Journal of the Nigerian Association of Mathematical Physics
***Volume27*, (*July, 2014*), pp 323 – 328**
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Predicted Variations of Electron Density at Some Fixed Height of the Ionosphere over Benin City Nigeria

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Abstract

The variations of the electron density in someregions of the ionosphere over Benin City (6.3°N, 5.6°E), Nigeria have been investigated. In order to investigate the solar cycle, altitude, and local time dependence of electron densities fluctuations, data from 2002, a year of high solar activity and 2008, a year of very low solar activity have been collected from the International Reference Ionosphere (IRI-2012 model). The data covers all twelve months and 24 hours of the day. Our results revealed that for the periods of high solar activity (HSA) and low solar activity (LSA), the ionospheric electron densities at the height of 120km have characteristics trend of maxima occurring at noon. The electron densities rose from about 06.00LT and peaked at 12.00LT at noon before dropping sharply at 18.00LT. At the peak of the F_2-layer, a predominance of pre noonmaximum electron densities (N_mF_2) were observed for HSA year and a predominance of post noon peaks of N_mF_2 were recorded for LSA year. Furthermore our results show that the expected minimum formation of N_mF_2 around noon was not observed in the month of March for the year of HSA. Instead a peak value of N_mF_2 appeared at midday. The anomaly confirmed in the result revealed that the morphology of N_mF_2 depends on different locations for a given solar activity: Hence the electron density enhancement is primarily caused by solar control of the ionosphere.

Keywords: Ionosphere, IRI-2012 model, electron density, solar activity

1.0 Introduction

The ionosphere is the upper region of the atmosphere where appreciable and sufficient ionization exist. This region extends from about 60km until it merges with the magnetosphere and interplanetary space**.** The ionosphere is usually divided into two main layers: (a) a lower layer called the E-layer or sometimes referred to as the Kennelly-Heaviside layer. The altitude of this layer which is from 90 to 140km above the surface of the earth reflects radio waves of low frequency. The electron density in this region is determined by the photochemical equilibrium equation [1-3].

$$I_i = \alpha {n_e}^2 \quad (1)$$

where

I_i= ion loss rate in photochemical equilibrium

α= recombination coefficients

n_e=electron density

(b) A higher layer designated F-layer or sometimes called the Appleton layer. This layer reflectsradio waves of high frequency. In the daytime, the F-layer has two divisions F1 and F2. The F1-layer begins at about 140km, while the F2- layer usually lies within the range from 200 to 400km.BiIitza [4], noted that the F2-peak electron density (N_mF_2) is an important parameter which is derived from the F2-layer critical frequency ($foF2$) measured by lonosondes.

$$N_mF_2 = 1.24 \times 10^4 \times (foF2)^2 \quad (2)$$

where N_mF_2 is in electrons/m^3 and $foF2$ in MHz

Knowledge of the ionospheric electron density distributions and its fluctuation is essential for predicting ionospheric characteristics for radio wave propagation and for other applications such as satellite tracking and navigation [5]. Variations in electron density of the ionosphere occasioned by the production or loss of electrons alter the propagation medium which

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causes dispersive and scattering effects on radio wave signal. Thus for a successful radio communication, it is imperative to predict the behavior of ionospheric regions that will affect radio communication signals. Such predictions will identify the time periods, the path regions and the sections of high frequency band that will allow or disrupt the use of selected high frequency communication circuit [6]. Several authors [7-9], have reported that the hourly variations of electron density showed a general trend with a maxima appearing during noon and minima at dawn and midnight.Oladipo *et al*. [10] have studied the variability of electron density profile at fixed heights below the F2 peak. Their work showed that the electron density in the E-region of the ionosphere has a peak around midday during the periods of low and high solar activity. Kolawole and Ishwood (1980),cited in[7] observed a diurnal variation in the peak electron density of the F2-layer. Their result revealed that there is a clear tendency for the afternoon maximum electrondensity to occur later as the solar activity decreases. Adeniyi *et al*. [11] showed that electron density varies with various reactions and processes taking place in the ionosphere resulted in it being stratified into layers. Liu *et al*. [12] showed the existence of seasonal and latitudinal dependence of solar activity variations on the electron density in the East Asia/Australia sector.The works of Balan *et al*. (1994) and Gorney, (1990) cited in [13], showed that the ionospheric electron density tends to linearly depend on the intensity of solar extreme ultraviolet (EUV) at low and moderate levels. Ionosonde measurements of maximum electron density (N_mF_2) variations at two Thailand ionospheric stations have been collected by Wichaipanich *et al*. [14]. Monthly median peak electron density data at Okinawa, Yamagawa, Kokubunji and Wakkanai have been collected to investigate the solar cycle dependence of the nighttime ionosphere [15]. Their result revealed that there are seasonal and latitudinal differences of solar activity variations of nighttime maximum electron density. The peak density of the F2-layer from digisondes at Anyang Korea has also been investigated[16]. The monthly average value of maximum electron density over Anyang show generally good linear relationship with increasing solar activities for all local time and geomagnetic activities. Radicella and Adeniyi [17] have investigated the morphology of electron density variations from 100km to the F2-layer. Statistical analyses on the seasonal behavior of electron density profile have been conducted by Liu *et al*. [18].In this paper, we investigate the electron density variations at a height of 120km and at the peak F2-layer of the ionosphere over Benin City, Nigeria. This investigation which has not been previously carried out in this location is essential to know the characteristics of the ionosphere and also to check the validity of ionospheric models.

2.0 Materials and Method

The electron density data used in this work were gotten from the International Reference Ionosphere model (IRI-2012). The collected data are from Benin City (6.3°N, 5.6°E), Nigeria. In order to investigate the solar cycle dependence of electron density variations, data from 2002, which is a year of high solar activity and data from 2008, a year of extreme low solar activity [6, 13,19] were obtained at a height of 120km and the peak F2-layer. For the prediction ofN_mF_2, the Union Radio Scientific Internationale (URSI) coefficient was used as a choice in the IRI-2012 model. The study covers all 24 hours of the day.

3.0 Results and Discussion

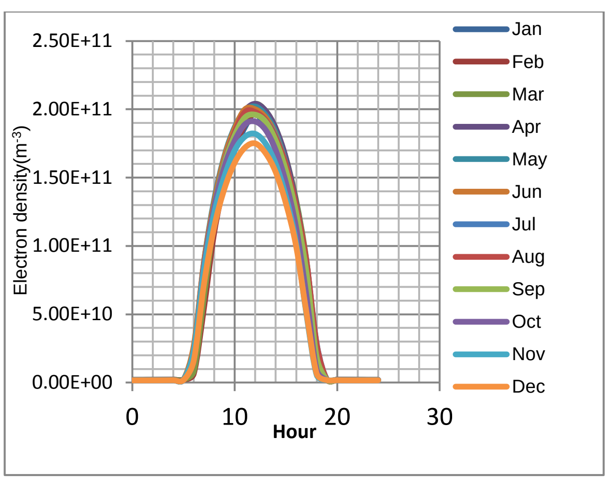


Fig 1a: Hourly electron density variations in 2002

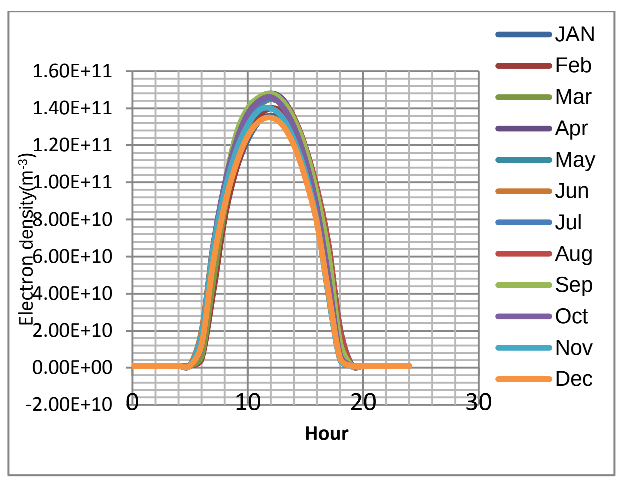
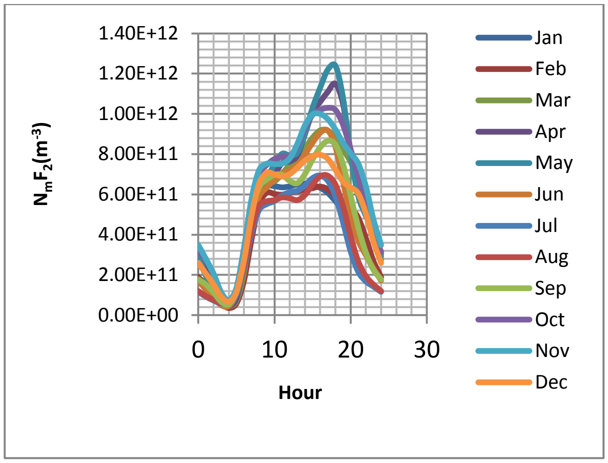


Fig 1b: Hourly electron density variations 2008



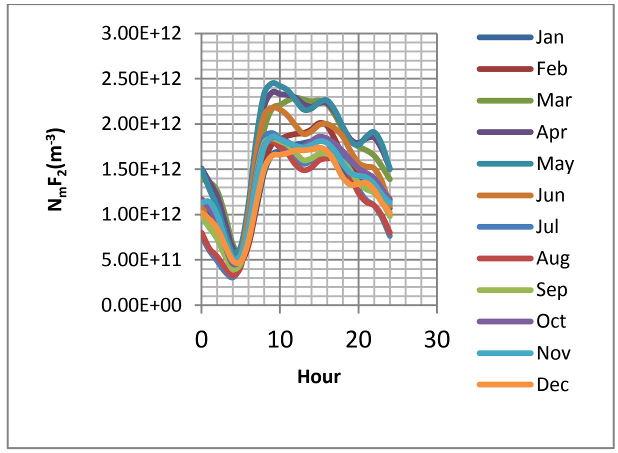


Fig 1c: Hourly maximum electron density variations in 2008 **1d:** Hourly maximum electron density variations in 2002

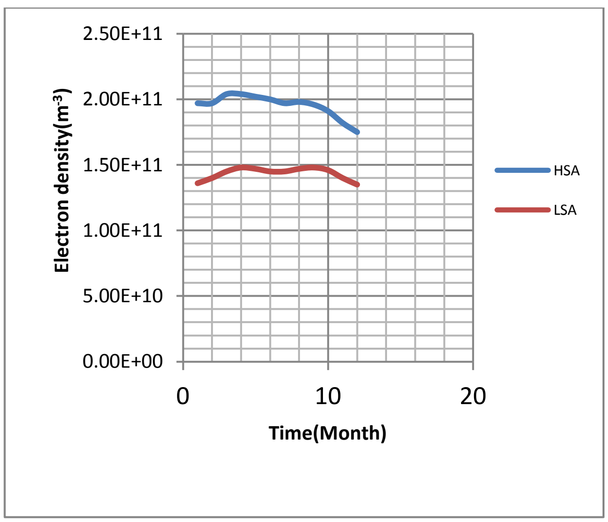


Fig2a: Noon time monthly variations of electron density at 120km

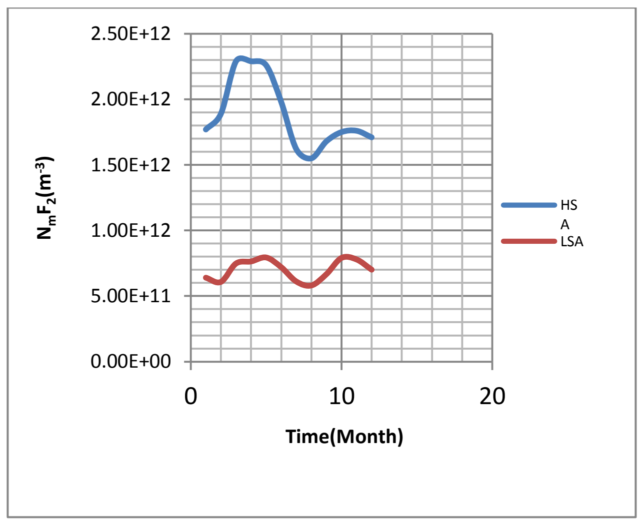


Fig 2b: Noon time monthly variations of maximum electron density

Fig1a and Fig1b show the plot of hourly variations of ionospheric electron densities at the height of 120km (a height which corresponds to the E-layer) for the Year of High solar activity (HSA) and low solar activity (LSA) respectively. In Fig1(a-b) the electron density is characterized by a general trend, with a maximum appearing during midday (12.00 LT). While the pre sunset and post sunset electron density values were low, since the sun which is the primary source of ionization is no longer present. The electron densities rise from about 06.00LT and peaked at 12.00LT before declining sharply at about 18.00LT. In the year of HSA, the electron densities are higher than those observed for the year of LSA. The drop in electron concentrations at dusk is explained to be as a result of sudden faster drift of electrons away from the equator and a spread out of electron in the region [8, 17]
Typical hourly variations of N_mF_2 for LSA year are given in Fig1c. In the months of December – February; N_mF_2 increases sharply from about 05.00 LT and had two peaks at about 09.00 LT before noon and a peak at about 16.00 LT, 14.00LT and 16.00LT respectively after noon time. The post noon time values of N_mF_2 for December through February are higher than the pre noon values. In between the two pronounced peaks, there is a minimum appearing at about 11.00 LT. In the months of March – July, the N_mF_2 rises sharply from 05.00LT and had pronounced peaks from 15.00LT to 18.00LT. In October and November, the peaks of N_mF_2 are observed at about 17.00 LT and 16.00LT respectively. For the months of August and September, the observed trend is similar to those of December-February. August and September have two peaks of N_mF_2 at 11.00LT before midday, while the post noon peaks occurred at 17.00LT. The minima between the peaks were observed at 13.00LT.In Fig1d, the electron density of the F2-layer for HSA increases from 05.00LT and reaches a single peak after midday at about 15.00LT.This characteristics is observed for the month of December – February. In March, the maximum electron density (N_mF_2) has a peak at exactly 12.00 LT as compared to all other months. In the months of April– September, there is a general trend of N_mF_2 increasing from 05.00LT and reaching two peaks at 9.00LT before noon and at 16.00 LT after noon, where the peaks of N_mF_2 before noon are higher than the peaks after noon. In between this two peaks, $N_mF_2$haveminimum appearing around 13.00LT.In addition, a third peak of N_mF_2 was observed in April and May at 22.00LT, giving rise to a minima between the two post noon peaks at 20.00LT. In October and November, the observed trend is similar to the one observed in April – September except that the peak after noon appeared one hour earlier. In contrast, the peak of N_mF_2 in October after noon is higher than the one before noon time. Fig2a shows typical monthly variations of electron densities at a height of 120km for both years of HSA and LSA. For the period of HSA, the ionospheric electron densities are higher in the months of March and April, having a constant value of $2.04\, x\, 10^{11} m^{-3}$and a leastvalue was observed in December($1.75 \times 10^{11} m^{-3}$). For LSA year, the noon time electron density has two equal peaks in the months of April and September ($1.48 \times 10^{11} m^{-3}$). Lowest values were observed in December ($1.35 \times 10^{11} m^{-3}$) and January ($1.36 \times 10^{11} m^{-3}$).In Fig 2b, for HSA year, it is easily seen that N_mF_2 has a higher value in March ($2.29 \times 10^{12} m^{-3}$) and a least value was observed in August ($1.55 \times 10^{12} m^{-3}$), while the characteristics of N_mF_2 for LSA year shows two peaks occurring in the months of May ($7.94 \times 10^{11} m^{-3}$) and October ($7.91 \times 10^{11} m^{-3}$) and two minima appearing in February ($6.08 \times 10^{11} m^{-3}$)and August($5.81 \times 10^{11} m^{-3}$). The behavior of the electron densities variations at 120km and peak of F2-layer (N_mF_2)over Benin City confirm the well-known fact that (a) the E- layer at night or dawn begins to disappear due to the absence of sun ionization while the F2-layer survive at night and remain 24 hours of the day. (b) That the electron concentrations in the F2-layer are higher than the E-layer.
The findings from this study therefore confirmed the altitude, local time and solar cycle dependence on variations of electron density at some fixed heights of the ionosphere over Benin City.

3.1 Comparison with other Studies

The results from these findings at a height 120km are consistent with the results [8-10, 17] in the literature.The results[17, 20] revealed that N_mF_2 increases with solar activity. The observation is confirmed in this study. The predominance of the general trend characterized by the appearance of a pre noon peak in $N_mF_2$at high solar activity (HSA) and a post noon peak at low solar activity (LSA) is also confirmed in this study. The cause of the predominance of the occurrence of a pre noon peak in N_mF_2 at high solar activity and a post noon peak at low solar activity was still elusive [20]. Anderson [21] remarked that at solar maximum, during the day, the morning peak incritical frequency of F2-layer ($foF2$) was greater than afternoon peak. This observation is confirmed in the results of this study since $N_mF_2$is directly proportional to the square of the critical frequency of F2-layer according to(2).
The predominance of a pre noon peak in electron density at HSA and a post noon one at LSA are ascribed to the fact that daytime upward plasma drift subsides earlier at LSA [17]. Also the movement of electrons away from the equatorial region (upward plasma drift) during the daytime is sustained for a longer time at HSA [17, 21]. Around midday, the ionosphere has attained a dynamic equilibrium as far as production by solar radiation and losses by recombination are concerned. This indicates that electrons are moving up and away from the equator and that the depletion of electrons during the daytime is maximum around noon. This situation favours the formation of a minimum around midday [17].A consequence of the

findings shows that in the month of March, during the year of HSA, a formation of minimum N_mF_2 around midday was not observed instead, the occurrence of a maximum appeared at midday (12.00 LT) as compared to all the months in both years of HSA and LSA under the study. This anomaly confirmed in the results show that the morphology of N_mF_2 depends on different locations for a given solar activity; hence the variations of ionospheric parameters have different tendencies for different locations.

4.0 Summary and Conclusion

For the first time, an attempt has been made to predict the variations of electron densities at some fixed heights of the ionosphere over Benin City (6.3^0N 5.6^0E) Nigeria, a location where such work has not been previously investigated. The local time, altitude and solar cycle dependence of the electron densities have been studied. The findings from the study are summarized below.

- In the E-layer of the ionosphere, the electron density is characterized by a general trend with a maximum appearing at noon. While the pre noon and post noon values were nearly constant and low as a result of the absence of sun's ionization. The electron densities rise from about 06.00 LT and reached a peak at 12.00LT before declining sharply at about 18.00LT.These characteristics are observed for the years of HSA and LSA with the exception that the electron densities in the year of HSA are higher than LSA year.
- Monthly variations of electron densities at 120km indicate that a maximum of equal magnitude appeared in March and April and the lowest magnitude was observed in December in the year of HSA. While the peak electron densities, observed for the year of LSA occurred in the months of April and September and lowest values were recorded in December and January. Generally, the magnitudes of the observed monthly electron densities are higher for HSA year as compared to that of LSA year, indicating that the ionospheric electron density variations at Benin City may be attributed to the solar control of the ionosphere.
- The observed trends of N_mF_2 for the year of HSA have a predominant peak just before noontime (09.00LT) with the exception of December-February where a single pronounced peak is observed after noon at exactly 15.00LT. The magnitudes of N_mF_2 peaks at pre noon were found to be higher than post noon ones.
- For the period of LSA year, N_mF_2 have predominant post noon peaks (14.00-18.00LT). These features are observed for all the months i.e. from January through December. The post noon electron densities of F2-layer were found to be higher than the pre noon values.
- Monthly variations of N_mF_2 for HSA showed that the months of March and April correspond to the month of higher peak electron density as compared to other months. While the lowest magnitude of peak electron density occurred in August. For LSA year, months of highest N_mF_2 were seen in May and October, and the lowest values appeared in February and August.
- The result shows that the expected minimum formation of peak electron density of F2-layer around midday was not observed for the month of March in year of HSA, instead a maximum value was observed at midday. The cause of this occurrence over Benin City is attributed to charged particles response to thermospheric winds. These winds can push the charged particles along inclined magnetic field lines to a different altitude and also the faster winds can induce faster vertical plasma drift and could result in higher electron density observed in March at 12.00LT. This anomaly confirmed in the results, reveals that the morphology of $N_mF_2$depends on different locations for a given solar activity.

Acknowledgements

The authors are grateful to the International Reference Ionosphere working group: The Union Radio Scientific Internationale (URSI) and the Committee of Space Research (COSPAR) for providing data of the electron density used in this work.

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