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Variation of Equatorial Estimated Vertical Ion Drifts During Low Solar Activity

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Abstract

Vertical ion drifts (v_z) estimated from F2-region peak heights was studied under the condition of international quiet days (IQDs) over Ilorin (lat. 8.31°N, long. 4.34°E, dip lat. 2.95°) during low solar activity (LSA), a station located at the equatorial dip. The 10-international quiet days (IQDs) monthly means across each local time hour were used for the estimation. v_z featured to two characteristics: the pre-noon and the post-noon peaks in the seasonal patterns. v_z pre-noon peak magnitudes are 1.0, 2.4 and 6.4 m/s for December Solstice, June Solstice and Equinox respectively between 0700 LT and 0900 LT; and v_z post-noon peak magnitudes are 0.6, 1.7 and 2.2 ms^{-1} for December Solstice, Equinox and June Solstice respectively at 1700 LT. Another v_z feature noticed is slight-transitory enhancement spikes in seasonal order with magnitudes of December (0.4 ms^{-1}) and June (0.5 ms^{-1}) Solstices, and Equinox (1.0 ms^{-1}) between 1200 LT and 1300 LT. Finally, v_z featured pre-reversal enhancement (PRE) night peaks in all seasons. The PRE peak magnitudes are [(-0.1)–(-1.2)] ms^{-1} at 2000 LT, [(-0.2)–(-4.0)] ms^{-1} at 2200 LT, [(-0.6)–(-3.0)] m/s at 0000 LT and [(-0.5)–(-1.8)] ms^{-1} between 0300 LT and 0400 LT respectively in all seasons. Similar phenomenal observation was noticed in the v_z annual pattern. In general, v_z magnitudes were greatest in Equinox (6.4 ms^{-1}) and least in Solstice (1.0 ms^{-1}). The continual steady fall in v_z is caused by the speedily moving away of electrons from the equator due to solar ionization in all seasons.

Keyword: Vertical Ion Drifts; Pre-noon peak; Post-noon peak; Enhanced Spikes; PRE

1. Introduction

The transmission of vertical ion in the equatorial latitude ionosphere especially the F2-region investigated by Kelley 1989 and Fejer 1997 had been ascribed with the resulting of anomalies of the equatorial ionization (EIA), which is controlled by the equatorial zonal electric fields. Thus, measuring of ion drifts in the equatorial F2-region in the vertical direction are means of emerging attestations on the electric field that are treasured. Therefore, the ion drifts in the equatorial region significantly change the equatorial F2-region mechanism and the equatorial ionization anomaly (EIA) growth.

Though, the interacting E- and F-regions in relation with the drifts of equatorial vertical ion efficiency is based on the complexity of the electrodynamic processes that fluctuates substantially with the time of day, from day to day, season and solar activities. The morphology of the F2-region drifts of the equatorial vertical E × B ionization had been executed, however on diverse stages and procedure by

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many investigators as medium to understand fully the drifts of the vertical E × B ionization and its ionospheric effects. Amidst the several investigators are: Eccles 1998 who studied the statistical and theoretical simulations around the equatorial dynamics of electric fields and currents; and also, Fesen *et al*., 2000 investigated the night uplift enhancement of velocity is accountable for the speedy growth of the equatorial F2-region post-sunset that stage the significant part in the uncertainties production of E- and F-regions ion. The drifts of equatorial vertical E × B ionization are noteworthy contributing parameters for ionospheric models, since they support the description of the movement of vertical ion close to the magnetic equator. Investigations from Jicamarca Ionospheric Observatory, using ground-based equipment called Incoherent Scatter Radar (ISR), had played the most leading role for the modelling of ion drifts by these various researchers: Fejer *et al*., 1991; Scherliess and Fejer 1999; Woodman *et al*., 2006. Besides, Fejer *et al*., 1995; Fejer *et al*., 2008; Luhr *et al*., 2008; Kil *et al*., 2009, using observational means of measuring equipment and satellites [e.g. Ions Drift Meter (IDM), CHAllenging Minisatellite Payload-SATellite (CHAMP-SAT), and Republic Of China SATellite 1 (ROCSAT-1)] to studied vertical E × B ion drifts at equatorial region. The two-measuring methods (IDM and SAT) resulted to the emerging studies of the universal model for the measurements of vertical E × B ion drifts in the ionospheric F2-region.

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 may be needed to estimate the drifts of vertical E × B ion. An initial anxiety encountered on the data worth 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 inputted in the digisondes, according to Reinisch *et al*., 2005. This is done to ensure that the now scaled-out data are trustworthy and valuable for models forecasting in the ionosphere.

Similar procedure was used by some early researchers at different sectors of the world. Batista *et al*., 1996; Anderson *et al*., 2002; Bertoni *et al*., 2006; Kelley *et al*., 2009 focused their investigations on the South America sector; also, Dabas *et al*., 2003; Liu *et al*., 2004; Araujo-Pradere *et al*., 2010; Uemoto *et al*., 2010 revolved their studies around the Asian sector. For the Africa sector, various researchers, such as, Obrou *et al*., 2003; Oyekola and Oluwafemi 2007; Oyekola 2009; Adebesin *et al*., 2013a, b; Adeniyi *et al*., 2014a, b; Ehinlafa *et al*., 2024 concentrated their investigations on different studies. The data employed for this for this our studies were auto-scaled data gotten 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), $R_z = 7$) 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 year 2010 – a low solar activity (LSA) period.

In estimating the pattern in ion drifts over Ilorin, the rate of change of F2-region peak height, h_mF2 for each local time were obtained and estimated. However, some previous studies have shown an enhancement by the peak height at some designated frequencies (say, 3, 4 or 5 MHz) as well as the means estimated at such particular frequencies (e.g. Abdu *et al*., 2004); other studies have shown the ion drifts estimated from the reflecting height, *h'F2* of the F2-region, e.g., Lee *et al*., 2005; Araujo-Pradere *et al*., 2010; Ehinlafa *et al*., 2023. Liu *et al*., 2011 exhibit notable equatorial changes in the peak height pattern (h_mF2), which controls the effect of solar activity in the equatorial regions, and also, the main drive of using it as an estimating quantity in this present study. Drifts of vertical E × B ion estimated from h_mF2, imposing the international quiet days (IQDs) condition, 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 ion drifts with night peaks indication between 1900 LT and 0500 LT. Hence, this recent study aimed to estimate the vertical E × B ion drifts from peak height, h_mF2; and also, to study the variation of the estimated drifts pattern. This is carried out as a confirmation to the earlier results obtained by Bittencourt and Abdu 1981; Adebesin *et al.*, 2013b; Adeniyi *et al.*, 2014a.

2. Analyzing Data

The major quantity used for this recent study is the auto-scaled peak height (h_mF2) of F2-region gotten from the digisonde located at Ilorin Ionospheric Observatory (Geo. Lat. 8.50°N, Long. 4.68°E, dip Lat. 2.95°N) on GIRO's website, an equatorial station in the West Africa sector. The hourly data of peak height (h_mF2) were obtained from the Digisonde Portable Sounder (DPS-4.2) version of the GIRO's online address (https://giro.uml.edu/didbase/scaled.php). The software program, developed by Huang and Reinisch 1996, known as the Calculated Average Representative Profile (CARP) inversion program, was employed for auto-scaling of data in the digisonde. The investigative data is year 2010, a period of low solar activity (Solar (F10.7) flux (SF), $\phi_z = 81$, and Sunspot number (SSN), $R_z = 16$; which is also the mean of the four-month sunspot numbers used here). The international quiet days (IQDs) data from Geoscience Australia 2009 is estimated at each interval of one-hour local time (LT). The F2-region peak heights, h_mF2 data analysed is built on the monthly mean computation 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 monthly mean for each hour, the drifts of vertical ion, according to Adebesin *et al.*, 2013b, were determined by estimating the time-rate of change of F2-region peak heights:

$$v_z = {d(h_mF2)}/{dt} \qquad 1$$

For the seasonal variation of vertical ion drifts pattern, v_z from the peak height, h_mF2 are determined by estimating the means for the selected months across each local time hour. Likewise, the variation of the v_z annual pattern is estimated by finding the annual mean of the four months at each local time hour for better illustrations.

3. Result and Discussion

3.1 Seasonal Vertical Ion Drifts (v_z) Variation

Figure 1 depicted the hourly mean seasonal drifts of vertical E × B ion pattern as estimated at Ilorin for the year of 2010.

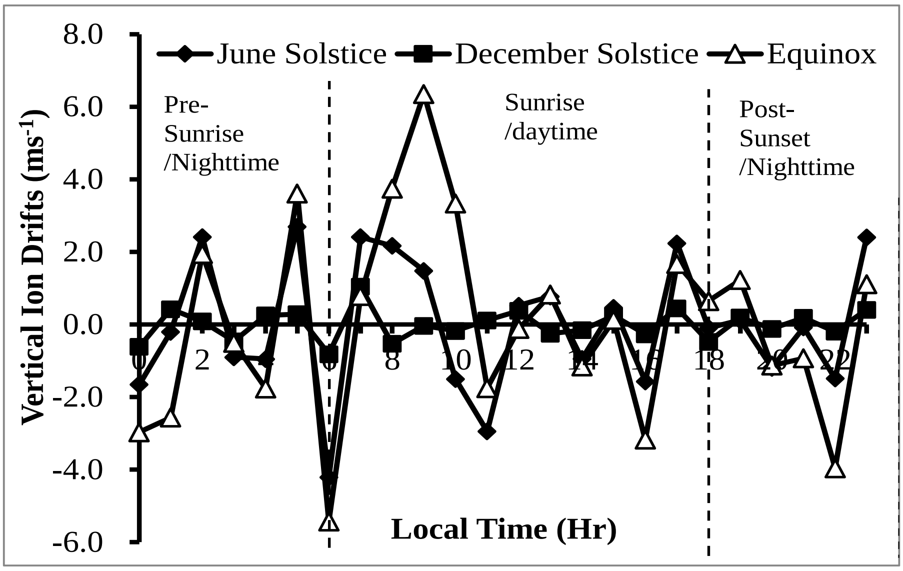

Figure 1: Hourly seasonal mean vertical ion drifts (v_z) during LSA period

The above figure exhibited that the ionosphere of F2-region accomplished dynamical non-equilibrium by the means of recombination procedure and enhanced upthrowing by radiation from the sun, that respectively results in the processes of loss and production rates due to ionization. In the daytime occurrences, the signs of upthrows and drop processes of the vertical ion drifts noticed in this our work were well discussed here. The experienced drift increases that started from 0600 LT to 0900 LT, reaching high-pitched (pre-noon) peaks of ion drift at 0700 LT for Solstice seasons and 0900 LT for equinox season. The least pre-noon peak magnitude was noticed in December solstice (1.0 ms^{-1}), as well as, the greatest pre-noon peak magnitude was found in Equinox (6.4 ms^{-1}) at the same hourly LT during the LSA. These noticed occurrences agreed with Oyekola and Oluwafemi 2007; Oyekola 2009 affirmative pacts for both seasons of Solstice and Equinox over another equatorial region in West Africa sector. Afterward, sudden downward depression of the pre-noon peaks surging below and slight above zero drifts of the vertical E × B ion in all seasons was noticed till 1600 LT. However, an enhancement of slight-transitory spikes occurred between 1200 LT and 1300 LT in December (0.4 ms^{-1}) and June (0.5 ms^{-1}) solstices, and Equinox (1.0 ms^{-1}). Another enhancement spikes (post-noon peaks) at 1700 LT greater than the initial one noticed in magnitude order of 0.6 ms^{-1} (December Solstice), 1.7 ms^{-1} (Equinox) and 2.2 ms^{-1} (June Solstice). These daytime notices, a steady and continuous downward drop to below and slight above zero of the drifts of vertical ion beyond 0700 LT and 0900 LT in all seasons noticed, explain that the F2-region of the ionosphere is dropped by the progression of vertical ion drifts over the equatorial dip along the magnetic field lines of the Earth. This is achieved by ensuring ion decrease about the equatorial dip creating a-twin distributing equatorial ionization hunched (EIA) on each side of the magnetic equator. The EIA created with the formation of crests near the equatorial dip between 0700 LT and 0900 LT, and also, improves in strength by the ion movement towards both poles. The high-pitched growth in ion drifts, v_z that is caused from the consolidating of crests formed, thus building up the drift of vertical ion pre-noon peaks between 0700 LT and 0900 LT in all seasons. These occurred notices show an agreement with noticed assertions in Adebesin *et al*., 2013b; Adeniyi *et al*., 2014b; Ehinlafa *et al*., 2024 in all seasons during the LSA period.

In the nighttime notices, an enhanced upthrow of the ion drifts occurred first between 1900 LT and 2300 LT having positive drifts peaks magnitudes of (0.1–1.2) ms^{-1} and (0.4–2.4) ms^{-1} respectively in all seasons, and also, the second one was between 0200 LT and 0500 LT having positive drifts peaks with greatest magnitude of (2.0–3.6) ms^{-1} occurred in Equinox, followed by the magnitude of (2.4–2.7) ms^{-1} in June Solstice and the least magnitude (0.1–0.3) ms^{-1} in December Solstice. Later, a night downward enhanced reversal was noticed. The night downward enhanced reversal occurred at two distinct hourly periods thus giving pre-reversal enhancement (PRE) occurrence of negative drift peaks: the first occurred at 2000 LT recording negative drifts peaks magnitudes of [(-0.1)–(-1.2)] ms^{-1} in all seasons and, the second at 2200 LT having negative drift peak magnitudes with greatest in Equinox (-4.0 ms^{-1}), then the June Solstice (-1.5 ms^{-1}) and the least in the December Solstice (-0.2 ms^{-1}). Same occurrence was noticed of night pre-reversal enhancement (PRE) negative drift peaks firstly at 0000 LT with magnitudes of [(-0.6)–(-3.0)] ms^{-1} in all seasons, and secondly, between 0300 LT and 0400 LT having magnitudes recorded with greatest in Equinox (-1.8 ms^{-1}), followed by the June Solstice (-1.0 ms^{-1}) and the least in December Solstice (-0.5 ms^{-1}). This indicates seasonal dependent of the vertical E × B ion drifts, and also, the occurred notices here conformed with the noticed affirmations of Adebesin *et al*., 2013a; Adeniyi *et al*., 2014a; Ehinlafa *et al*., 2024 in all seasons.

Depicted in Figure 2 is the hourly annual mean pattern of the F2-region drifts of vertical ion shown in the given plot below.

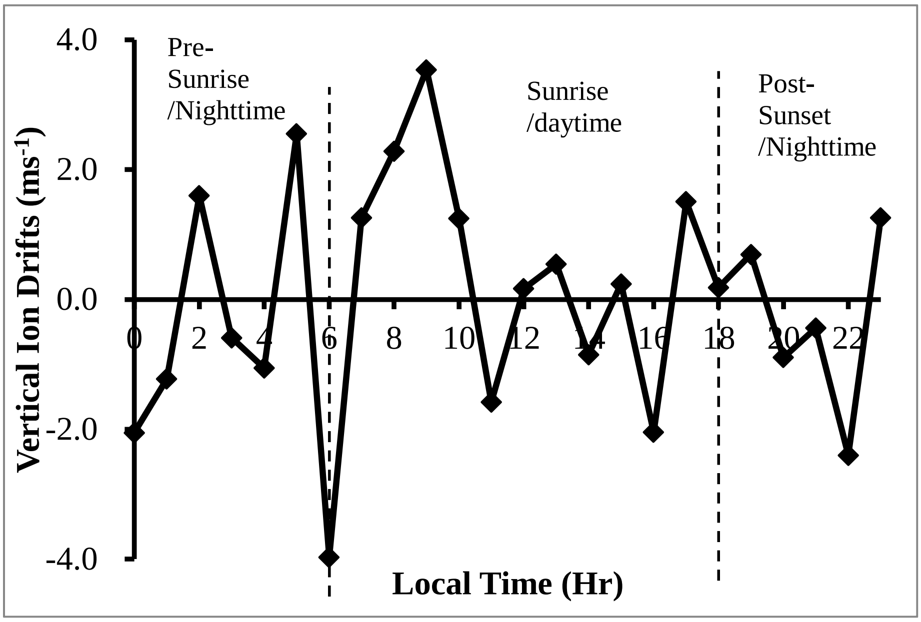

Figure 2: Annual mean pattern of vertical ion Drifts (v_z) during LSA period

In the daytime, the drift high-pitched pre-noon peak with mean magnitude of 3.5 ms^{-1} at 0900 LT period after a sudden upgrow that began at 0600 LT was noticed. This notice is in conformity with the discovered affirmations (e.g. Oyekola 2007; Oyekola, 2009). Also, the steady and continuous downward dropping below and slight above zero drifts of the vertical ion at different local times were noticed respectively with mean magnitudes as follows: -1.6 ms^{-1} at 1100 LT, 0.2 ms^{-1} between 1200 LT and 1500 LT, -0.9 ms^{-1} at 1400 LT, and -2.0 ms^{-1} at 1600 LT. In addition, a slight-transitory enhanced spikes occurred mainly at two periods with drift mean magnitudes of 0.6 ms^{-1} at 1300 LT and 1.5 ms^{-1} at 1700 LT. These are the daytime notices of the annual mean plot of vertical ion drifts pattern for the LSA which conformed with Adebesin *et al.*, 2013b; Adeniyi *et al.*, 2014a; Ehinlafa *et al.*, 2024 findings.

In the nighttime as well, the ion drift peaks of upthrow enhancement of the annual mean plot between 1900 LT and 2300 LT with mean magnitudes of 0.7 ms^{-1} and 1.3 ms^{-1} respectively noticed is less than that of same ion drift peaks of enhanced upthrow between 0200 LT and 0500 LT having mean magnitudes of 1.6 ms^{-1} and 2.6 ms^{-1} respectively. The night pre-reversal enhancement (PRE) negative drift peaks between 2000 LT and 2200 LT with mean magnitudes of -0.9 ms^{-1} and -2.4 ms^{-1} respectively occurred is greater than the same PRE negative drift peaks between 0000 LT and 0400 LT having mean magnitudes of -2.1 ms^{-1} and -1.1 ms^{-1} respectively. Also, it is noticed that a continuous steady drop at 1900 LT after sunset occurred until a pre-sunrise minimum time at 0600 LT was noticed in general. This discovery of the continuous downward drop in vertical ion drifts between 1900 LT and 0600 LT noticed here, is caused by the rapidly 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 ion drifts noticed between 0600 LT and 0900 LT here, is caused by the enhanced upthrow of electrons speedily from the equator in F2-region of ionization production due to solar radiation. These occurrences are noticed in the equatorial ionosphere here (see Figure 2), which conformed with Adebesin *et al.*, 2013a; Adeniyi *et al.*, 2014b; Ehinlafa *et al.*, 2024.

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4. Conclusion

This study has investigated vertical ion drifts as a quantity estimated from peak height, h_mF2 engaging Ilorin data, a station located at the equatorial ionization dip (EIA). The following outputs of this research were construed and concluded as:

A high-pitched drifts (pre-noon) peaks of vertical ion were noticed with magnitude range of (1.0–6.4) ms^{-1} in all seasons between 0700 LT and 0900 LT for the LSA period. Two slight-transitory enhanced spikes occurred having the first spike magnitudes (0.4–1.0) ms^{-1} between 1200 LT and 1300 LT less than the second spike (post-noon peak) magnitudes (0.6–2.2) ms^{-1} at 1700 LT in all seasons as confirmed by Adeniyi *et al.*, 2014a. A steady and continuous downward drop of vertical ion drifts to below and slight above zero between 1000 LT and 1600 LT in all seasons were noticed, which is due to the progressional drop of vertical ion drifts over the equatorial dip along the magnetic field lines of the Earth. An enhanced upthrow of the ion positive peak magnitudes of (0.1–1.2) ms^{-1} and (0.4–2.4) ms^{-1} was first noticed between 1900 LT and 2300 LT respectively was seen to be less than the second noticed ion positive peak with magnitudes of (0.1–2.4) ms^{-1} and (0.3–3.6) ms^{-1} 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 hourly periods having magnitudes of [(-0.1)–(-1.2)] ms^{-1} at 2000 LT and [(-0.2)–(-4.0)] ms^{-1} at 2200 LT respectively in all seasons, which is greater in same quantity of night pre-reversal enhancement (PRE) negative drift peak firstly around 0000 LT with magnitudes of [(-0.6)–(-3.0)] ms^{-1} and, secondly between 0300 LT and 0400 LT having magnitudes of [(-0.5)–(-1.8)] ms^{-1} in all seasons as established by Adeniyi *et al.*, 2014a. A gradual reversal of drifts during the high periods of vertical ion drifts, v_z noted here depicts that the Pre-Reversal Enhancement (PRE) is fundamentally accountable for the huge upthrow of the F2-region vertical ion, and in return, the creation of the equatorial dip (EIA). Similar phenomenal effects are noticed in the annual pattern of v_z variation.

In conclusion, a strong dependent relation of the estimated vertical E × B ion drifts computed from the corresponding hourly means of peak heights, h_mF2 was noticed generally in each season mentioned here.

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