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VERTICAL PLASMA DRIFTS ESTIMATED FROM IONOSPHERIC F2-REGION REAL HEIGHTS AT A LOW LATITUDE STATION DURING LOW SOLAR ACTIVITY

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Abstract

Vertical plasma drift velocities (v_z) estimated from peak heights of F2-region (h_mF2) was investigated over Ilorin (lat. 8.31°N, long. 4.34°E, dip lat. 2.95° N) during a year of Low Solar Activity (LSA), a station sited at the low latitudinal dip. The monthly means of vertical plasma drifts, v_z were estimated from 10-international quiet days (IQDs) monthly means of h_mF2 computed across each local time hour. Diurnally, v_z had behavourial patterns of pre-noon and post-noon peaks noticed for all seasons, but in h_mF2, it had pre-noon and post-sunset peaks occurred for all seasons. The v_z pre-noon peak magnitudes are 1.0, 2.4 and 6.4 m/s for December Solstice, June Solstice and Equinox respectively; and v_z post-noon peak magnitudes are 0.6, 1.7 and 2.2 m/s for December Solstice, Equinox and June Solstice respectively. The h_mF2 pre-noon peak magnitudes is from 316 to 353 km, and post-sunset peak magnitudes is from 310 to 392 km for all seasons. Also, v_z displayed pre-reversal enhancement (PRE) night peaks for all seasons. The PRE peak magnitudes are from -0.1 m/s to -1.2 m/s at 2000 LT, from -0.2 m/s to -4.0 m/s at 2200 LT, from -0.6 m/s to -3.0 m/s at 0000 LT and from -0.5 m/s to -1.8 m/s between 0300 LT and 0400 LT respectively for all seasons. The same phenomenal occurrence was noticed in the annual patterns of h_mF2 and v_z. In general, the v_z and h_mF2 magnitudes were highest in equinox (6.4 m/s and 353 km) and lowest in solstice (1.0 m/s and 310 km). The v_z and h_mF2 steady and incessant drop shows the rapidly drifting away of electrons from the equator caused by solar ionization in the low latitude region for all seasons.

Keywords: Peak Heights; Plasma Drifts, Pre-noon peak; Post-noon peak; Post-sunset peak

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1. Introduction

Morphological studies of the F2-region vertical drift velocities of ionization due to vertical E × B drifts had been widely investigated using different observational techniques and measuring equipment at different equatorial stations and continents of the world to derive models. Studies from Jicamarca Ionospheric Observatory had played the most leading role for the modelling of plasma drifts by these various researchers: Fejer *et al*., 1991; Fejer 1997; Scherliess and Fejer 1999; Woodman *et al*., 2006. Furthermore, Fejer *et al*., 1995; Fejer *et al*., 2008; Kil *et al*., 2009; Luhr *et al*., 2008, using observational means of measuring instrument and satellites [e.g. Ions Drift Meter (IDM), CHAllenging Minisatellite Payload-SATellite (CHAMP-SAT), and Republic Of China SATellite 1 (ROCSAT-1)] to study vertical E × B drifts at equatorial and low latitude regions. The two-measuring methods (IDM and SAT) resulted to the emerging studies of the universal model for the measurements of F2-region vertical E × B drifts.
The ionospheric real-time data from Digisondes, as suggested by Reinisch *et al*., 2005 are actually valuable parameters in ionospheric studies. Ionosondes data of the ionospheric F2-region available can be used to estimate the velocities of vertical E × B drifts. An initial apprehension encountered on the worth of data obtained from ionograms during the automatic scaling of its echo traces had been described by Reinisch *et al*., 1998. But an algorithm called 'ARTIST' developed as an auto-scaling program for the ionograms has been inculcated in the digisondes, attributed to Reinisch *et al*., 2005. This is done to ensure that the now scaled-out data are dependable and useful for models forecasting in the ionosphere.

Similar methodology was used by some early researchers at different sectors of the world. Batista *et al*., 1996; Buonsanto and Witasse 1999; Kelley *et al*., 2009 concentrated their studies on the sector of South America; also, Liu *et al*., 2004; Sastri 1996; Uemoto *et al*., 2010 carried out their investigations in the Indian sector. For the Africa sector, various investigations were carried out by numerous researchers, such as, Adebesin *et al*., 2013a, b; Adeniyi *et al*., 2014a, b; Obrou *et al*., 2003; Oyekola and Kolawole 2010; Oyekola 2007; Radicella and Adeniyi 1999. The datasets used for this our present work were auto-scaled data obtained from Ilorin Observatory Station (8.5°N, 4.68°E, dip 2.96°N) of GIRO site for the months of April (Sunspot number (SSN), $R_z = 7$) representing March equinox, July (Sunspot number (SSN), $R_z = 15$) stands for June solstice, October (Sunspot number (SSN), $R_z = 21$) used for September equinox and November (Sunspot number (SSN), $R_z = 21$) stands for December solstice during year 2010 – a period of low solar activity (LSA).

In estimating the plasma drifts pattern over Ilorin, the time-rate of change of F2-region peak height, h_mF2, were extracted and computed. However, some previous works have revealed an improvement by the real height at some particular frequencies (say, 3, 4 or 5 MHz) as well as estimating the averages at such designated frequencies (e.g. Abdu *et al*., 2004); other studies have shown the plasma drifts computed from the reflecting height, *h'F2* of the F2-region, e.g., Araujo-Pradere *et al*., 2010; Ehinlafa *et al*., 2023a, b; Lee *et al*., 2005. Liu *et al*., 2011 display notable latitudinal changes in the real height pattern (h_mF2), which controls the effect of solar activity in the low latitude regions, and also, the purpose of using it as an estimating parameter in this study. Drifts of vertical E × B plasma estimated from h_mF2 shows a better statistical illustration of the enhanced ionization uplifting with pre-noon/post-noon peaks during the daytime, and also, a well representation of the pre-reversal enhancement of vertical plasma drifts with night peaks indication between 1900 LT and 0500 LT. Hence, this is the major reason for adopting the peak height, h_mF2 as a parameter in estimating drifts of vertical E × B plasma in this our recent study using the international quiet days (IQDs). In essence, this recent work aimed to study the variation of peak height, h_mF2; to estimate the vertical E × B plasma drifts from peak height, h_mF2; and finally, to investigate the estimated drifts pattern of the F2-region. This is carried out as a confirmation to the earlier results obtained by Bittencourt and Abdu 1981; Adeniyi *et al*., 2014a.

2. Data Analysis

The main parameter used for this present study is the auto-scaled ionospheric peak height of F2-region (h_mF2) obtained from the digisonde sited at Ilorin Observatory (Geo. Lat. 8.50°N, Long. 4.68°E, dip Lat. 2.95°N) on GIRO's site, a low latitude station in the sector of West Africa. The hourly datasets of peak height (h_mF2) of F2-region were extracted from the Digisonde Portable Sounder (DPS-Version 4.2) of the GIRO's web address (https://giro.uml.edu/didbase/scaled.php). The software program, designed by Huang and Reinisch (1996), known as the Calculated Average Representative Profile (CARP) inversion program, was used for auto-scaling of data in the digisonde. The examining data is year 2010, a period of low solar activity (Sunspot number (SSN), $R_z = 16$; which is also the mean of the four-month sunspot numbers used here, and Solar (F10.7) flux (SF), $\phi_z = 80$). The international quiet days (IQDs) data from Geoscience Australia 2009 is measured in each one-hour local time (LT). The peak heights, h_mF2 of F2-region data obtained is analysed by the computation of monthly average over ten international quiet days (IQDs) for each month considered except five international quiet days (IQDs) were used in December Solstice due to the scanty data available. From these values of hourly monthly average, the drift velocities of vertical plasma, according to Adeniyi *et al*., 2014a, were estimated by determining the time-rate of change of F2-region peak heights:

$$v_z = \frac{d(h_m F2)}{dt} \quad (1)$$

For the seasonal pattern of variation of vertical plasma drift velocities, v_z from the peak height, h_mF2 are computed by estimating the means for the selected months across each local time hour. Similarly, the variation of the annual pattern of v_z is resolved by finding the annual average of the four months across each hour for a better interpretation.

3. **Results and Discussion**

3.1 Variation Patterns of Seasonal Real Heights, h_mF2

Figure 1 shows the mean seasonal variation of the peak electron density real height, h_mF2 during low solar activity over Ilorin.

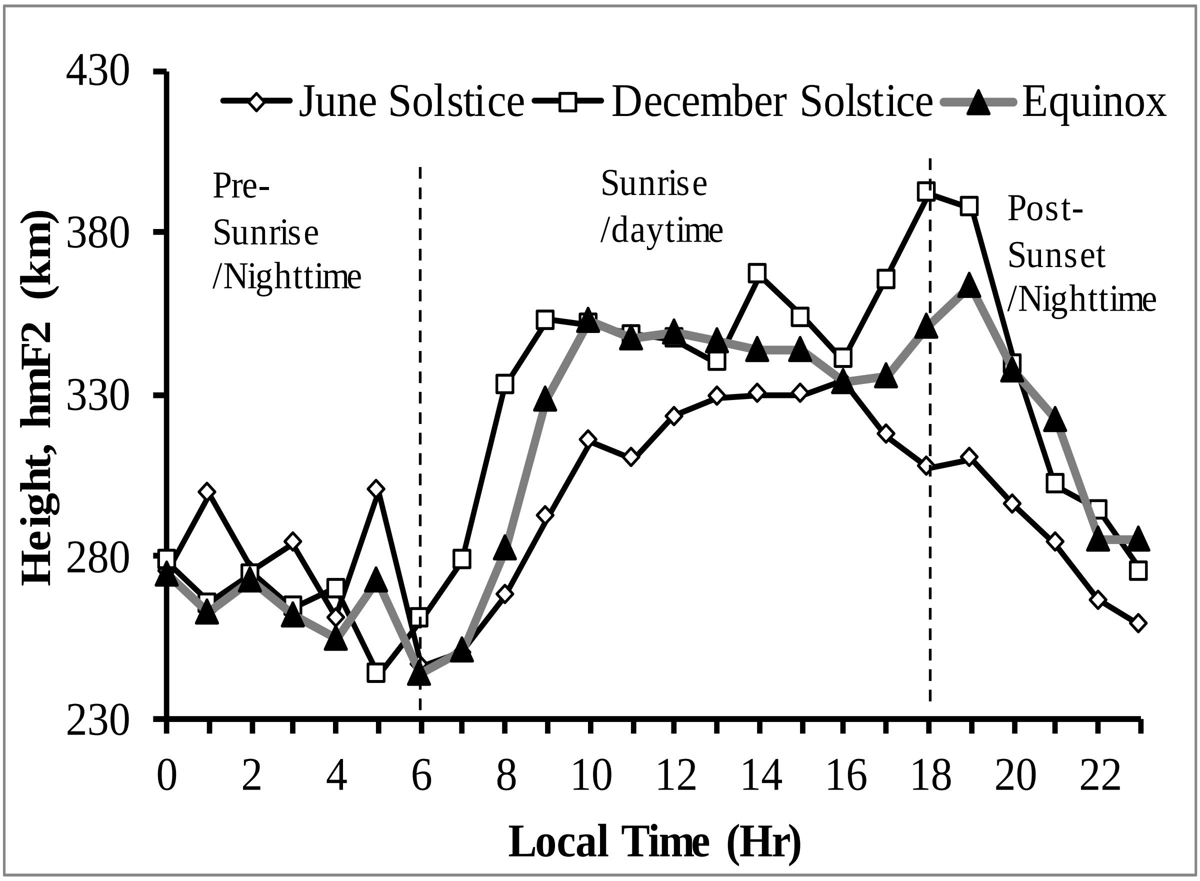

Figure 1: Hourly mean of peak heights, h_mF2, for all the seasons during LSA period

h_mF2 variations display a steady and gradual growth for all the seasons between 0600 LT and 1000 LT. During the daytime, a pre-noon peak around 1000 LT with magnitudes of (316–353) km for all seasons was noticed. The pre-noon peak magnitudes of peak height, h_mF2 was noticed to be least in June Solstice (316 km), and also, highest in equinox (353 km) around 1000 LT during the low solar activity period. It is adjudged that the stronger drifting of electron density to higher altitudes as noticed in peak height of equinoctial season where the loss rate due to recombination becomes much weaker; the electron density found in higher altitudes therefore has a longer life, and thereby yielding a higher magnitude in equinox, which is in agreement with Chen *et al*., 2008 and Ehinlafa *et al*., 2023b. A much broader variation between 1100 LT and 1600 LT was thereafter noticed and the magnitudes of the peak height, h_mF2 is (310 –367) km for all seasons. Another steady growth of peak height, h_mF2 between 1600 LT and 1900 LT for all seasons was witnessed by attaining a second peak (post-sunset peak) except during June solstice that experienced steady drop. During the night period, a post-sunset peak of peak height, h_mF2 between 1800 LT and 1900 LT for the entire season was obtained. However, the highest magnitude of peak height, h_mF2 around 1800 LT was obtained in December Solstice (392 km) and the least magnitude around 1900 LT was noticed in June Solstice (310 km) during LSA period. According to Adebesin, *et al*., 2013a, b; Adeniyi, *et al*., 2014a, b; Ehinlafa *et al*., 2023b, the abrupt movement of electron density triggered by the onset and turn-off of solar ionization, as well as the superimposition of Spread-F on the peak height of electron density between 1800 LT and 2300 LT may be helpful in symbolizing the post-sunset peak of the peak height, h_mF2 between 1800 LT and 1900 LT here. Instantly after this local time, a steady and continuous drop was noticed in the patterns of seasonal variation up till the 0500 LT with magnitudes of (245–320) km during the LSA period. The differences between the magnitudes of pre-noon peaks and post-sunset peaks for all seasons are considerably not distinct except during the December Solstice where highest magnitude (392 km) of peak height, h_mF2 was noticed.

Figure 2 is the hourly annual mean of peak height of F2-region revealed similar to Figure 1. The post-sunset peak with mean magnitude of 356 km around 1900 LT, which is higher than the pre-noon peak of mean magnitude 343 km around 1000 LT was noticed in Figure 2 for the peak height, h_mF2 annual plot for the period of LSA.

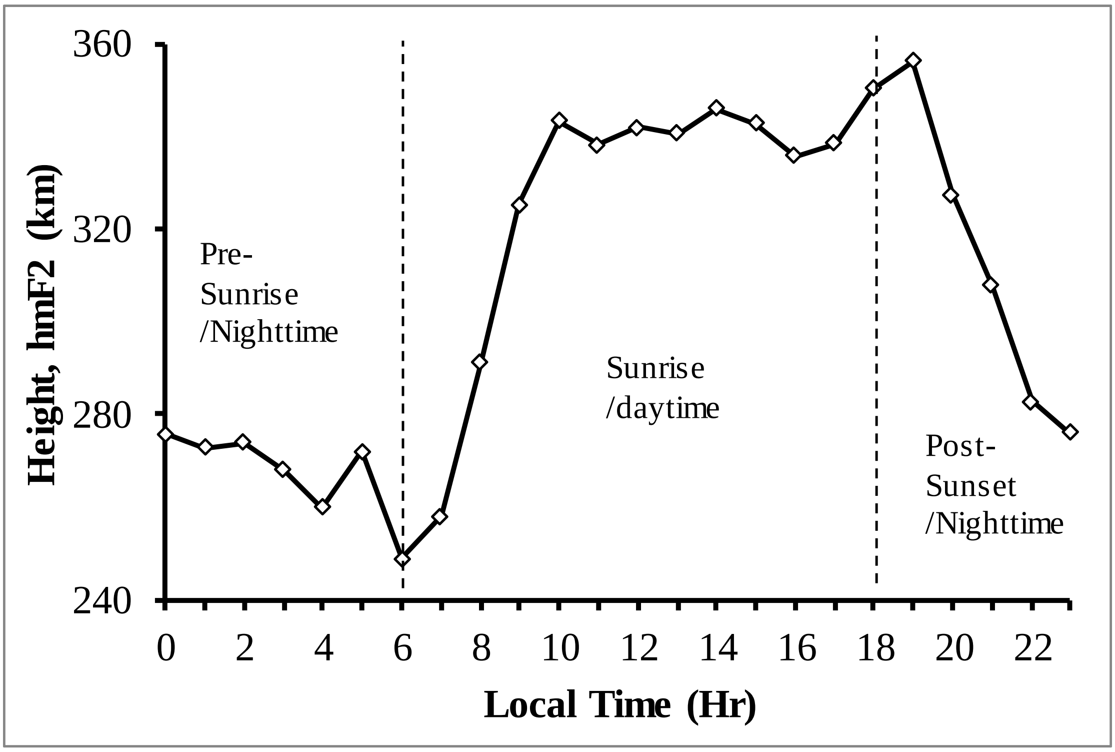

Figure 2: Hourly annual mean of peak height, h_mF2 during period of LSA

The annual variation in peak height, h_mF2 creates a small trough between 1500 LT and 1800 LT during the sunrise period. Also, a continuous steady drop was noticed around 1900 LT, and the drop progresses until a pre-sunrise minimum time around 0600 LT was noticed during the night period. This finding conforms with the continuous downward decay in the speedily driving away of electrons from the equator caused by solar ionization in the low latitude ionosphere [Ehinlafa *et al*., 2023a, b].

3.2 Seasonal Vertical Plasma Drifts (v_z) Effects

Figure 3 depicted the hourly seasonal mean plasma drift of vertical E × B velocities pattern as estimated at Ilorin for the year of 2010. The figure in term of its seasonal patterns showed that the ionosphere of F2-region achieved dynamical equilibrium by the means of recombination process and enhanced uplifting by the solar radiation, that respectively results in the processes of loss rate and ionization production. The signs of uplifts and decay processes of the vertical plasma drift noticed here in this our study during the LSA period as the daytime observations were well discussed. The experienced velocity increases which started from 0600 LT to 0900

LT, attaining a shrill (pre-noon) peak of plasma drift around 0700 LT for Solstice seasons and 0900 LT for equinoctial season.

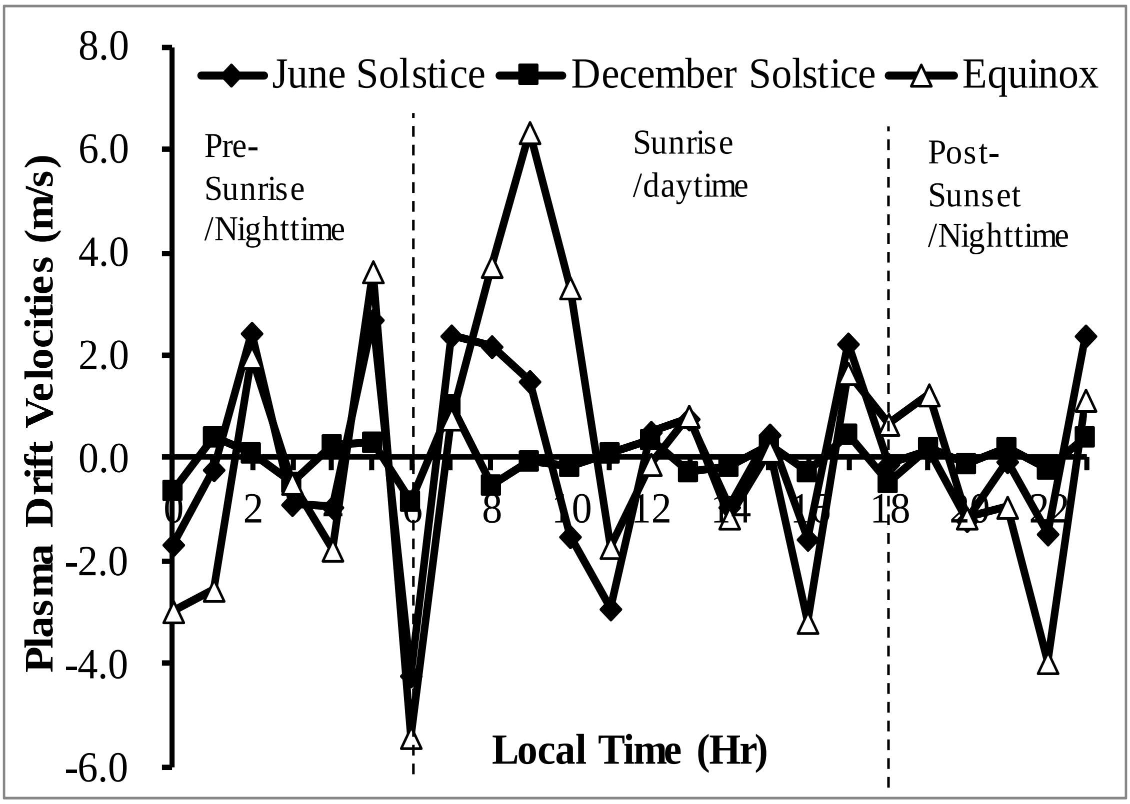

Figure 3: Hourly diurnal average vertical plasma drifts (v_z) for all seasons during the LSA period

The lowest pre-noon peak magnitude was seen in December Solstice (1.0 m/s), as well as, the highest pre-noon peak magnitude was found in Equinoctial season (6.4 m/s) around the same local time during the LSA period. This noticed occurrence agreed with Oyekola and Kolawole 2010 observations for both seasons of Solstice and Equinoctial over another low latitude region in West Africa sector. After the pre-noon peak, a sudden downward descending to below zero and a bit above zero drifts of the vertical plasma for all seasons was noticed till around 1600 LT. However, an enhancement of slight-transitory spikes occurred between 1200 LT and 1300 LT in December (0.4 m/s) and June (0.5 m/s) Solstices, and Equinoctial (1.0 m/s). Another enhancement spikes (post-noon peaks) around 1700 LT higher than the first in seasonal order of December Solstice (0.6 m/s), Equinox (1.7 m/s) and June Solstice (2.2 m/s) occurred. These daytime observations of a steady and continuous downward decay to below zero and a bit above zero of the drifts of vertical plasma beyond 0700 LT and 0900 LT for all seasons noticed, explain that the ionospheric F2-region is dropped by the progression of vertical plasma drift over the low latitudinal dip along the magnetic field lines of the Earth. This is achieved by ensuing plasma decrease about the low latitudinal dip creating a-twin distributing latitudinal hunched (EIA) on each side of the magnetic equator. The EIA created with the formation of crests near the low latitudinal dip between 0700 LT and 0900 LT, and also, improves in strength by the plasma movement towards both poles. The sharp growth in peak height, h_mF2 which is resulted from the consolidating of crests formed, thus building up the drift of vertical plasma pre-noon peak between 0700 LT and 0900 LT for all seasons. These noticed observations show an agreement with observed occurrences in Adebesin *et al*., 2013b; Adeniyi *et al*., 2014b for the entire season during the daytime.

During the nighttime observations, an enhanced uplift of the plasma drift was first noticed between 1900 LT and 2300 LT having positive drift peak magnitudes of (0.1–1.2) m/s and (0.4–2.4) m/s respectively for the entire season, and also, the second was noticed between 0200 LT and 0500 LT having positive drift peak with highest magnitudes of (2.0–3.6) m/s occurred in Equinoctial, followed by the magnitudes of (2.4–2.7) m/s in June Solstice and the least magnitudes of (0.1–0.3) m/s in December Solstice. Thereafter, a downward enhanced reversal was noticed. The downward enhanced reversal occurred at two separate periods of local time thereby giving pre-reversal enhancement (PRE) occurrence of negative drift peaks: the first one occurred at 2000 LT having negative drift peak magnitudes of [(-0.1)–(-1.2)] m/s and, the second at 2200 LT recording negative drift peak magnitudes with highest in Equinoctial (-4.0 m/s), then the June Solstice (-1.5 m/s) and the lowest in the December Solstice (-0.2 m/s). Similar occurrence was noticed of night pre-reversal enhancement (PRE) negative drift peaks firstly around 0000 LT with magnitudes of [(-0.6)–(-3.0)] m/s for all seasons, and secondly, between 0300 LT and 0400 LT having magnitudes recorded with highest in Equinoctial (-1.8 m/s), followed by the June Solstice (-1.0 m/s) and the least in December Solstice (-0.5 m/s). This indicates seasonal dependent of the vertical E × B plasma drift, and also, the observed occurrences agreed with the noticed observations of Adebesin *et al*., 2013a; Adeniyi *et al*., 2014a in all seasons during the nighttime.

Depicted in Figure 4 is the hourly annual mean pattern of the F2-region vertical E × B drifts shown similar to Figure 2. During the daytime, the drift shrill peak of pre-noon with mean magnitude of 3.5 m/s around 0900 LT after a sudden growth that commenced around 0600 LT was noticed. Also, the steady and continuous downward decaying to below zero and a bit above zero drifts of the vertical plasma at various local times were noticed respectively with mean magnitudes as follows: -1.6 m/s at 1100 LT, 0.2 m/s between 1200 LT and 1500 LT, -0.9 m/s at 1400 LT, and -2.0 m/s at 1600 LT. In addition, a slight-transitory enhanced spikes occurred mainly at two local times with drift mean magnitudes of 0.6 m/s at 1300 LT and 1.5 m/s at 1700 LT. These are the daytime occurrences of the annual plot of vertical plasma drifts variation for the period of LSA which conformed with Adebesin *et al*., 2013b; Adeniyi *et al*., 2014a.

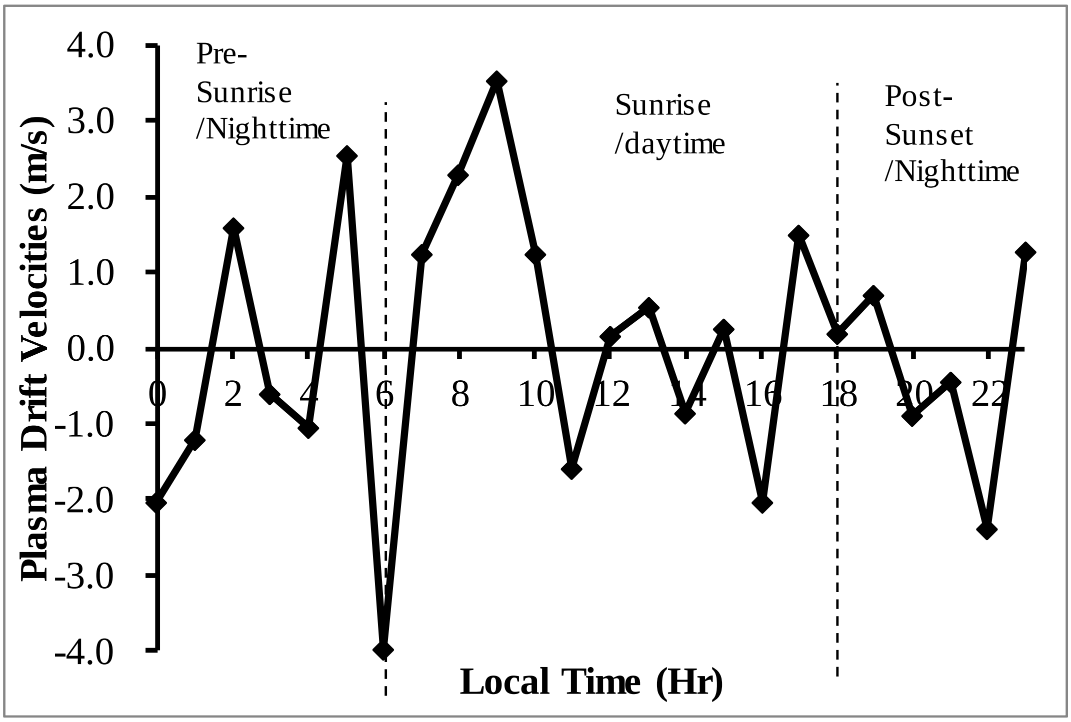

Figure 4: Annual mean pattern of Vertical E × B Plasma Drift (v_z) for all seasons during LSA period

During the nighttime, an enhanced uplift of the annual plasma drift peak between 1900 LT and 2300 LT having respectively mean magnitudes of 0.7 m/s and 1.3 m/s noticed is less than that of same plasma drift peak of enhanced upthrow between 0200 LT and 0500 LT with mean magnitudes of 1.6 m/s and 2.6 m/s respectively. The night pre-reversal enhancement (PRE) negative drift peaks between 2000 LT and 2200 LT with mean magnitudes of -0.9 m/s and -2.4 m/s respectively occurred is higher than the similar PRE negative drift peaks between 0000 LT and 0400 LT having respectively mean magnitudes of -2.1 m/s and -1.1 m/s. Also, it is noticed that a continuous steady drop around 1900 LT after sunset occurred until a pre-sunrise minimum time around 0600 LT was noticed for all seasons in general during the nighttime occurrence. This finding of the continuous downward decay in vertical plasma drift velocities between 1900 LT and 0600 LT noticed here, which is caused by the quick drifting away of electrons from the equator as a result of abruptly onset and turn-off of solar ionization in F2-region. Also, the upward rise in vertical plasma drift velocities observed between 0600 LT and

0900 LT here, which is caused by the enhanced uplift of electrons rapidly from the equator in F2-region of ionization production due to solar radiation. These noticed occurrences are observed in the low latitude ionosphere here (see figure 4), which conformed with Adebesin *et al*., 2013a; Adeniyi *et al*., 2014b.

4. Summary and Conclusion

This work has investigated peak height, hmF2 as a parameter in estimating drifts of vertical E × B plasma using Ilorin data, a station found at the low latitudinal dip (EIA). The following outcomes of this paper were summarily deduced and concluded as:

A pre-noon and post-sunset peaks in h_mF2 with magnitudes of (316–353) km around 1000 LT and (310–392) km between 1800 LT and 1900 LT for all seasons occurred respectively during the LSA period. The variances in h_mF2 magnitudes noticed amidst the pre-noon and the post-sunset peaks in all seasons are not so pronounced except during the December Solstice. During the nighttime, a night enhanced uplift in h_mF2 with mean magnitude of 356 km around 1900 LT noticed after sunset (figure 2) is an indicative that electrons are driven from the equator to a region due to solar ionization in the low latitudinal dip. However, a continuous steady drop noticed around 1900 LT progresses until a pre-sunrise minimum time around 0600 LT was noticed for all seasons. Seasonal peaks in h_mF2 noticed here are suspected to be controlled by the enhanced vertical E × B ion drifts which conforms with nearly erstwhile outcomes gotten at some stations in the West African sector during periods of LSA especially by Adeniyi *et al.*, 2014a. This is possible because of the strong relation established in estimating vertical plasma drifts, v_z from peak heights, h_mF2. As well, it has become essential to demonstrate the mean height profile for the entire 24-hour plot of peak height, h_mF2 here. In conclusion, there is worthy note in a generalized theory that a peak height above 300 km, the superficial velocity of plasma drift is nearly similar to the real velocity of vertical plasma drift, which conforms with our obtainable values of the mean peak height, h_mF2 (Bittencourt and Abdu 1981). Hence, our result promoted a fact that the peak height, h_mF2 displays quick growth.

A drift Shrill (pre-noon) peaks of vertical plasma were noticed with magnitude range of (1.0 – 6.4) m/s for all seasons between 0700 LT and 0900 LT for the period of LSA. Two slight-transitory enhanced spikes occurred having the first spike magnitudes (0.4–1.0) m/s between 1200 LT and 1300 LT less than the second spike (post-noon peak) magnitudes (0.6–2.2) m/s around 1700 LT for all seasons as confirmed by Adeniyi *et al.*, 2014a. A steady and continuous downward drop of vertical plasma drifts to below zero and a bit above zero between 1000 LT and 1600 LT in all seasons were noticed, which is due to the progressional drop of vertical plasma drifts over the low latitudinal dip along the magnetic field lines of the Earth. An enhanced uplift of the plasma positive peak magnitudes of (0.1–1.2) m/s and (0.4–2.4) m/s was first noticed between 1900 LT and 2300 LT respectively was found to be less than the second noticed plasma positive peak with magnitudes of (0.1–2.4) m/s and (0.3–3.6) m/s between 0200 LT and 0500 LT respectively in all seasons for the LSA period. A night pre-reversal enhancement (PRE) of negative drift peak occurred at first and second periods of local time having magnitudes of [(-0.1)–(-1.2)] m/s at 2000 LT and [(-0.2)–(-4.0)] m/s at 2200 LT respectively for all seasons, which is higher in similar quantity of night pre-reversal enhancement (PRE) negative drift peak firstly around 0000 LT with magnitudes ranging of [(-0.6)–(-3.0)] m/s and, secondly between 0300 LT and 0400 LT having magnitudes ranging of [(-0.5)–(-1.8)] m/s for all seasons as established by Adeniyi *et al.*, 2014a. A gradual reversal of drifts during the high periods of peak height, h_mF2 noted here depicts that the Pre-Reversal Enhancement (PRE) is fundamentally accountable for the huge uplift of the F2-region vertical plasma, and in return, the creation of the low latitudinal dip (EIA).

In conclusion, a solid dependent relation was noticed generally with the hourly mean values computed between the corresponding peak heights, h_mF2 and the estimating enhanced vertical E × B drift velocities in each season mentioned here.

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