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Low Latitude Estimated Virtual Vertical Plasma Drifts Variation During Solar Minimum

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ABSTRACT
Virtual vertical plasma drifts estimated from hourly virtual heights (*h'F2)* extracted from the digisonde found on GIRO's website are used in this recent study by engaging the international quiet days (IQDs) conditions. Virtual vertical plasma drifts (v_z') estimated from low latitude F2-region virtual heights was examined over Ilorin (lat. 8.31°N, long. 4.34°E, dip lat. 2.95º) during solar minimum (SM), a station Located along the latitudinal hollow. The 10-international quiet days (IQDs) monthly averages across each hourly period of the day were used for the estimation. Two characteristics of v_z' highlighted are the pre-noon and the post-noon peaks of the diurnal patterns for each season. The v_z' pre-noon peaks magnitudes between 0800 LT and 0900 LT are 6.8, 14.4 and 15.0 m/s for June Solstice, Equinox and December Solstice respectively; and its post-noon peaks magnitudes around 1800 LT evening time are 0.8, 7.4 and 7.9 m/s foe December and June Solstices, and Equinox respectively. v_z' displayed an enhanced phenomenon of slight-transitory spikes having magnitudes of -0.3 m/s (December Solstice) and -0.8 m/s (Equinox), and 3.6 m/s (June Solstice) around 1200 LT noontime. Finally, v_z' depicted pre-reversal enhancement (PRE) night peaks for the entire season. The PRE peaks magnitudes are [(-4.0)–(-13.4)] m/s at 2000 LT, [(-4.9)–(-9.3)] m/s between 2200 LT and 2300 LT, [(-3.6)–(-6.6)] m/s between 0100 LT and 0200 LT and [(-3.0)–(-6.4)] m/s between 0300 LT and 0400 LT respectively for all seasons. Same phenomenon in the v_z' annual pattern as showcased in the v_z' diurnal patterns occurred. In general, v_z' magnitudes were highest in Solstices and lowest in Equinox during solar minimum. The v_z' gradually and continuous decay is ensued by the electrons hastily turnoff movement from the low latitude due to solar ionization for all seasons.

Keywords:
Virtual Vertical Plasma Drifts,
Pre-noon peak,
Post-noon peak,
PRE,
Low latitude.

INTRODUCTION

The transmission of virtual vertical plasma drifts of the low latitude ionosphere especially in the F2-region investigated by Fejer (1997) and Kelley (1989) had been ascribed with the resulting of solar ionization of the latitudinal anomalies (EIA) that is controlled by the low latitudinal zonal electric fields. Thus, determining of plasma drifts in the ionospheric F2-region of low latitude in the vertical direction are avenues of evolving proofs on the electric field that are valued. Therefore, the plasma drifts in the region of low latitude considerably alter the mode of latitudinal F2-region transmission and the ionization of latitudinal anomaly (EIA) improvement. Though, the intermingling E- and F-region with relative to efficiency of the drifts of latitudinal vertical plasma are based on the intricacy of the electrodynamic procedures that oscillates significantly with the time of day, from day to day, season and solar activities. The morphological studies of the F2-region drifts of vertical E × B plasma in the low latitude had been performed, yet through various phases and procedures by several researchers as avenue to fully understand the vertical E × B plasma drifts and its effects. Amidst the several researchers are: Eccles (1998) who investigated the statistical and theoretical simulations around the latitudinal dynamics of electric fields and currents; and also, Fesen *et al*. (2000) the studied night enhanced drift uplift is responsible for the swift rise of the latitudinal F2-region post-sunset which provide the important aspect of the uncertainties production of E- and F-region plasma. The drifts of vertical E × B plasma in low latitude are notable contributing parameters for models in the ionosphere, since they back the explanation of the vertical plasma movement close to the magnetic equator. Studies from Jicamarca Observatory Station had engaged the foremost role for the plasma drifts modelling by these several researchers (Fejer *et al*., 1995; Fejer, 1997; Scherliess and Fejer, 1999; Woodman *et al*., 2006). Furthermore, (Fejer *et al*., 1991; Luhr *et al*., 2008; Fejer *et al*., 2008; Kil *et al*., 2009), by observational means of measuring instruments and satellites [e.g. Ions Drift Meter (IDM), CHAllenging Minisatellite Payload-SATellite (CHAMP-SAT), and Republic of China SATellite 1 (ROCSAT-1)] were used to investigate vertical E × B plasma drifts at the region of low latitude. The double measuring methods (IDM and SAT) ensued the evolving investigations of the universal model for the ionospheric F2-region vertical E × B plasma drifts measurements.

The virtual-time data of the ionosphere from Digisondes, as suggested by Reinisch *et al*. (2005) are actually cherished parameters in ionospheric studies. Ionosondes data of the ionospheric F2-region readily available may be used to estimate the vertical E × B plasma drifts. An early anxiety faced on the data worth gotten from ionograms during the auto-scaling of its echo traces had been explained by Reinisch *et al*. (1998). However, an auto-scaling algorithm program called 'ARTIST' designed for the ionograms has been inculcated in the digisondes, according to Reinisch *et al*. (2005). This is done to ensure that the now scaled-out data are trustworthy and reliable for ionospheric models forecasting.

The same procedure was used by some early researchers at different sectors of the world. Researchers (Richmond *et al*., 1980; Batista *et al*., 1996; Anderson *et al*., 2002; Bertoni *et al*., 2006; Kelley *et al*., 2009) concentrated their studies around the South America sector; also, (Dabas *et al*., 2003; Liu *et al*., 2004; Araujo-Pradere *et al*., 2010; Uemoto *et al*., 2010) spun their investigations within the Asian sector. For the Africa sector, several researchers, such as, Radicella and Adeniyi (1999), Obrou *et al*. (2003), Oyekola and Ojo (2006), Oyekola (2007), Oyekola (2009a, b), Oyekola and Kolawole (2010), Adeniyi *et al*. (2014a, b), Adebesin *et al*. (2015) focused their investigations on diverse studies. The data engaged for this our studies were auto-scaled data extracted from Ilorin Ionospheric Observatory (8.5°N, 4.68°E, dip 2.96°N) of GIRO site for the months of April (Sunspot number (SSN), $R_z = 7$) stands for March equinox, July (Sunspot number (SSN), $R_z = 15$) representing June solstice, October (Sunspot number (SSN), $R_z = 21$) used for September equinox and November (Sunspot number (SSN), $R_z = 21$) representing December solstice during 2010 – a year of solar minimum (SM)

In estimating the patterns in plasma drifts over Ilorin, the time-rate of change of F2-region virtual heights, $h'F2$ for each period of local time were extracted and estimated. However, some earlier studies have indicated an improvement by the virtual heights at some particular frequencies (say, 3, 4 or 5 MHz), and also, estimating the averages at such selected frequencies, e.g., Abdu *et al*. (2004); other studies have shown that the plasma drifts estimated from the F2-region reflecting heights, $h'F2$, e.g., Lee *et al*. (2005), Araujo-Pradere *et al*. (2010) and Ehinlafa *et al*. (2023). Liu *et al*. (2011) highlight notable latitudinal changes in the virtual height patterns ($h'F2$), which controls the solar activity effect in the regions of low latitude, as well as, the reason of embracing it as an estimating parameter in this recent study. Vertical E × B plasma drifts estimated from $h'F2$, via the condition of international quiet days (IQDs), indicates showcasing of a well representation of the daytime ionization enhancement upthrusting of vertical plasma drifts with pre-noon/post-noon peaks, and also, a better statistical illustration of vertical plasma drifts with nighttime pre-reversal enhancement peaks. Hence, this recent study aimed to estimate the vertical E × B plasma drifts from virtual heights, $h'F2$; and also, to study the variation of the estimated drifts patterns. This is performed in order to endorse the prior results secured by Bittencourt and Abdu (1981), Adeniyi *et al.* (2014b) and Adebesin *et al.* (2015).

MATERIALS AND METHODS

The major engaging parameter for this recent study is the auto-scaled F2-region virtual heights of reflection ($h'F2$) extracted from the Digisonde Portable Sounder (DPS-4.2 Version) situated at Ilorin Ionospheric 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 Nigeria North central of West Africa sector. The hourly data of F2-region virtual heights ($h'F2$) were extracted from the DPS-4.2 Version of the GIRO's web address (https://giro.uml.edu/didbase/scaled.php). The algorithm program, developed by Huang and Reinisch (1996), known as the Calculated Average Representative Profile (CARP) inversion, was adopted for auto-scaling of data in the digisonde. The engaging data period is 2010, a year of solar minimum [Sunspot number (SSN), $R_z = 16$; which is also the average of the four-month sunspot numbers adopted here, and solar flux (SF), $\phi_z = 80$]. The international quiet days (IQDs) data from world data centre (wdc) (2020) is determined at an interval of one-hour local time (LT). The F2-region virtual heights, $h'F2$ data extracted is analysed by computing the monthly mean over ten international quiet days (IQDs) for each month examined but five international quiet days (IQDs) were engaged in December Solstice due to the availability of scanty data. From these monthly averages for each hourly local time, the vertical plasma drifts, attributed to Adeniyi *et al*. (2014b), were estimated by computing the time-rate of change of F2-region virtual heights:

$$v_z' = \left[{d(h'F2)}/{dt} \right] \quad (1)$$

For the seasonal variation of vertical ion drifts pattern, v_z' from the virtual heights (*h'F2*) are computed by determining the averages for the adopted months across each hourly local time. Similarly, the annual pattern of v_z' variation is determined by finding the annual average of the four months across each hour for a better presentation.

RESULTS AND DISCUSSION

3.1 Seasonal Vertical Ion Drifts (v_z') Patterns

Figure 1 depicted the hourly seasonal average patterns of vertical E × B plasma drifts as estimated over Ilorin for the period of 2010 – a year of solar minimum (SM).

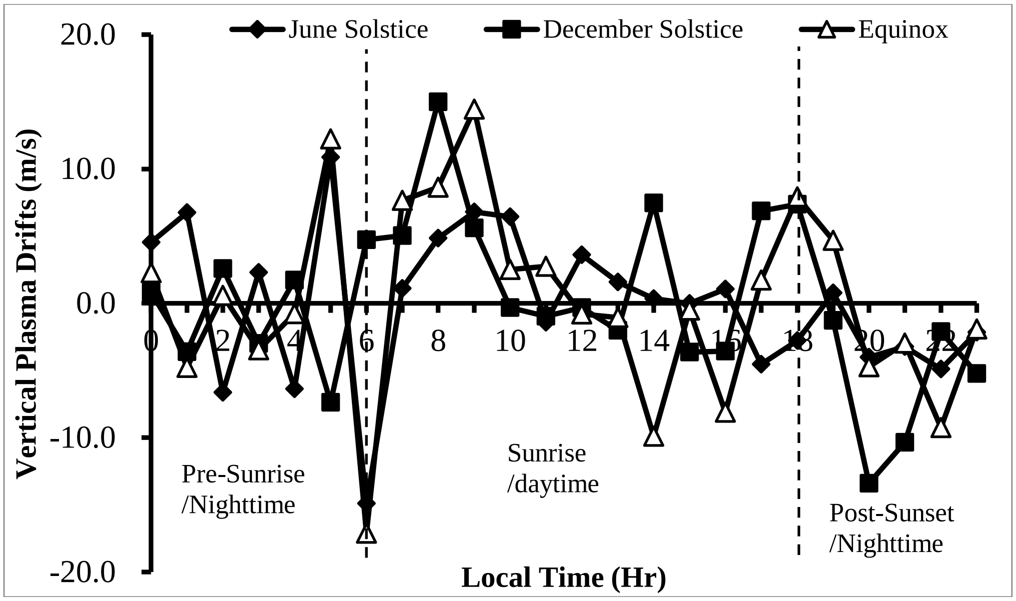

Figure 1: Hourly plot of seasonal average of vertical plasma drifts (v_z') during the period of SM

The figure above showcased that the seasonal vertical plasma drifts (v_z') patterns of ionospheric F2-region approved dynamical equilibrium by the means of recombination process and enhanced uplifting by the solar ionization, that respectively yields the processes of loss rate and production rate. In the daytime, the signs of upthrust and decay processes of the vertical plasma drifts, v_z' noticed here in this our recent study during the solar minimum were well discussed. The experienced drift, v_z' upthrust that started from 0600 LT to 0900 LT, reaching shrill (pre-noon) plasma drifts peaks between the local times of 0800 LT and 0900 LT for all seasons. The v_z' lowest pre-noon peak magnitude 6.8 m/s is noticed for June Solstice at 0900 LT, then next magnitude 14.4 m/s is noticed for Equinox at 0900 LT and the highest pre-noon peak magnitude 15.0 m/s is noticed for December Solstice at 0800 LT during the solar minimum. This noticed observation agrees with Oyekola (2009a) and Oyekola and Kolawole (2010) daytime drifts peak results of 15.0 m/s and 18.6 m/s for Solstice and Equinox seasons respectively over another region of low latitude in West Africa sector. Thereafter, a hasty downward decaying of v_z' is noticed by reaching below zero and slight above zero vertical plasma drifts for the entire season between periodic time-interval of 1000 LT and 1600 LT. However, an enhanced v_z' slight-transitory spike is noticed at 1200 LT noontime with magnitudes in order of -0.3 m/s (December Solstice) as the lowest value, followed by -0.8 m/s (Equinox) and the highest value of 3.6 m/s (June Solstice). An enhanced v_z' shrill (post-noon) peaks lower than the previous is noticed between 1800 LT and 1900 LT evening time having magnitudes in seasonal order of 0.8 m/s as the lowest for December Solstice and then next value of 7.4 m/s for June Solstice, and the highest value of 7.9 m/s for Equinox seasons. These daytime observations of a continuous hasty and downward decay to below zero and slight above zero of the virtual plasma drifts, v_z' beyond 0800 LT and 0900 LT for all seasons noticed, explain that the F2-region of the ionosphere is decayed due to the virtual plasma drifts progression over the latitudinal hollow along the magnetic field lines of the Earth. This is grasped by the plasma depression resultant about the latitudinal hollow creating a-double distributing latitudinal hunched (EIA) on each side of the magnetic equator. The EIA formed with the peaks creation near the latitudinal hollow between 0800 LT and 0900 LT, and also, increases in strength by the plasma motion towards both poles. The shrill rise in virtual plasma drifts, v_z' that is formed from the consolidating of peaks created, thereby building up the virtual plasma drifts, v_z' pre-noon peaks between 0800 LT and 0900 LT for all seasons. These noticed observations agree with observed occurrences in Adeniyi *et al*. (2014b) and Adebesin *et al*. (2015) for all season during the solar minimum period.

In the nighttime, an enhanced plasma drifts, v_z' uplift is noticed first at 1900 LT displaying positive peaks of highest value 4.9 m/s for Equinox, then next value of 1.3 m/s for December Solstice and the lowest value 0.8 m/s for June Solstice, and also, the second one is noticed at 0000 LT having positive v_z' peaks magnitudes of (0.8–4.5) m/s for all seasons. After that, a downward reversal enhancement is noticed. The downward reversal enhancement take place at two distinct local time periods thus resulting to pre-reversal enhancement (PRE) of negative drift, v_z' peaks: the firstly, it is noticed at 2000 LT having negative v_z' peaks of lowest magnitude -13.4 m/s for December Solstice, followed by magnitude -4.7 m/s for Equinox and the highest magnitude -4.0 m/s for June Solstice and, the second between 2200 LT and 2300 LT with negative v_z' peaks magnitudes of [(-4.9)–(-9.3)] m/s for all seasons. The same night pre-reversal enhancement (PRE) negative v_z' peaks is noticed firstly between 0100 LT and 0200 LT recording magnitudes of [(-3.6)–(6.6)] m/s for all seasons, and secondly, between 0300 LT and 0400 LT with magnitudes of -6.4 m/s recorded as the lowest for June Solstice, then next value of -3.5 m/s for Equinox and the highest value of -3.0 m/s for December Solstice. These occurrences highlight seasonal dependent of the vertical E × B plasma drifts, and also, the noticed occurrences conform with the occurred observations of Adeniyi *et al*. (2014a) and Adebesin *et al*. (2015) in term of the seasonal effect during the nighttime.

Highlighted in Figure 2 is the hourly plot of annual average patterns of the F2-region vertical E × B plasma drifts revealed similar to Figure 1.

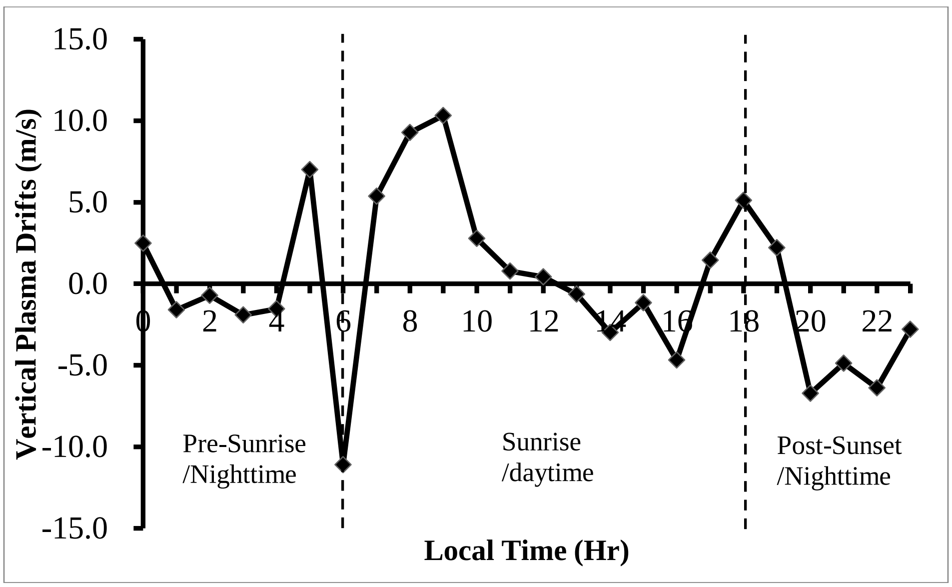

Figure 2: Hourly plot of annual average patterns of vertical plasma drifts (v_z') during solar minimum

During the daytime, the drift shrill (pre-noon) peak with average magnitude of 10.3 m/s at 0900 LT after a swift uplift that commenced at 0600 LT is noticed. Also, the gradually and downward declining to below zero and trifling above zero vertical plasma drifts at different periods of local time is noticed respectively with average magnitudes recorded as: 0.8 m/s at 1100 LT and [(-0.6)–(-4.7)] m/s between 1300 LT and 1600 LT. In addition, an enhancement of slight-transitory spikes is noticed majorly at different local time periods having drifts average magnitudes of 0.4 m/s at 1200 LT and -1.2 m/s at 1500 LT. An evening enhanced drift (post-noon) peak recording average magnitude of 5.1 m/s at 1800 LT is noticed. These are the daytime observations of the annual pattern plot of vertical plasma drifts for the solar minimum which conforms with the similar occurrences of Oyekola and Oluwafemi (2008) and Adeniyi *et al*. (2014a).

During the nighttime, an enhanced uplift of plasma drift peak between 0000 LT and 0500 LT in the annual pattern plot having average magnitudes of 2.5 m/s and 7.0 m/s found to be higher than that of similar enhanced uplift of plasma drift peak between 1900 LT and 2300 LT recording average magnitudes of 2.2 m/s and -2.8 m/s. The night pre-reversal enhancement (PRE) negative drift peaks between 2000 LT and 2200 LT with average magnitudes of -6.7 m/s and -6.4 m/s occurred is less than the similar PRE negative drift peaks between 0100 LT and 0400 LT having the same mean magnitudes of -1.6 m/s each. Also, a continuous stable decline at 1900 LT after sunset advances until a pre-sunrise minimum period at 0600 LT is noticed in general during the nighttime. This finding of the continuous downward drop in vertical plasma drifts between 1900 LT and 0600 LT noticed here, which is instigated by the hasty electrons drifting away from the equator due to tersely onset and turn-off of solar ionization in F2-region. Also, the upward growth in vertical plasma drifts noticed between 0600 LT and 0900 LT here, which is triggered by the enhanced uplift of electrons speedily from the equator in F2-region of ionization production due to solar radiation. These noticed occurrences take place in the low latitude of the ionosphere here (see figure 2) that is truce with Oyekola (2009b) and Adeniyi *et al*. (2014b) occurred observations.

CONCLUSION

The results of v_z' seasonal peaks noticed here are suspected to be controlled by the meridional neutral winds as factor responsible for its enhancement in general that is in treaty with almost earlier outcomes acquired at some stations in the West African sector during closely related solar activity periods. This is ensured due to the solid expression stated in computing the virtual vertical plasma drifts, v_z' from virtual heights, *h'F2*. Also, it is important to generalized that the apparent vertical plasma drifts are approximately assumed to the same as the real vertical plasma drifts, which is conform with our obtainable magnitudes here. Hence, our results showcased a statement that the virtual vertical plasma drifts depict quick uplift of enhancement. A stable reversal of drifts during the high local times noted here displays that the Pre-Reversal Enhancement (PRE) is fundamentally accountable for the enormous F2-region vertical plasma drifts uplift, and in return, the latitudinal hollow (EIA) formed.

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