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The 300 km threshold value for vertical drifts inferred from F-region heights: Past observations, present developments, and future works

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Abstract The variability of the quiet time F-region vertical plasma drift in the low latitude region if well understood forms an essential subject in the equatorial ionosphere–thermosphere environment. Vertical drift velocities obtained from the time rate of change of the F-layer height have been adjudged a realistic representation of the true velocities when the F-layer altitudes are greater than a threshold value of 300 km. In this light, the sufficiency of this threshold value of some outstanding past results was discussed in relation to some present observations, especially in the African sector where there is paucity of data, and a new direction for future developments was suggested.

1. Introduction

The appearance of vertical plasma drifts (Vz) in the equatorial region has been established as a result of the interaction between zonal electric field with the plasma in the presence of the horizontal geomagnetic field $E \times B$. Santos et al. (2013) and Sreeja et al. (2009) had explained the electric field responsible for the quiet time vertical plasma motion on the basis of the dynamo process in the E and F ionospheric regions. Typically, Vz is upward at daytime (around 08–18 LT), with a pre-reversal enhancement (PRE) around 18–19 LT, and downward at nighttime. Thermospheric winds have been attributed as a major driver of the F-region electric fields (e.g. Eccles, 1998). According to Bertoni et al. (2006 and the references therein), owning to the high conductivity along the magnetic field lines at daytime, E-region dynamo electric fields outside the magnetic equator interact/diffuse into the F-region, thereby inhibiting the dynamo electric fields of the region. At sunset, during which time the E-region conductivity (which maximizes at daytime) begins to decrease rapidly, the electric fields from both the E and F regions combine such that Vz is considerably enhanced along the magnetic equator leading to the emergence of the PRE. The mechanisms for E–F coupling and their manifestation had been explained by Cosgrove (2013).

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There are several models that describe the low-latitude dynamo electric fields. Few among them are Anderson and Mendillo (1983), Farley et al. (1986), Haerendel and Eccles (1992). Buonsanto and Witasse (1999) had observed the climatology of the ion drifts at Millstone Hill using data covering 1984–1997, Scherliess and Fejer (1999) had developed a first quiet-time empirical F region vertical drift global model for different seasons and solar conditions using Jicamarca ISR and AEE satellite observations. Fejer et al. (2008) had developed a new empirical global model for moderate and high solar conditions for three seasons using the ROCSAT-1, and observed that night-time vertical drifts are much stronger than earlier reported by Scherliess and Fejer (1999). Further, Lühr et al. (2008) had employed the CHAMP satellite to perform an indirect measurement of daytime F-region drifts at different longitudes using magnetic field measurements, especially at low latitudes.

However, the results obtained by Bittencourt and Abdu (1981) had shown that for some distinct time periods (especially post-sunset), at which time the ionospheric F-layer height is well above the threshold value of 300 km, the apparent vertical drift inferred from ionosonde measurements is equal to the vertical $E \times B$ drifts. Consequently, when the F-layer is above 300 km, the drift obtained from the ground-based digisonde (i.e. dh′F/dt), as well as the ISR velocities is influenced by chemical (recombination) effects (e.g. Bertoni et al., 2006). It is believed that under this condition, the digisonde accurately depicts the electromagnetic drift velocity. Further, the F-layer peak height (hmF2) is believed to be affected by ambipolar diffusion, recombination and neutral wind; and the changes in the condition of recombination cause changes in the ion vertical velocity. In essence, for F-layer height less than 300 km, it is assumed that chemical recombination could result in an apparent inferred vertical drift which needs to be corrected for, before it can match the $E \times B$ drifts, so as to be able to maintain realistic drift velocity values at such hours (e.g. Oyekola and Kolawole, 2010 and the references therein). Refer to the work of Sumod et al. (2012) and Richards (2011) for explicit analysis on the chemical correction process. It has also been suggested by Woodman (1970) that the most precise observations evolve within the 300–450 km height range, whereas the height range of 150–300 km is occasionally polluted by noise arising from echoes from the electrojet irregularities.

In this work, the sufficiency and exactness of the 300 km threshold value of the F-layer height was discussed from the point of view of past outstanding works and their results, coupled with some present observations related to some key issues, and a likely new direction to look at, for future work.

2. Past observations versus present developments

Vertical plasma drifts obtained from both digisonde (DPS-4) and ISR measurements from Jicamarca were compared by Bertoni et al. (2006). The observation spans 7–11 October, 2002 and 19–23 March, 2003. They recorded better correlation between both procedures within 17–21 LT (signifying sunset hours) and starting from around 02 LT through 08 LT when the F-layer peak height is well above 300 km, but deviates away from each other at other periods of the day. However, for other periods when hmF2 < 300 km, the digisonde observations are more positively enhanced than that of the ISR. The deviation during most of the daytime hours (according to the authors) is attributed to photochemistry (see also Ambili et al., 2012). They also observe good relationship between the two techniques during events of magnetically disturbed periods. During this period, the ionospheric drift is influenced by the disturbed electric fields arising from some dynamo actions. These results had in no small way added to the confidence in the use of ground-based digisonde height observations in inferring drift (especially during night-time period) in a situation where direct drift measurements are not obtainable, or impaired as a result of defective antennas and operational problems.

The correlation coefficient (R) between the night-time Jicamarca ISR drift observation and the inferred drift obtained from hmF2 over Ilorin, both for the year 2010 (Adebesin et al., 2013a) between 17 and 21 LT is approximately 0.7. For the time period of 02–08 LT, $R = 0.6$ (not shown in that work). This correlation values are consistent with Bertoni et al. (2006) observation. Adebesin et al. (2013a) had suggested that the general theory that vertical drifts obtained by digisonde measurements only match the $E \times B$ drift if hmF2 > 300 km is reliable, but may not hold for the night-time period within 22–06 LT and early morning (06–09 LT) periods under condition of solar minima (tentative result). Therefore, a good correlation relationship between the ISR and DPS-4 during conditions of h'F ⩾ 300 km (by Bertoni et al., 2006) and hmF2 ⩽ 300 km (by Adebesin et al., 2013a) between the hours of 17–21 LT and 02–08 LT should generate enquiry for future work. In addition, Risbeth (1981) had earlier submitted that though the hmF2 > 300 km and beyond is generally considered as a necessary condition for the triggering of Rayleigh–Taylor (R–T) instability, but may not necessarily be a sufficient condition.

At above the 300 km threshold value, the F-layer is practically high enough for transport processes to dominate over recombination effects; and at such time, can be equivalent to those determined from incoherent scatter radar measurement of the F-region. However, the method of obtaining drift velocity from F-layer peak height value has been found to underestimate the magnitude of plasma drift when the F-layer is not high enough, arising from the effects of plasma transportation (Bittencourt and Abdu, 1981). This may have suggested the reason behind the underestimation of the Jicamarca observation by the Ilorin digisonde observation, more importantly during the night-time period by Adebesin et al. (2013a) – see Fig. 1. Refer to the work of Adeniyi et al. (2014a) for the inhibiting factors affecting ground-based inferred vertical drifts measurements using height observations.

One other contributing factor to the differences in Vz observed at Ilorin and Jicamarca is the location of these stations with respect to the geographic equator. The equatorial electric fields are a result of the E/F region dynamos. The winds and tides driving the dynamos are known to vary with geographic latitude. Therefore, the neutral winds and tides over (and near) Ilorin and Jicamarca are expected to be distinct as a result of their latitudinal differences. The reversal peak magnitudes are −8.9 m/s (at 22 LT) and −35.5 m/s (at 01 LT) for Ilorin and Jicamarca respectively during March equinox; as well as −13 m/s at 21 LT (Ilorin) and −19 m/s at 00 LT (Jicamarca) during December solstice. During September equinox, there is a smaller downward reversal at Ilorin

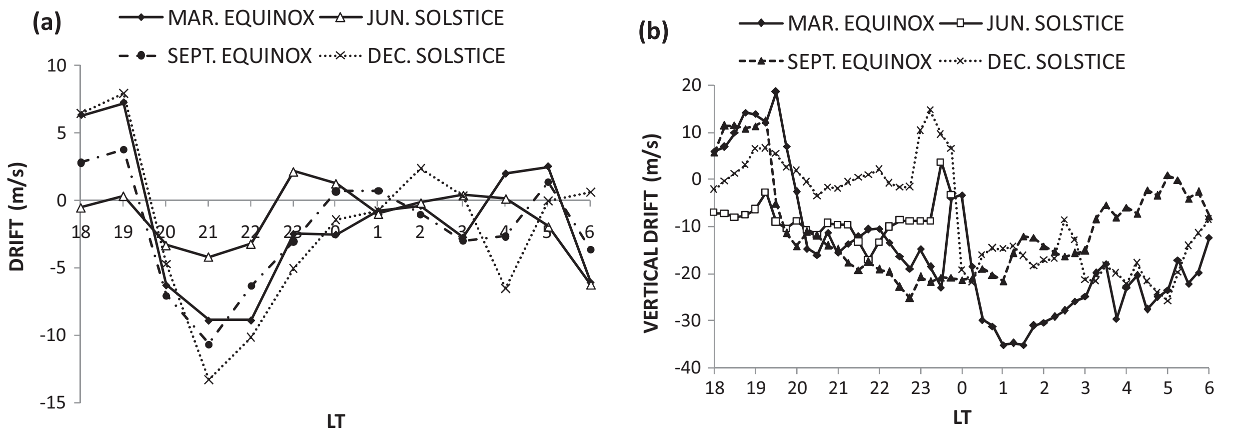

Figure 1 (a) Average seasonal Vz inferred from hmF2 observations over Ilorin (b) corresponding Vz measured at Jicamarca using ISR observations for the same period as in (a). *Source:* Adebesin et al. (2013a).

compared to that of Jicamarca. The root mean square (RMS) deviations between the two stations are 1.3, 2.3, 3.5, and 5.5 for December and June solstice, September and March solstice respectively. The work of Adeniyi et al. (2014b) had validated the results obtained by Adebesin et al. (2013a). The former had compared the inferred apparent vertical drift obtained by the latter with the maximum morning time proxy parameter described by the parameter $E = \{d(\Delta H/dt)_{max.}$ (e.g. Sreeja et al., 2009) in the morning hours representing the east–west electric field in equatorial electrojet (EEJ) over the same location (Ilorin) and period of investigation (2010). They recorded a linear regression fit (R^2) of 0.94 between parameter E and plasma drift. This affirms that the inferred drift velocity from the ground-based observation used by Adebesin et al. (2013a) is consistent and hence reliable. Recall that Anderson et al. (2002) have established a quantitative relationship whereby the vertical $E \times B$ drift velocity in the equatorial F-region can be estimated using ground-based magnetometer observations. Thus, we can suggest that there is no influence of ionospheric noise in the observation of the height profile reported by Adebesin et al. (2013a)

From the work of Bittencourt and Abdu (1981), three $E \times B$ drift models, Vz_{real} (e.g. Fig. 2 – after the authors) obtained from the work of Woodman (1970) were used and were represented by the solid lines. The F-layer apparent vertical drift displacement ($Vz_{app.)}$ described as the time rate of change of the F-layer virtual height is denoted by the dots, and the virtual height of the F-layer is denoted by dashed line. They showed that at sunset and evening hours, $Vz_{real} \approx Vz_{app}$ for height magnitude greater than 300 km. However, observations of the author of the present work from Fig. 2 seem to indicate that even at lower heights less than the threshold 300 km (i.e. within 20–21 LT for the second model, and 21–23 LT for both the first and third models), $Vz_{real} \approx Vz_{app}$. Though it was reiterated by Bittencourt and Abdu (1981) that the electric field which manifests at these lower heights of the F-region still produce vertical $E \times B$ plasma drifts, but because of recombination processes, the apparent drift fades in strength; and consequently cannot match the $E \times B$ drift in magnitude. But an area of interest/consideration is the rationale behind Vz_{real} being approximately equal to Vz_{app} for

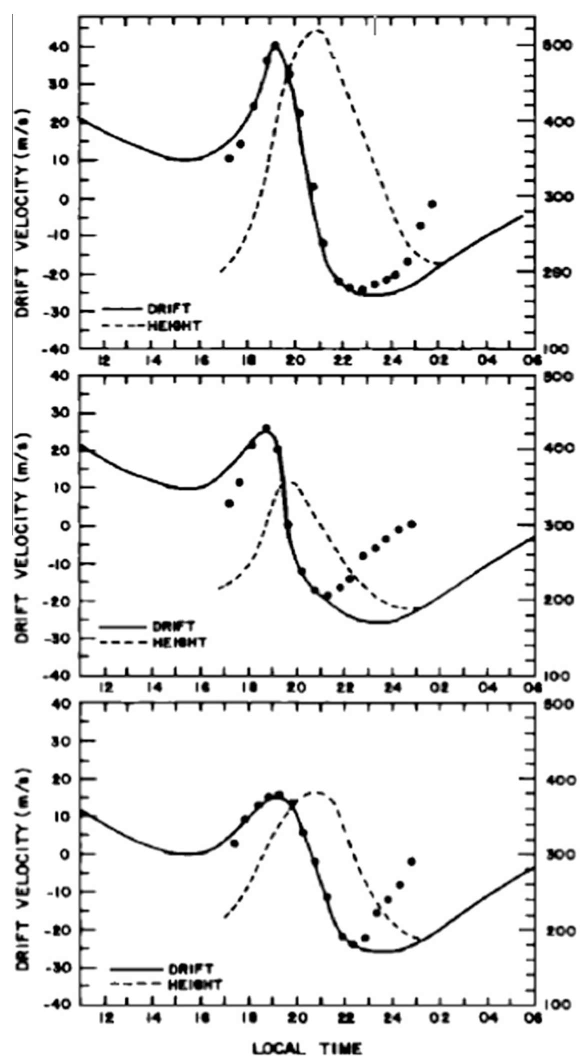

Figure 2 Magnetic equatorial variation in the vertical $E \times B$ drift velocity (solid lines), apparent drift inferred from F-layer virtual height (dots), and F-layer virtual height (dashed lines) for three different models (after Bittencourt and Abdu, 1981).

h′F < 300 km for the LT period mentioned by the present author in Fig. 2.

3. Future works

A good correlation relationship between the ISR and digisonde observations during conditions of h'F ⩾ 300 km reported by Bertoni et al. (2006) over Jicamarca between the hours of 17–21 LT and 02–08 LT; as well as between Jicamarca ISR and Ilorin digisonde observations for conditions of hmF2 ⩽ 300 km reported by Adebesin et al. (2013a) (without performing any chemical correction on the inferred drift) between the same hour as those considered by Bertoni et al. (2006) should pose a concern for future work. Ordinarily, if the threshold height value of 300 km is taken into consideration, one should not expect a good correlation around those hours in the work of Adebesin et al. (2013a). This is because the ionosonde measures the reflection height of the radio wave and the rate of change of the F-layer height is a good representative of Vz on the basis that other processes like ionizing radiation (production process) and recombination (loss process) do not have effect on the height.

The result obtained by Bertoni et al. (2006) revealed that the digisonde observations are more enhanced than that of the ISR observation. Similarly, the result of Abdu et al. (2006) while comparing the digisonde true height iso density lines data over Sao Louis (for June and December 2000) with the Scherliess and Fejer (1999) drift model revealed that the PRE magnitude of the ionosonde observations over Sao Louis during both periods of observation is higher than that of the modeled observations. Both results are consistent. However, the reverse is the case for Adebesin et al's (2013a) observations as seen in Fig. 1. This seems to suggest that there is little or no input of the drift observations from African sector into the global drift model. Recall that the drift included in the International Reference Ionosphere (IRI) model is obtained mostly from the Scherliess and Fejer's (1999) model. Although the model is based on global satellite data, it has a large contribution from Jicamarca ISR measurements. Hence, there should be a need to incorporate the few available ground-based ionosonde inferred drift measurements into the global modeling, or better still to start with regional model in the African sector.

According to Adebesin et al. (2013a), satellites probing of the ionospheric F-layer have shown tremendous longitudinal differences in the structure and dynamics of the equatorial region. The highest episodes of such occurrences are in the Africa sector. It is therefore very necessary to make available ISR observation station in the African sector, instead of only the ground-based inferred measurements; for future improvements in the global modeling of equatorial *Vz*. Even the ground-based measurements over Africa are sparsely studied because of paucity of data arising from so many other factors like defective antennas and operational problems of equipments. The work carried out by Adebesin et al. (2013b) is the first to investigate *Vz* over Ilorin. Further, most of our perception of Vz in the equatorial region is based on Jicamarca ISR observations. At Jicamarca (South America sector), the geomagnetic equator dips, resulting in a reasonable large digression between the geodetic and geomagnetic equator; whereas in the African sector both the geodetic and geomagnetic equators fairly aligned. So there is bound to be a kind of disparity in the observations obtained from both sectors.

It is believed that a good input of Vz observations from the African region into the global model will be able to address issues on the probable prevailing mechanisms that create distinctive equatorial compositions in Africa, as well as explaining the specific activity of the equatorial and off-equatorial E-region in stabilizing the current system during the evening time pre-reversal enhancement.

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References

Abdu, M.A., Batista, I.S., Reinisch, B.W., Sobral, J.H.A., Carrasco, A.J., 2006. Equatorial F region evening vertical drift, and peak height, during southern winter months: a comparison of observational data with the IRI descriptions. Adv. Space Res. 37, 1007–1017.

Adebesin, B.O., Adeniyi, J.O., Adimula, I.A., Reinisch, B.W., 2013a. Low latitude Nighttime Ionospheric vertical E × B drifts at African Region. Adv. Space Res. 52 (12), 2226–2237. http://dx.doi.org/10.1016/j.asr.2013.09.033.

Adebesin, B.O., Adeniyi, J.O., Adimula, I.A., Reinisch, B.W., 2013b. Equatorial vertical plasma drift velocities and electron densities inferred from ground-based ionosonde measurements during low solar activity. J. Atmosph. Solar Terr. Phys. 97, 58–64. http://dx.doi.org/10.1016/j.jastp.2013.02.010.

Adeniyi, J.O., Adebesin, B.O, Adimula, I.A., Oladipo, O.A., Olawepo, A.O., Ikubanni, S.O., Reinisch, B.W., 2014a. Comparison between African Equatorial Station Ground-based inferred vertical E × B drift, Jicamarca direct measured drift, and IRI model. Adv. Space Res. http://dx.doi.org/10.1016/j.asr.2014.06.014.

Adeniyi, J.O., Adimula, I.A., Adebesin, B.O., Reinisch, B.W., Oladipo, O.A., Olawepo, A.O., Yumoto, K., 2014b. Quantifying the EEJ current with Ground-based ionosonde inferred vertical E × B drifts in the morning hours over Ilorin, West Africa. Acta Geophys. 62 (3), 656–678. http://dx.doi.org/10.2478/s11600-014-0202-0.

Anderson, D.N., Mendillo, M., 1983. Ionospheric conditions affecting the evolution of equatorial plasma depletion. Geophys. Res. Lett. 10, 541–544.

Anderson D.N., Anghel, A., Yumoto, K., Ishitsuka, M., Kudeki, E., 2002. Estimating Daytime, vertical E × B drift velocities in the Equatorial F-region using Ground-based Magnetometer Observations, GRL, vol. 29, No. 12, http://dx.doi.org/10.1029/2001GL014562.

Ambili, K.M., St. Maurice, J.P., Choudhary, R.K., 2012. On the sunrise oscillation of the F region in the equatorial ionosphere. Geophys. Res. Lett. 39, L16102. http://dx.doi.org/10.1029/2012GL052 876.

Bertoni, F., Batista, I.S., Abdu, M.A., Reinisch, B.W., Kherani, E.A., 2006. A comparison of Ionospheric vertical drift velocities measured by Digisonde and Incoherent Scater Radar at the magnetic equator. J. Atmosph. Solar Terr. Phys. 68 (6), 669–678. http://dx.doi.org/10.1016/j.jastp.2006.01.002.

Buonsanto, M.J., Witasse, O.G., 1999. An updated climatology of thermospheric neutral winds and F-region ion drifts above Millstone Hill. J. Geophy. Res. 104, 24675–24687. http://dx.doi.org/10.1029/1999JA900345.

Bittencourt, J.A., Abdu, M.A., 1981. A theoretical comparison between apparent and real vertical ionization drift velocities in the equatorial F-region. J. Geophys. Res. 86, 2451–2454.

Cosgrove, R., 2013. Mechanisms for E–F coupling and their manifestation. J. Atmosph. Solar-Terr. Phys., http://dx.doi.org/10.1016/j.jastp.2013.03.011 (in press).

Eccles, J.V., 1998. A modelling investigation of the evening prereversal enhancement of the zonal electric field in the equatorial ionosphere. J. Geophys. Res. 103, 26709–26719.

Farley, D.T., Bonelli, E., Fejer, B.G., Larsen, M.F., 1986. The prereversal enhancement of the zonal electric field in the equatorial ionosphere. J. Geophys. Res. 91 (A12), 13723–13728.

Fejer, B.G., Jesen, J.W., Su, S., 2008. Quiet time equatorial F-region vertical plasma drift model derived from ROCSAT-1 observations. J. Geophys. Res. 113, A05304. http://dx.doi.org/10.1029/2007JA012801.

Haerendel, G., Eccles, J.V., 1992. The role of the equatorial electrojet in the evening ionosphere. J. Geophys. Res. 97, 1181–1197.

Lühr, H., Rother, M., Häusler, K., Alken, P., Maus, S., 2008. The influence of non-migrating tides on the longitudinal variation of the equatorial electrojet. J. Geophys. Res. 113 (A08313). http://dx.doi.org/10.1029/2008JA013064.

Oyekola, O.S., Kolawole, L.B., 2010. Equatorial vertical E × B drift velocities inferred from ionosonde measurements over Ouagadougou and the IRI-2007 vertical ion drift model. Adv. Space Res. 46 (5), 604–612.

Richards, P.G., 2011. Reexamination of ionospheric photochemistry. J. Geophys. Res. 116, AO8307. http://dx.doi.org/10.1029/2011JA016613.

Risbeth, H., 1981. The F-region dynamo. J. Atmos. Terr. Phys. 43, 387–392.

Santos, A.M., Abdu, M.A., Sobral, J.H.A., Mascarenhas, M., Nogueira, P.A.B., 2013. Equatorial evening prereversal vertical drift dependence on solar EUV flux and F10.7 index during quiet and disturbed periods over Brazil. J. Geophys. Res.: Space Phys. 118, 1–10. http://dx.doi.org/10.1002/jgra.50438, 2013.

Scherliess, L., Fejer, B.G., 1999. Radar and satellite global equatorial F-region vertical drift model. J. Geophys. Res. 104, 6829–6842.

Sreeja, V., Devasia, C.V., Ravindran, Sudha, Pant, Tarun Kumar, 2009. Observational evidence for the plausible linkage of Equatorial Electrojet (EEJ) electric field variations with the post sunset F-region electrodynamics. Ann. Geophys. 27, 4229–4238.

Sumod, S.G., Pant, T.K., Nayar, S.R.P., 2012. On the variability of the observed HF Doppler derived equatorial F-region plasma drifts during evening and morning hours and the chemical corrections therein. Indian J. Radio Space Phys. 41, 130–140.

Woodman, R.F., 1970. Vertical drift velocities and east-west electric fields at the magnetic equator. J. Geophys. Res. 75, 6249–6259.