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Height gradient of F region vertical drift in the evening equatorial ionosphere

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Abstract. Simultaneous measurements of F-region vertical drift are made in the evening hours (1700-2100 IST) at Trivandrum (dip 0.6°N) and Kodaikanal (dip 4°N) on fifteen days during December 1993- January 1994 using the HF phase path technique on two different probing frequencies. The data are used to study the height dependence of vertical plasma drift in the bottomside F-region in the dusk sector after correcting the drifts (at Kodaikanal) for meridional wind effects and chemical loss. It is found that growth and decay of a positive height gradient in vertical drift occurs fairly regularly in the dusk period. On the average the vertical velocity gradient is positive in in the interval 1815-1925 IST and is preceded by negative values. The positive height gradient of vertical plasma drift below the F layer peak is interpreted in terms of altitude dependence of the relative contributions of E and F region dynamos to the electric fields responsible for plasma drifts (vertical and zonal) of the dusktime equatorial F-region. These results are for winter solstice solar minimum conditions.

Introduction

Extensive measurements of zonal and vertical drift of equatorial F region have been made at Jicamarca (dip 2°N), Peru with the incoherent scatter radar over the past two-and-half decades. These have helped establish the diurnal cycle of F-region plasma drifts and gain a picture of the changes in it from day-to-day, with season and level of solar and geomagnetic activity [see Fejer, 1991 and references therein]. Plasma drifts are also derived in recent times from ground based HF techniques like ionosonde and phase path sounder [e.g. Batista et al, 1986; Balan et al, 1992; Subbarao and Krishnamurthy, 1994; Sastri et al, 1994] and satellite measurements of vector electric field and ion drifts [e.g. Coley and Heelis, 1989]. Several theoretical and numerical models are developed to explain the F-region drifts in terms of electric fields generated by E and/or F-region dynamos [see Crain et al, 1993 a,b and references therein].

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The early observations at Jicamerca showed the F-region vertical plasma drift, V_z to be essentially height independent near the F-region peak and above [Woodman, 1970; MeClure and Petersen, 1972]. Murphy and Heelis [1986] pointed out that height gradients are to prevail in the plasma drifts to be consistent with a curl-free electric field. The curl-free nature of the low latitude electric field is verified from simultaneous measurements of zonal and vertical drifts at Jicamarca as well as with instrumentation aboard DE-2 satellie [Pingree and Fejer, 1987; Coley and Heelis, 1989]. The height gradient of vertical drift at Jicamarca is, on the average, small (< 0.025m/sec/km) and negative in the afternoon and evening hours and positive during late night and morning periods. Subbarao and Krishnamurthy [1994] also reported the presence of a negative height gradient in the dusk period at Trivandrum on one day. These measurements which are extremely limited are further confined to equinoxes. The seasonal pattern (if any) in the height gradient of F region vertical drift is not known. Moreover, the height dependence of vertical drift in the bottomside F region is obscure as the radar measurements at Jicamarca typically cover the altitude region around and above the F peak. Against this background, we present here the first results on the altitude gradients of F-region vertical drift below F peak during the evening hours of winter solstice in the Indian dip equatorial region using the HF phase path technique.

Measurement Technique

HF pulsed phase path (Doppler) sounders are operated at Trivandrum (8.5°N, 77°E; dip 0.6°N) and Kodaikanal (10.25°N, 77.5°E; dip 4°N) to provide continuous information on the time rate of change of phase path (Doppler frequency shift) of reflections from discrete ionospheric regions at normal incidence [Balan et al, 1982; Sastri et al, 1985]. The basic design features of the two systems are the same and they differ, in their present configurations, only in the mode of data acquisition. The sounder consists of a broadband pulse transmitter, phase coherent receiver (s) with quadrature detection, a frequency synthesizer, timing and logic circuitry and analog/digital recording facilities. The system is rendered phase-coherent by generating all the signals required for the transmitter and the receiver from a single crystal oscillator with a frequency stability of better than one part in 10^7. The transmitter radiates pulsed rf energy (pulse width 100 μ sec; pulse repetition rate 50 Hz; peak power 3 Kw) on any chosen frequency in the band 2-20 MHz. In the receiver the phase of the ionospheric echo is compared at the intermediate frequency (IF) with two reference signals in phase quadrature (derived from the frequency synthesiser unit) in two separate phase detectors. The output of the two phase detectors are seperately amplified and band-limited using low-pass filters. At Kodaikanal, the quadrature channels outputs (A cos ϕ, A Sin ϕ) of the receiver are used in a logic scheme to provide analog data on the sense and magnitude of the changes in phase path with a time resolution of 6 sec. At Trivandrum, the quadrature outputs of the receiver are recorded in the digital mode, and the Doppler frequency shift is computed from FFT of the digital data. The group height resolution is 1.5 km. The operating frequency is 4 MHz (5.5 MHz) at Kodaikanal (Trivandrum).

Observations and Discussion

The present study is based on simultaneous and continuous measurements of F region vertical drift, V_z in the evening hours (1700 - 2100 IST) at Trivandrum and Kodaikanal on fifteen days during December 1993-January 1994. The data correspond essentially to quiet to moderately disturbed geomagnetic conditions (A_p <21 on 13 out of the 15 days) at an epoch of low to moderate solar activity (81< $F10.7$ < 122 units) and under non-spread F conditions. The time rate of change of phase path, $\Delta P/\Delta t$ of F region echoes during the evening hours is primarily a measure of vertical plasma motion near the reflection level because the contribution of electron density changes below the reflection level is negligible at such times. The vertical plasma drift, V_z is then 0.5 $\Delta P/\Delta t$ which, at and near the dip equator, represents the combined effect of electromagnetic EXB drift and an apparent upward drift due to chemical loss. The later is estimated to be negligible in the evening period if the height of reflection is > 300 km [Bittencourt and Abdu, 1981]. This condition is met on almost all the days at Trivandrum, while at Kodaikanal it was not met on some days. This necessitated the application of corrections to V_z for layer decay due to chemcial loss (apparent vertical drift, V_β due to chmical loss = β L where β is the loss coefficient and L is the electron density scale length) following standard procedure [see for example, Sastri et al, 1992]. For each day, V_z is calculated at 1 minute intervals and the values are smoothed with a running mean filter of 55 minute width to suppress the short-period (< 1 hr) fluctuations, which prevail quite commonly in F-region V_z near the dip equator during the evening hours, and which are believed to be due to zonal electric field variations associated with atmospheric gravity waves at E/F region heights [e.g. Nair et al, 1992; Subbarao and Krishnamurthy, 1994]. This procedure yields the steady vertical drift pattern at the two stations.

The F-region vertical velocity due to zonal electric field of a given amplitude is to be essentially the same at Trivandrum and Kodaikanal in view of their proximity to each other and the dip equator (the ratio of velocity at Kodaikanal to that at Trivandrum is 0.9981). Thermospheric meridional neutral winds could however affect the F layer vertical drift preferentially at Kodaikanal(dip 4°N) in view of the larger dip angle at the location. As such the vertical drift data of Kodaikanal must also be corrected for meridional wind effects to derive those due to zonal electric fields alone. We do not have any direct measurements of meridional neutral winds(using the optical Fabry-Perot Interferometer technique) in the Indian region for the days of our plasma drift observations. We have, therefore, relied on the emperical HWM87 model of Hedin et al [1988] for correcting the drift measurements at Kodaikanal for meridional wind effects. The poleward neutral wind predicted by HWM87 steadily decreases in amplitude with time in the evening period for the geophysical conditions relevant to our measurements. The magnitude of neutral wind is in the range 25-56 m/sec, and its effect on V_z at Kodaikanal is in the range 1.5-3.5 m/sec. Measurement of vertical drift at Trivandrum and Kodaikanal on 5.5 MHz and 4.0 MHz respectively, with application of corrections for meridional wind effects and chemical loss (when the reflection height is < 300 km) thus amounts to multi-height probing of the bottomside F-region at a single location, for the determination of the height gradient of F-region electromagnetic vertical drift. This is the rationale of the present work.

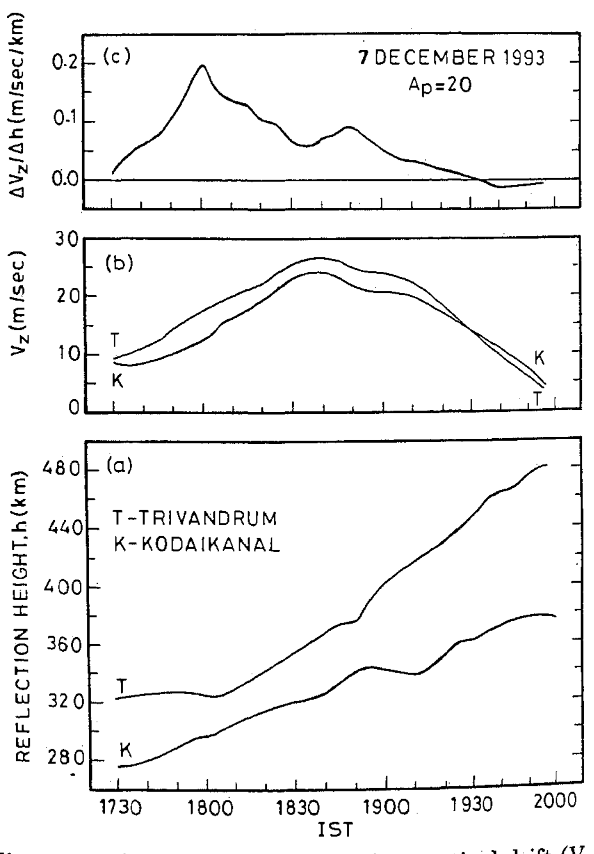

Figure 1. Time variation of F region vertical drift (V_z) and reflection height (h) at Trivandrum and Kodaikanal in the evening hours on 17 December 1993. Top panel shows the time variation of the height gradient of vertical drift. Note the growth and decay of positive height gradient in vertical drift in the evening hours.

The temporal pattern of F region V_z is found to be more or less the same at Trivandrum and Kodaikanal on all the days as is to be expected, namely, an enhancement and decay of upward drift in the dusk period, followed by the reversal to downward direction around 2000 IST. But the magnitude of drift is different (sometimes significantly) at the two stations on all the days testifying to the presence of height gradients in vertical drift. The height gradient is evaluated from the difference in the group height of reflection at the two operating frequencies. The use of group height instead of true height is not expected to introduce any significant error in the estimate of height gradients because what is taken is not the absolute value of the reflection height but the difference in heights. In our data sample, the difference in group height varies from 20km to 103 km with 95 per cent of the values in the range 30-103km (85 per cent in the range 30-80 km). It is also ascertained that the probing frequency is well below the critical frequency of the layer (by 2 MHz and more) at the individual stations during the observations.

The height gradient of F region V_z thus derived is found to a strong function of local time so as to attain in general positive values around the time of the evening enhancement in ambient upward drift. This can be seen from Figure 1 wherein the temporal variation of V_z and reflection height in the evening hours at Trivandrum and Kodaikanal on 7 December 1993 are shown. That the upward velocity at Trivandrum is higher than that at Kodaikanal throughout the dusk period is quite evident. As can be seen from the top panel of Figure 1, the height gradient of V_z which is positive at 1730 IST increased up to a maximum value of$\approx$ 0.20 m/sec/km by 1800 IST and decayed more or less steadily thereafter reaching very low values around the time (2000 IST) of downward reversal of drift. The growth and decay of the positive height gradient in vertical plasma motion illustrated in Figure 1 is more or less a regular feature noticed in our winter data. This can be seen from the mass plot of the temporal profile of the height gradient on the fifteen days presented in Figure 2. The height gradient is, on the average, positive in the time interval 1815-1925 IST (maximum value 0.068 m/sec/km) and is negative or very small outside this interval. It is appropriate to mention here that sunset at the conjugate E regions corresponding to F region(300 km) over Trivandrum occurs during the period 1745-1820 IST in local winter months. The magnitude of the gradient exhibits considerable day-to-day variability at any given local time. In our data sample, the gradient ranges from -0.24 m/sec/km to +0.22 m/sec/km in the interval 1730-2030 IST as can be seen in Figure 2.

The fixed frequency measurements of F-region vertical drift reported here do not correspond to any particular height but to the reflection level which varies with local time and from day-to-day at a given local time. The evening pattern of the height gradient of V_z (Figure 2) therefore suggests an altitude dependence of the velocity gradient as well. But it is difficult to entangle the height and time dependencies of the velocity gradient in our data because of their very nature. In this respect the incoherent scatter radar measurements of plasma drifts are advantageous as they provide the altitude profile of V_z as a function of local time.

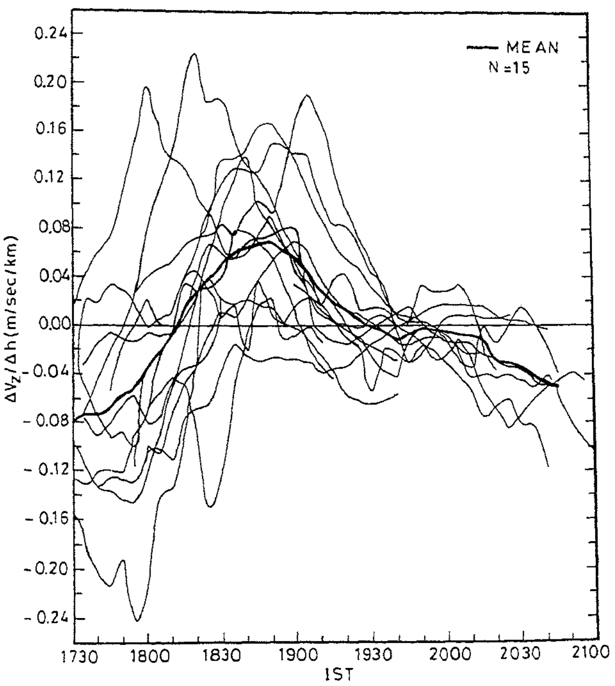

Figure 2. Mass plot of the time variation of height gradient of F-region vertical drift (V_z) in the evening hours. The average pattern is shown by the thick line.

Though the positive velocity gradient reported here seems to be at variance with the earlier radar measurements at Jicamarca during the equinox, a closer scurtiny shows that it is not totally inconsistent. For example, the height profile of dusktime (1912-24 hrs) vertical drift at Jicamarca presented by McClure and Petersen [1972] indeed shows a slight increase of vertical drift with height below about 400 km and a steeper decrease above 400 km (see Figure 2 of their paper). The subsequent improved measurements reported by Pingree and Fejer [1987] also show the occasional presence of a positive gradient in the dusksector (see Figure 3 of their paper). It is pertinent to add here that the positive height gradient in F region vertical drift evidenced in the present study provides a logical explanation for our very recent observation that the postsunset peak in F region vertical drift at Kodaikanal(based on measurements on 4 MHz) is lower than that at Trivandrum (based on measurements on 5.5 MHz) for the same season and epoch of the solar cycle [Sastri et al, 1994].

The vertical and zonal drifts of equatorial F region plasma are due to electric fields generated by the dynamo action of tidal winds in E region and thermospheric winds in F region. During the day the electric fields are determined primarily by the tidal E region dynamo because the fields due to F region dynamo are largely shorted out by the highly conducting E region. Beginning at sunset, the control of the electrodynamics passes from the E region to the F region due to the significant decrease in E region conductivity that allows the development of polarization electric fields of the F region dynamo. The numerical modelling studies have, in fact, highlighted the importance of the F-region dynamo to the F region plasma motions at night, in particular to the postsunset enhancement of the upward vertical drift near the dip equator [e.g. Crain et al, 1993 a,b].

The relative role of E and F region dynamos in generating electric fields depends on altitude. Around the F layer peak and above (about 400 km and higher) most of the conductivity is located in the F region and the polarization fields (vertical and zonal) due to F region dynamo contribute most to the zonal and vertical plasma drifts. As the altitude decreases, the E region dynamo begins to gain in importance and may become dominant at lower altitudes (around 300 km). The net result of this altitude dependence of E and F-region dynamo fields is the dusk time development of vertical shear in zonal plasma drift with eastward drift at and above F peak and westward drift well below the peak, which is widely observed [e.g. Fejer et al, 1985; Aggson et al, 1987] and adequately modeled [e.g. Crain et al, 1993b]. We believe that the dusktime development and decay of positive height gradient in vertical plasma drift in the lower F region reported here is another signature of this physical situation. The relative importance of F region dynamo to the E region dynamo increases with altitude in the lower F-region and since the polarisation electric fields of E region dynamo are weaker those of F region dynamo, a positive gradient in vertical plasma drift has to develop in the lower F region. The large variability of the height gradient (Figure 2) is not very surprising since the electrical coupling of E and F regions in the evening quadrant depends on several highly variable factors like the altitude(or latitude) profiles of plasma density and wind systems in the two regions.

We do not have zonal plasma drift measurements at either of the two stations, simultaneous with those of vertical drift to substantiate the simple and qualitative explanation given. The earlier observations of Balan et al [1992], however, clearly show that at Trivandrum, the evening reversal of zonal plasma drift from westward to eastward occurs 2-3 hrs later in the lower F-region than that seen at Jicamarca at F-region peak and above. This is what is to be expected inview of the increase in importance of E region dynamo over F region dynamo with decrease in altitude below the F peak. To conclude, we advance the view that the positive dependence of the vertical plasma drift in the equatorial lower F-region around the time of the sunset increase of upward drift is an additional facet integral to the complex electrodynamics of the dusktime equatorial ionosphere.

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