stations. *International Journal of Geophysics,* 2012, 1-10.

[25] Forbes, J.M.; Palo, S.E.; Zhang, X. Variability of the ionosphere. *Journal of Atmospheric and Solar-Terestrial Physics,* 2000, 62, 685-693.

[26] Zolesi, B.; Cander, L.R. Ionospheric Prediction and Forecasting. Springer Geophysics, DOI: 10.1007/978-3-642-38430-1, eBook ISBN: 978-3-642-38430-1. Hardcover ISBN: 978-3-642-38429-5. Springer-Verlag Berlin Heidelberg.

[27] Adebesin, B.O. On the ionospheric variability of critical frequency along the equatoranomaly trough and plausible role of vertical E × B drift. *Journal of Life and Physical Sciences,* 2014 5(1), 37-51.

[28] Adebesin, B.O.; Rabiu, A.B.; Obrou, O.K.; Adeniyi, J.O. Ionospheric peak electron density and performance evaluation of IRI-CCIR near magnetic equator in Africa during two extreme solar activities. *Space Weather,* 2018, 16, 230-244.

[29] Mikhailov, A.V.; Forster, M.; Leschinskaya, T.Y. On the mechanism of the post-midnight winter NmF_2 enhancements: Dependence on solar activity. *Ann. Geophysical,* 2000, 18(11), 1422-1434.

[30] Fejer, B.G.; Scherliess, L. Time dependent response of equatorial ionospheric electric fields to magnetospheric disturbances. *Geophys. Res. Lett.* 1995, 22 851-854.

[31] Fejer, B.G. The electrodynamics of the low latitude ionosphere recent results and future challenges. *J. Atmos. Sol. Terr. Phys.,* 1997, 59, 1465-1482.

[32] Somoye, E.O.; Akala, A.O.; Adeniji-Adele, R.A.; Iheonu, E.E.; Onori, E.O.; Ogwala, A. Equatorial F2 characteristic variability: A review of recent observations. *Advances in Space Research,* 2013, 52, 1261-1266.

[33] Ogwala, A.; Somoye, E.O.; Ogunmodimu, O.; Adeniji-Adele, R.A.; Onori, E.O.; Oyedokun, O. Diurnal, seasonal and solar cycle variation in total electron content and comparison with IRI-2016 model at Birnin Kebbi. *Ann. Geophys.* 2019, 37, 775-789.

[34] Berkner, L.V.; Wells, H.W. F-region ionosphere – investigation at low latitude. *Terres. Magn.* 1934, 39, 215-230.

[35] Bagiya, M.S.; Joshi, H.P.; Iyer, K.N.; Aggarwal, M.; Ravindran, S.; Pathan, B.M. TEC variations during low solar activity period (2005–2007) near the Equatorial Ionospheric Anomaly Crest region in India. *Ann. Geophys.* 2009, 27, 1047-1057.