CHAPTER V

FLUCTUATIONS IN THE VERTICAL DRIFTS IN THE POST SUNSET EQUATORIAL F-REGION DURING MAGNETICALLY QUIET AND DISTURBED PERIODS

5.1 Introduction

Ionosphere is a dynamical system, in which its different layers exhibit drift motions. The ionospheric plasma drifts and electric fields at equatorial/low latitude region are controlled by the complex E and F-region electrodynamical processes. Since the electron density distribution over the entire low latitude region is controlled by the F-region plasma drift over the dip equator, it is important to understand the electrodynamics of this region in detail. Due to the high electrical conductivity of the equatorial ionosphere, the electric field variations near the magnetic equator are very sensitive to the changes in the electric field imposed on it and any change in the electric field of the equatorial ionosphere will have an immediate effect on the plasma drift in the ionosphere (Nayar et al., 1993; Rastogi and Patel 1975; Rastogi and Krochel, 1978).

Extensive studies on the equatorial ionospheric drifts and electric fields have been conducted using Jicamarca Incoherent Scatter Radar in Peru (Woodman, 1970; Fejer et al., 1979, 1985, 1991) and from radio measurements over India (Ramesh and Sastri, 1995; Subbarao and Murthy, 1994) and Brazil (Batista et al., 1986). A global empirical model of the equatorial vertical plasma drift velocity was developed from radar and satellite measurements (Scherliess and Fejer, 1999). National Centre for Atmospheric Research’s (NCAR’s) Thermosphere-Ionosphere-Electrodynamic
General Circulation Model (TIEGCM) successfully simulated the local time, seasonal and solar cycle dependence of the quiet time F-region plasma drifts measured at Jicamarca (Fesen et al., 2000). Satellites like AE-E used to examine the vertical drifts in detail. AE-E data from January 1977 to December 1979 was used by Fejer et al. (1995) to examine the solar cycle, seasonal and longitudinal dependence of the equatorial vertical plasma drift. They have pointed out that the satellite observation of the daytime upward drift is about 20 ms$^{-1}$ and is in good agreement with the radar data, particularly during equinox and winter solstice. But the nighttime downward drift observed by the satellite is usually smaller than that of the radar results, particularly during summer solstice. Equatorial vertical drifts obtained by vector electric field measurements onboard the San Marco satellite during the moderate solar activity period of April - August 1988 are generally consistent with AE-E and Jicamarca drifts (Maynard et al., 1995).

The F region vertical drift velocity is found to have a typical pattern (Figure 5.1) around the sunset period. The motion of the equatorial ionosphere due to the E x B drift is generally upward during daytime and downward during nighttime. The vertical drift reaches a maximum upward value, known as the pre-reversal enhancement (PRE) after the sunset. Following this maximum, the plasma drift slowly decreases, becomes zero and then reverses its direction and in general remains downward.

![F-region Vertical Velocity Profile of 2004 November 06 at 3.5MHz](image)

**Figure 5.1:** Typical evening vertical drift pattern showing PRE
5.2 Pre-Reversal Enhancement in Plasma drift (PRE)

The pre-reversal enhancement is a regular feature observed in the global equatorial F-region vertical plasma drift in the evening time. The daytime upward plasma drift and its reversal after sunset are caused by the eastward and westward electric fields respectively. The daytime equatorial F-layer ionization moves upward due to $E \times B$ drift arising from the E-region dynamo-induced eastward electric field that gets reversed at night, causing a reversal in the plasma drift. If the underlying E-region is sunlit and sufficiently conducting, it will short-circuit the F-region polarization field and current continuity will be assured by a flow of field-aligned current between the E- and F-regions. At night when the E-region conductivity is small, the short-circuiting effect disappears and a polarization field builds up. Kelley (1989) and Fejer et al. (1991) have mentioned that during the daytime, the F-region winds are reduced by the conductivity of the E-region but are important at night. After sunset, E-region dynamo action will decrease. Though mainly vertical during the night, the F-region polarization field has east-west components near the sunset and sunrise terminators, where the current geometry is strongly influenced by the rapid changes in E-region electron density. This east-west component gives rise to vertical drift. At the equatorial latitudes, any change in the east-west electric field is reflected in the vertical drift driven by the $E \times B$ mechanism. So the upward daytime vertical drift also shows a rapid enhancement (PRE), caused by the build-up of F-region polarization electric field (Rishbeth, 1971). The exact mechanism for the post sunset F-layer uplift i.e. whether it is due to the F-region dynamo electric fields getting freed from the field line E-region loading effect (Farley et al., 1986) or due to the irrotational nature of the electric field at the sunset terminator manifesting itself as an enhanced zonal wind (Rishbeth, 1981) or due to the evening EEJ (Haerendel and Eccles, 1992) is still not fully understood. Recently, Kelley et al., (2009) considered the above three competing mechanisms that exist for the PRE, in the light of the penetration of a large electric field of interplanetary origin. Their study suggests that the normal PRE must be created by the Haerendel and Eccles (1992) mechanism, in which the EEJ partially closes in the post sunset F-region, and that the other two mechanisms are secondary.
Namboothiri et al. (1989) have shown that the average peak vertical drift is higher in equinox compared to that during winter and summer months using HF Doppler Radar. Also the equinoctial peak in pre-reversal enhancement is found to decrease with the decrease in 10.7cm solar radio flux value. The plasma drift drops by more than a factor of 2 as the magnetic activity changes from quiet to moderate condition, and increases well above the quiet day value for high activity. During equinox, the pre-reversal enhancement peak is found to depend on the solar activity for both magnetically quite and disturbed conditions. Balachandran Nair et al. (1993) have studied monthly average of pre-reversal enhancement, time of occurrence of maximum value and time of its reversal. They found that the maximum plasma drift value fall off during summer and winter month and the time of occurrence of maximum vertical velocity and reversal time do not have much of a dependence on season. Fejer et al. (1991) determined the seasonal averages of the equatorial F region vertical drifts from Jicamarca during 1968-1988. They found that the evening pre-reversal enhancement of vertical plasma drifts increases linearly with solar flux during equinox but tends to saturate for large fluxes during winter.

There are different theoretical suggestions have been put forward, to explain the observed pre-reversal enhancement in zonal electric field (Farley et al., 1986; Haerendel and Eccles, 1992; Crain et al., 1993b). Eccles (1998b) pointed that these may be only the supporting mechanisms and the basic physical thrust for the pre-reversal enhancement comes from the curl-free nature of F-region vertical electric field as proposed by Rishbeth (Rishbeth, 1971). In this context, Fesen et al. (2000) remarked that the pre-reversal enhancement remains poorly understood theoretically. So, experimental investigation during the sunset period is necessary to understand the electric field behaviour that governs the pre-reversal enhancement.

The following give an explanation understand PRE based on F-region dynamo which was first given by Farley et al. (1986) after a modeling study, which was developed using the concepts of Heelis et al. (1974). The thermospheric neutral wind (U) at altitudes of the equatorial F-region blows eastward, especially after noon time. The eastward motion of neutral particles causes only ions to drift upward by collision; the vertically downward electric field produced by the charge separation is projected onto the E-region through magnetic field lines having high electric conductivity.
However, during daytime, since the F-region dynamo is a constant current source with high internal resistance, it is readily short-circuited by the E-region with high Pedersen conductivity. Hence there will be no prominent F-region dynamo during daytime. Around sunset, conductivity is reduced by the decrease in E-region electron density, causing the growth of a downward electric field in the F region. The $E \times B$ drift induced by this electric field has the same direction as thermospheric winds. The electric field created by the F-region dynamo effect maps to the magnetically conjugate E-region points along the sunset terminator. The E-region electron density drops suddenly to a very low value at sunset, only negligibly small currents can flow on the night side, and so the net zonal current on the dayside of the terminator must be negligibly small also. To nullify the current divergence, a negative charge accumulation takes place along the sunset terminator and thereby an eastward field will be developed on the dayside and westward field on the nightside. Projected back onto the F region, the resulting electric field ($E_p$) is eastward and westward to the west and east of the sunset terminator respectively. In other words, the eastward electric field is intensified immediately before the reversal to westward, hence producing a pre-reversal enhancement in vertical drift. These phenomena are illustrated in a simple diagram (Figure 5.2)

![Figure 5.2: PRE of ionospheric electric field as explained by Farley et al. (1986)](image)

5.3 Periodic fluctuations in Vertical plasma drift

As is known, over the dip equator, upward propagating tides lead to the generation of a global electric field and through the E-region dynamo. Recent studies have shown that upward propagating tides modulate the E-region dynamo electric
field and hence the vertical F-region plasma drifts over the dip equator (Abdu and Ramkumar 2006; Immel et al. 2006). Therefore, the formation of the dynamo electric field is controlled by the variability of upward propagating tides. In contrast, the tides themselves are also known to be modulated by the gravity waves and planetary waves of different periodicities. In fact, the equatorial electric fields and currents found to exhibit fluctuations with quasi periods ranging from a few minutes to few tens of minutes. A detailed description of such short period fluctuations in the ionospheric wind dynamo system was given by Richmond (1995). The quasi-periodic variations with periods of 5 to 60 minutes are believed to be due to zonal electric field perturbations associated with atmospheric gravity waves (Nair et al., 1992). The longer period (> 4 hours) quiet-time perturbations and irregular day-to-day variations are generally associated with the variability of tidal forcing and the planetary wave activity (Richmond 1995). Reddy and Devasia (1976) have reported short-period fluctuations of ~ 25 minutes periodicity in the equatorial electrojet (as inferred from the magnetic field measurements at surface) during geomagnetically quiet periods.

Apart from those generated in the lower atmosphere, the ionosphere can support a variety of waves which are generated by different sources. One such source is the auroral zone, which can produce waves in connection with the interplanetary disturbances and geomagnetic storms (Altadill et al., 2001). During magnetically disturbed periods, significant perturbations occur over the higher latitude ionosphere. The fluctuations in the electric fields over equatorial F-region during such conditions are thought to be due to the perturbation of the interplanetary electric field which penetrates into the low latitude ionosphere (Patel and Pablo Lagos, 1985; Earle and Kelley, 1987; Nayar et al., 1993). Another source is the solar terminators at sunrise and sunset which can produce waves associated with differential heating of the sunlit and sunset regions Galushko (1998). Similarly, a wide spectrum of gravity waves can be produced during solar eclipses (Chimonas and Hines, 1970; Altadill et al., 2001). It has been found that short period fluctuations in the range 5 - 33 minutes are very common over the equatorial ionosphere (Sastri, 1995).

Namboothiri et al., (1989) have shown that the vertical velocity had quasi-periodic fluctuations superposed on the gross pattern. Studies have shown the presence of periodicities below 50 minutes in the vertical drift (Subbarao and Krishna
5.4 Short period fluctuations in Plasma drift during quiet and disturbed periods

In the present work, the vertical drift measurements using HF radar, geomagnetic field at surface at the equatorial region and the Interplanetary Magnetic Field have been analyzed to characterize the nature of oscillations present in these parameters on both during quiet and disturbed periods. The motivation behind extending the analysis during quiet days is the short-period fluctuations in electrojet reported by Reddy and Devasia. (1976).

5.4.1 Data and Method of Analysis

The HF Doppler Radar system developed at the University of Kerala, Trivandrum, India is used for measuring vertical drift ($V_d$) in the equatorial F-region. The system has been operated at frequency 3.5 MHz to probe the bottom side of the F-region during the evening hours. In the present study, the data during the years 2004 and 2005 have been used to investigate the nature of short period fluctuations in vertical drift during both quiet and disturbed geomagnetic conditions. It has been observed that, in general, the $V_d$ exhibits significant oscillations in its temporal variation and also exhibits large day-to-day variability. In order to quantify these periodicities, the data have been subjected to wavelet analysis (Torrence and Compo, 1998) and the power spectra are obtained. To study the relationship between the oscillations in the interplanetary medium and $V_d$, interplanetary planetary magnetic field obtained from ACE satellite during post sunset hours have been analyzed. The magnetic field values obtained from Indian Institute of Geomagnetism are also incorporated to analyze the equatorial magnetic field at surface. Here $\Delta H$ (TRV) -$\Delta H$ (ALB) is taken as a proxy of equatorial magnetic field and here after referred as $\Delta H$. 

Murthy. 1994; Balachandran Nair et al., 1992; Sastri 1995). Earle and Kelley (1987) have studied the fluctuating components below 10 h period. Medium scale gravity waves are considered as the source of these fluctuations. The drift velocity was found to show large fluctuations relative to quiet time values (Gonzales et al., 1979; Fejer, 1986).
5.4.2 Observations

In order to characterize the nature of the oscillations present in equatorial magnetic field $\Delta H$, vertical drift ($V_d$) and in the Interplanetary Magnetic Field north-south component (IMF $B_z$), the time evolution of these parameters during evening hours for 3 quiet days ($Ap \leq 19$) and 3 disturbed days (of $Ap$ indices 50, 140 and 119) during the year 2004 have been analyzed. Figure 5.3 shows the time variation of the IMF $B_z$ (top panel), $\Delta H$ (middle panel) and $V_d$ (bottom panel) for three quiet days i.e. January 11, February 24 and November 06, 2004 respectively. It is clear from the figure that the parameters do not exhibit significant changes during these days. IMF $B_z$ is more or less steady during the time interval considered and varies between $\pm 5$ nT. The $V_d$ on February 24 and November 06 exhibit the signatures of pre-reversal enhancement (PRE) and shows short period oscillations. In order to find out the nature of these oscillations, the parameters are subjected to wavelet analysis and the periodograms are depicted in Figure 5.4. It is clear from the figure that $V_d$ on all these days exhibit oscillations of periodicity 0.4 - 0.5 hours (24 - 30 minutes), which is more prominent on February 24. However, the amplitudes of the oscillations are very small during January 11 and November 06. These oscillations are believed to be due to the gravity waves, which are lower atmospheric in origin since they are totally absent in IMF $B_z$.

In other words it indicates that $V_d$ during quiet days are controlled mainly by the waves of lower atmospheric in origin. Among the days analyzed, February 24 and November 09, 2004 was equatorial spread F (ESF) with occurrence time 19:30 and 20:00 IST respectively. So the vertical drift measurements after that may not be correct and we are concentrating the periodicities till that time on such days.
Figure 5.3: Time variation of the IMF Bz (top panel), ΔH (middle panel) and Vd (bottom panel) for three quiet days during the year 2004.
For characterizing the behavior of $V_d$ during disturbed days, the variability of the aforesaid parameters during three disturbed days have been looked into and depicted in Figure 5.5. As is well known, the IMF Bz shows significant fluctuations on these days. On November 07, 2004 ($Ap = 50$) the IMF Bz varies between -20 and 20 nT whereas on November 08 ($Ap = 140$) it varies between -10 and +10 and during November 09 ($Ap = 119$) it fluctuates between -8 and 10 nT. The PRE is present on November 07, 2004 with peak values of about 40 m/s. But on November 08 and November 09 (recovery phase of the geomagnetic storm), PRE is absent or inhibited. However, compared to that of the quiet days, the fluctuations present in $V_d$ are amplified on the magnetically active days, with maximum amplitudes of $\sim 20$ m/s.
on November 07 and ~ 40 m/s on November 09. In order to bring out the nature of these oscillations the data has been subjected to the wavelet analysis and Figure 5.6 shows the periodograms for the disturbed days. It is clear from figure that the dominant period present in all the three parameters are those of 30 - 48 minutes (0.6 - 0.8 hours). The amplification of this periodicity in both the parameters is found to be nearly simultaneous. It is interesting to note that the short period oscillation of 12 - 18 minutes as seen during the quiet days are totally absent on these disturbed days.

Figure 5.5: Same as Figure 5.3 but for three disturbed days.
Figure 5.6: Same as Figure 5.4 but for three disturbed days.

In order to check the consistency of this behavior, the IMF Bz, ΔH and Vd during the year 2005 have also been analyzed. It has been observed that the same observation holds good in the year 2005 too. Figure 5.7 shows the time variation of the IMF Bz (top panel), ΔH (middle panel) and Vd (bottom panel) for the two quiet days, January 10, 2005 and February 11, 2005 respectively. It is clear from the figure that IMF Bz does not vary significantly on these days. However a closer look reveals the presence of short scale fluctuations in Vd similar to the quiet days during the year 2004. The wavelet periodograms as depicted in Figure 5.8 shows the presence of short periods waves ranging from 0.2 to 0.4 in Vd and this is found to be absent in IMF Bz.
Figure 5.7: Time variation of the IMF Bz (top panel), ΔH (middle panel) and $V_d$ (bottom panel) for two quiet days during the year 2005.
Figure 5.8: Wavelet periodograms of IMF Bz (top panel), ΔH (middle panel) and Vd (bottom panel) for two quiet days during the year 2005.

This observation further confirms the lower atmospheric control of Vd during geomagnetically quiet periods. On the other hand, during disturbed days (January 17 and February 07) both the parameters (IMF Bz and Vd) exhibit significant variability as evident from Figure 5.9. On January 17, the IMF Bz shows large fluctuations, which varies between - 10 and + 30, whereas on February 07 it fluctuates between -10 and +10. The Vd also exhibits significant short-scale fluctuations during these days. The wavelet periodogram as shown in Figure 5.10 reveals that both IMF Bz and
V_d exhibit similar periodicities during disturbed days. In general, it is clear from these observations that the fluctuations in V_d during quiet periods are mainly controlled by the gravity wave activity while on disturbed days they are controlled by the oscillation in interplanetary medium. During the year 2005 also some days (February 11 and February 07) was spread with occurrence time from 20:00 from 19:30 IST respectively. So the drift measurements after the occurrence of ESF may be incorrect.

It is to be mentioned here that wavelet periodogram of equatorial magnetic field ∆H for all disturbed days also shows signatures of periodicity almost similar to the periodicity in V_d. (Refer Figure 5.6 and 5.10). But this is absent during quiet days except January 11 and February 24, 2004. This aspect will be discussed later. Since IMF B_z also shows significant periodicities during disturbed days the observed periodicity in ∆H is believed due to the solar wind influence of magnetospheric origin.

![Figure 5.9: Same as Figure 5.7 but for two disturbed days](image-url)
5.4.3 Discussion

(a) Observed periodicities in $V_d$ during quiet and disturbed days

Gravity waves (GWs) of lower atmospheric in origin plays a major role in controlling the day-to-day variability of the equatorial upper atmosphere/ionosphere region. These waves exert significant drag in the middle atmosphere, which in turn affects the winds and temperatures of the Mesosphere Lower Thermosphere region. Further they can modify the tidal structure in the upper mesosphere region. In an
earlier Fritts and Vincent (1987) proposed a simple model and using that they could show the modulation of tidal winds by gravity waves. They showed that the vertical divergence of the flux of horizontal momentum associated with the dissipating gravity waves (gravity-wave drag), acted to advance the phase fronts of the tide and decrease its amplitude. McLandress and Ward (1994) and Meyer (1999) used parameterizations based on the work of Lindzen (1981) to study the effect of gravity-wave drag on tidal amplitudes and found the parameterized gravity-wave drag acted to decrease the amplitude of the tide and advance the tidal phase. Further, Meyer (1999) showed the relative effects of parameterized gravity-wave drag and eddy diffusion on the amplitude of the diurnal tide using the Global Scale Wave Model (GSWM). (Hagan et al., 1999) demonstrated that vertical eddy diffusion significantly damps the amplitude of the diurnal tide. McLandress (1998) compared the effects of several different gravity wave parameterizations in the same mechanistic tidal model and found that the diurnal tidal amplitude could be either increased or decreased depending on the parameterization used, but all were found to advance the phase of the tide by varying amounts. However, most of the time these wave get dissipated below turbopause altitudes (~110 km) and therefore their presence at F-region altitudes could be explained through an indirect mechanism.

At ionospheric altitudes, the GWs can modify the integrated E region conductivities and thereby modulate the polarization electric field, which in turn will get reflected in the vertical plasma drift of the F region (Abdu et al., 2006; Pedatella and Forbes, 2009). In other words, once the tidal structure in the upper mesosphere region is modified due to the activity of GWs, it will affect the zonal electric field, since the tidal winds is the major driving force behind the generation of this field. The fluctuations in electric field can be communicated to the F-region electrodynamically to cause fluctuations in the vertical velocity. Therefore, on quiet days when the system is not perturbed due to the external forcing, it is believed that the GWs of lower atmospheric in origin play a major role in controlling both E and F region phenomenon.

When it comes to the disturbed days, the interplanetary fields play a prominent role in the transfer of energy from solar wind to the magnetosphere. The north-south component of IMF Bz is found to be controlling the transfer of energy carried by the
solar wind into the magnetosphere and there after into the lower atmosphere (Nishida, 1975; Kelley et al., 1979). This is happening mainly due to the influence of the variations in Interplanetary Electric field (IEF). Abrupt changes as well as quasi periodic fluctuations of the IEF known to correlate with the equatorial ionospheric electric field variations. They are called penetrating electric fields (Huang et al., 2005; Nicolls et al., 2007). In general, the eastward (westward) IEF is associated with southward (northward) IMF Bz. It has been established that during daytime the southward excursion of IMF Bz results in an increase in normal eastward electric field, while northward turning IMF Bz leads to a decrease of this eastward field up to its reversal. During nighttime, the northward (southward) IMF Bz induces an eastward electric (westward) field in the equatorial ionosphere. Therefore, the short scale fluctuations in the IMF Bz could very well modify the equatorial electric field.

The fluctuations in V_d up to 40 m/s are observed on the storm days, which are believed to be due to the magnetospheric effects. Similarly, the fluctuations present in the interplanetary field would get imprinted in the equatorial electric fields, which can be clearly noticed from the ∆H values. It has been shown earlier that short period fluctuations in the range of 33.5 minutes are the common features of V_d in the evening hours and the spectral component of 32 minute is always present in the power spectrum (Sastri, 1995). In the present case also, the periodicity observed is some what similar (30-40 minutes). On magnetically active days where the fluctuation in electric field is very high, it is believed that the gravity wave induced effect on the vertical drift would be masked by the electric fields fluctuations of magnetospheric origin. In brief, this study shows that the vertical plasma drift at equatorial F-region during quiet days are controlled mainly by the gravity waves of lower atmospheric in origin and the fluctuations observed on disturbed days are the effect of induced electric fields of magnetospheric origin.

(b) Influence of Auroral Electrojet on ∆H during quiet days

Looking at the Figure 5.4, it can be seen periodicities in ∆H ranging from 0.4-0.7 hours on January 11 and February 24, 2004 even though these days are considered as quiet according to Ap values. (For January 11 Ap=19 and for February 24 Ap=11). These periodicity is similar to the one observed in V_d. But IMF Bz doesn’t show any significant variation and periodicities. Analysis of AE index (a measure of the auroral
electrojet), reveals the same periodicity which is observed in $V_d$ (Refer Figure 5.11). This is believed due to the coupling from high latitude.

**Figure 5.11**: Auroral electrojet index (line plot and periodogram) for January 11 and February 24, 2004

### 5.4.4 Summary

This chapter discusses about the fluctuations/periodicities present in vertical drift at dip equatorial F-region during geomagnetically quiet and disturbed periods. The analysis based on the wavelet analysis clearly shows that the oscillations in vertical drift during quiet days over the dip equator are mainly driven by the gravity waves of lower atmospheric origin. On the other hand, during disturbed days the vertical drifts are controlled by the changes in inter planetary medium, through the coupled electric field. The result presented in the chapter is very important for better understanding the unique electrodynamical features of the equatorial ionosphere, especially in the generation of equatorial Spread F.