Seasonal variation of Velocity at Pre-reversal Enhancement(Vzp)and reflection height at Equatorial F-region

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***Abstract:* The** Seasonal variation of Velocity at Pre-reversal Enhancement and reflection height at Equatorial F-region during the year 2005-2006 has been studied using Ionosonde data. The variation of Vzp and the reflection height are almost similar

Index Terms - Equatorial ionosphere, F region dynamo, Velocity at Pre-reversal Enhancement(Vzp),

Introduction

A very important feature of the equatorial F region is its post- sunset height rise which is due to an enhanced electric field. The enhanced electric field itself is mainly a result of F region dynamo driven by thermospheric zonal winds resulting in polarization electric fields. These polarization fields are normally shorted out during day time by the conducting E region. However, in the post-sunset period because of the large reduction in the E region conductivity this shorting is not effective. This leads to an enhancement of the electric field. Farley et al.(1986) presented a model for the post sunset height rise of the equatorial F region based on the F region dynamo and showed a satisfactory agreement with the VHF radar observations at Jicamarca.

Experimental investigations on the post sun set height rise (or the vertical velocity) have been carried out using HF sounders such as ionosonde and incoherent scatter radars (Krishna Murthy and Rao, 1963; Fejer et al.1991).These experiments have provided a wealth of information especially on the seasonal and solar activity dependence. However, it is difficult to extract information on time variations (of the order of few minutes) from these experiments. This because the incoherent scatter technique generally involves signal integration of the order of 5 minutes (Fejer et al., 1991) and ionosondes are usually operated at 15 minutes intervals. Though the ionosonde in principle can be operated at shorter intervals of time or even continuously for h'-t recording at a single frequency, its utility for shorter period variation is very limited because the height variation cannot be determined better than ~ 3 km.

For the present study, ionosonde data of 15 minute resolution from Space Physics Laboratory, Trivandrum and multi frequency HF Doppler radar data from University of Kerala have been used.

Characteristics of Vertical plasma drift during evening hours

Most of the database regarding vertical drift comes from Jicamarca incoherent scatter radar [Woodman, 1970]. There are other stations in Brazil like Fortaleza, Cachoeira Paulista, etc. [Batista et al., 1986], in Philippines like Cebu island, Manila, etc. [Maruyama et al., 2002] and in India like Trivandrum [Balan et al., 1992]. The vertical drift of all these stations is reported to exhibit an enhancement during evening time called as Pre-reversal Enhancement (PRE) and is attributed to the enhancement of evening equatorial F-region zonal electric field. The Pre-reversal enhancement or post-sunset enhancement of the zonal electric field occurs during all epochs and seasons studied except for the solar minimum solstices. The effect of this brief duration large eastward electric field can be quite significant since the F-layer plasma often is driven to very high altitudes, where recombination is slight and collisions are rare.

Typical post-sunset vertical drift profile obtained from the multi-frequency HF Doppler radar on Mar. 03-04, 2004 ($K_p = 3$) as a result of single frequency sounding at 3.5 MHz is shown in Figure 1. The 30 min. running averaged vertical drift data observed by HF Doppler radar presented in the figure (full line) reveal the general behaviour of the plasma drift at equatorial F-region during the post-sunset period. The curve with circles represents the vertical drift values for Trivandrum obtained by using the global equatorial vertical drift model of Scherliess and Fejer, 1999 for the same day. The vertical plasma drift observed by HF Doppler radar exhibits deviations from the model calculation both during the pre-reversal and post-reversal periods. However, both the model calculation and observation exhibit the reversal of plasma drift direction at the same time. While the model calculation shows a peak vertical plasma drift value of 12 m/s, the observation show a value of 22 m/s around 1830 - 1900 hrs LT. Similarly, during the post-reversal period, the vertical plasma drift exhibits a variety of oscillations in addition to the deviation in the average values of plasma drifts.

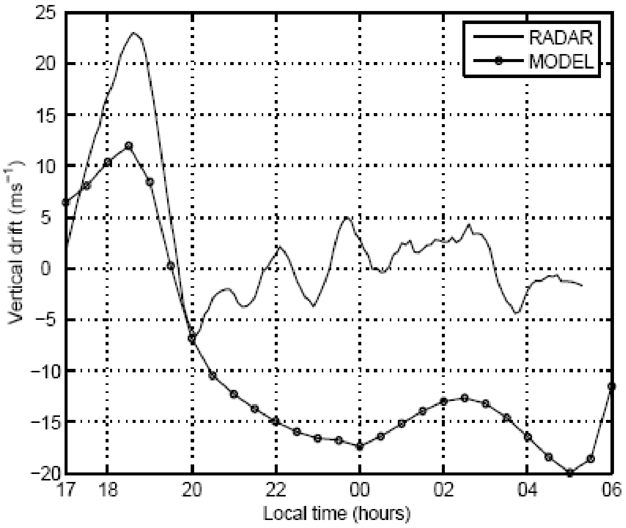

Figure 1: Vertical plasma drift profiles at equatorial F-region during post-sunset period on 03-04 March 2004 from HF Doppler radar (full line) and from global vertical drift model (line with bubbles).

The magnitude of the peak value of vertical plasma drift, the time of reversal of the drift and the nature of fluctuations in the plasma drift exhibit day-to-day variations depending on a number of controlling parameters including the interplanetary electric field. The fluctuations observed in the plasma drift pattern may be associated with gravity waves, TIDs or interplanetary electric field fluctuations at the magnetopause.

It is well accepted that the ionospheric electric fields have a dominant role on the low latitude electrodynamics. The electrojet [Baker and Martyn, 1953] and the associated plasma instabilities in the equatorial region are driven by west to east electric fields [Fejer and Kelley, 1980]. The upward motion of the equatorial F2 layer results from upward electromagnetic (E×B) drift caused by a west to east electric field generated in the E region.

In the equatorial region the thermospheric winds provide the source of energy that maintains the electric field. The winds are eastward and quite strong (~150 m/s) in the post sunset period, decaying in amplitude to less than 50 m/s after midnight [Meriwether *et al*., 1986].

The E-region dynamo fields are important during daytime while F-region dynamo fields are important during nighttime, especially near sunset. During the daytime, E-region dynamo is dominant because F region dynamo is short circuited due to the high conductivity of the E region. But after sunset, the conductivity of E-region reduces and F region dynamo can develop an appreciable electric field. One of the important features of evening behavior of F layer is the Pre reversal enhancement. This can be explained using the Dynamo theory. During the daytime the field is eastward and the E-region dynamo is strong while the F region dynamo is short-circuited. During the sunset the field gets reversed and the F-region dynamo comes in to action due to the poor conductivity of the E- region. As a result an upward drift of F layer is observed. In other words, PRE can be considered as the resultant of switching between the E region dynamo and the F region dynamo. The lower end of the PRE represents the decay of E layer that can also be considered as the building up of F layer. The F-region dynamo contribution is predominant during the time of maximum value of PRE (V_{zp}). After this the sounding station enters to night side hemisphere where the electric field is westward and accordingly the drift reverses its direction downwards.

Pre-Reversal Enhancement (PRE)

The equatorial ionosphere and the thermosphere constitute a coupled system whose phenomenology is controlled primarily by the electric field structure resulting from the interaction of the thermospheric wind, geomagnetic field, ionospheric plasma and gravity. The most observable effect of such coupled processes occurs at sunset when the rapid decay of field line integrated conductivity, into the night side, gives rise to an enhanced zonal (eastward) electric field arising from the F layer dynamo driven by thermospheric wind that blows eastward at these hours. This enhanced electric field, widely known as pre reversal enhancement electric field (PRE). The PRE development was originally modeled on the principles of electrical coupling between the E and F layers by Heelis et al. The basic relationship between the F region dynamo vertical electric field and the zonal electric field that constitute the PRE arises from a curl free requirement for electric field as proposed by Rishbeth.

Causes of the Pre reversal Enhancement

Over the two decades since Rishbeth (1971) proposed the importance of F region neutral wind dynamo in determining low-latitude electric fields, researchers have modeled F region dynamo effects in support of his thesis [*Heelis et al*., 1974; *Haerendel* *et al.*, 1992]. The clarity of Rishbeth's original explanation of the vertical polarization field's creation from diverge4nces in the F region dynamo current after sunset remains the fundamental example of the F region dynamo effects. However, the source of the evening prereversal enhancement (EPE) of the zonal electric field is still vague. There are three descriptions of the physics involved in the evening zonal field enhancement.

Mechanism 1: Divergence of Hall currents

At equatorial latitudes, both the geomagnetic field and the F-region zonal electric field are almost perpendicular to each other. This will generate a vertical drift through the E×B mechanism. In the equatorial ionosphere where the intensity of earth's magnetic field varies significantly with longitude, an electric field of 1 mV/m corresponds to an F-region E×B plasma drift of about 30-40 m/s. The enhancement of zonal electric field in the evening provides peculiar electrodynamics situation in the equatorial ionosphere. Heelis et al. (1974) successfully predicted the post sunset effect in their model, which included horizontal conductivity gradients near sunset in the F-layer dynamo mechanism. In effect, near such a sharp east-west gradient, an enhanced zonal electric field is established to keep $\nabla.\mathbf{J} = 0$. Experimental data support this explanation since the enhancement begins when the sun sets on either of the E-layers in contact along **B** with the equatorial F-region.

Farley et al. (1986) completely suppressed the E-region dynamo although the E-region conductivity and its loading effect on the F-region electrodynamics were retained. They then injected a uniform 200 m/s eastward wind everywhere and this model could successfully reproduce the PRE as an F-region dynamo effect.

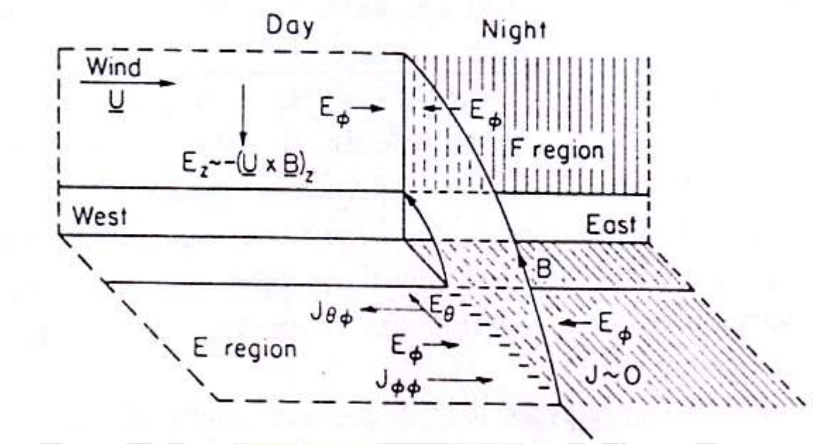

Figure: 2 Simplified model of the F-region prereversal enhancement driven by a uniform F-region wind **U** as put forward by Farley et al. (1986)

Figure.2 shows a simple sketch of the evening equatorial electrodynamics conducive for a vertical drift enhancement as modeled by Farley et al. (1986). The equatorial plane is shown as the vertical plane and its projection onto the southern hemisphere along **B** is also shown. The wind blows across the sunset terminator (the boundary line between day and night), generating a vertical electric field E_z that is downward on both sides. E_z is much smaller on the dayside than on the night side but it is not zero. Thus, E_z maps along **B** to an equator ward electric field component off the equator. This field drives a westward Hall current $J_{\theta\phi}$ on both sides of the terminator. However, even though E_z is smaller on the dayside by up to 90%, the Hall conductivity is more than 10 times the nighttime value. The result is that a negative charge density builds up near the terminator, creating the zonal electric field E_ϕ as shown in the figure. This electric field maps back to the equatorial F-region providing the necessary additional electric field required for the PRE. The current $J_{\phi\phi}$ cancels $J_{\theta\phi}$ in a steady state.

Mechanism 2: EEJ Current Channel to Night time

Another mechanism was proposed by *Haerendel and Eccles* [1992]. Again the fundamental driver of the prereversal enhancement is the zonal neutral wind in the equatorial F region, but the EEJ region is the location of the source for the EPE.

The F region dynamo near sunset is almost entirely a vertical current driver. The strong eastward neutral wind drives a vertical Pedersen dynamo current. The divergence of the vertical dynamo current is the cause of the vertical polarization field E_L [*Rishbeth*, 1971]. In turn E_L induces an opposing Pedersen current that tries to balance the vertical dynamo current. These opposing currents exactly balance in a stratified ionosphere. However, near sunset the ionosphere and the neutral wind are changing rapidly, so the induced Pedersen current does not quite balance the dynamo current. One can see this net vertical current in effect after sunset by comparing the post sunset Sq current patterns. In Figure the F region neutral wind is set to zero, resulting in no net vertical current after sunset.

In figures when the F region wind is present, there is a net vertical current after sunset. This remnant of the R region vertical current dynamo after sunset draws a current from below the integrated F region (below 300 km) through current

continuity demands. These current flow lines after 1800 LT trace back from the night side F region altitudes to the integrated EEJ and, eventually, to the dayside. This provided the impetus for *Haerendel and Eccles* [1992] to propose that zonal Cowling conductivity gradients in the EEJ at sunset in combination with the current demands from the evening F region dynamo may have a causal relationship with the EPE. The rapid droop in conductivity in the EEJ at sunset requires an enhanced zonal electric field to draw the current zonally to the night side, where it then is diverted upward to meet the vertical current demands at the bottom of the F region. The direct involvement of the EEJ in the F region dynamo current system can be explicitly seen in the figure. Only the zonal F region dynamo winds are present to demonstrate the current path through the EEJ to the vertical current dynamo of the night side F region.
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The current demand explanation given above also contains a positive feedback mechanism. The upward current and the enhanced zonal electric field further reduce the EEJ conductivity by lifting plasma from the EEJ altitudes, which in turn require a larger E field to draw zonal current to the night side, hence a larger EPE.

Mechanism 3: Curl of E

The third proposed mechanism is the oldest description for the origin of the EPE. Recent literature fails to mention that Rishbeth proposed a mechanism for the evening enhancement. The work is more often cited for identifying the origin of evening enhancement of vertical electric fields [Rishbeth, 1971]. Rishbeth, 1971 saw the pre-reversal enhancement of the zonal field as a direct result of the rapid enhancement of vertical field. The zonal winds of the F-region dynamo maintain large polarization fields at night when E-region conductivities are low. The upward dynamo current begins abruptly at the F-region ledge and ends less abruptly above the equatorial F-region (pole ward of the equatorial ionization anomaly). There are positive charges in the upper F-layer and negative charges in the lower F layer. The charge density (per unit distance in longitude) is proportional to wind velocity, which does not vary much between 2000LT and 2400 LT; it then decreases towards zero near sunrise. Near sunset and sunrise where the charge density is varying with local time the electric lines of force are curved; the plasma drifts, being normal to the electric lines of force, therefore converge or diverge in the vertical direction as shown by the broken arrows.

The abrupt creation of the polarization charges at sunset below and above the integrated F layer at sunset produces edge effects in the electric fields that result in enhanced vertical velocities. In other words, the zonal electric field is a result of curl free properties of the electric field when the vertical electric field changes rapidly near sunset. Because the present modeling paradigm uses currents, one does not speak of charge collection but of current divergence. Thus there is no divergence in a zonal current dynamo to create a zonal polarization field corresponding to the EPE, but only a curl of E effect in response to the rapidly changing vertical electric field.

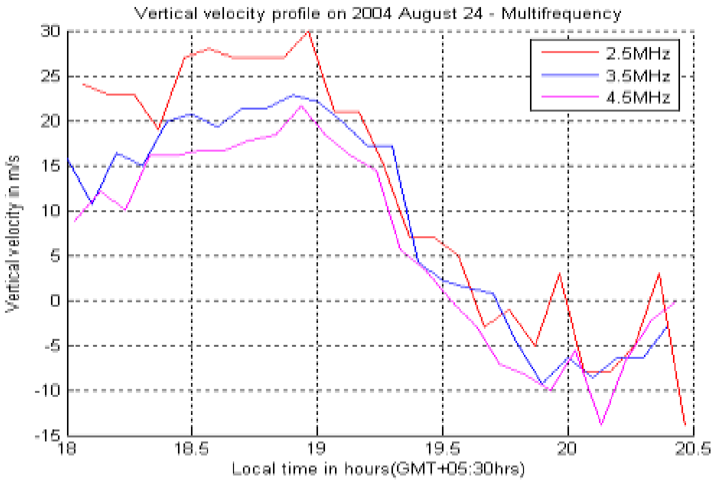

Fig 3: Velocity profiles using HF Doppler radar

A typical multifrequncy profile during very hours on 24 August 2004 is shown in the figure 3. The pre reversal enhancement is clearly seen at three frequencies. The vertical velocity in hours after local sunset reaches a maximum value and gradually decreases. Correspondingly the eastward vertical electrical field attains maximum after local sunset and turns to westward after 1915 LT.

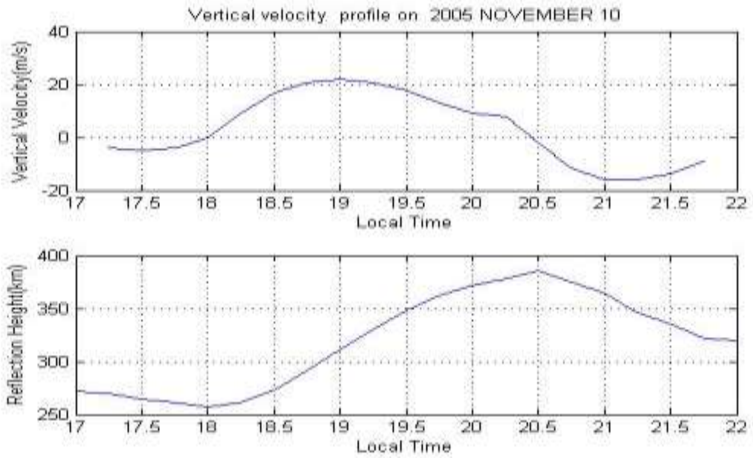

Figure 4: Some typical vertical velocity profiles
using Ionosonde data (4MHz)

Variation of PRE using HF Doppler radar data during 2003 -2004

The seasonal variation of pre-reversal enhancement in zonal electric field is studied using vertical drift data of single frequency sounding at a specific frequency. For this study, the maximum value of the vertical drift (*Vzp*) during the time of the pre-reversal enhancement is noted on all available days. The seasonal variations of *Vzp* can be directly attributed to the variations of the strength of the F-region dynamo action with season. It is observed that as season advances from summer to September equinox, the magnitude of Vzp increases. During summer the range of Vzp is 10 - 20 m/s and this gradually increases to equinox where the range is 35 - 45 m/s. Again as one goes from equinox to winter, the peak value of vertical drift falls to lower values of the range 15 - 25 m/s. These results are evident from figure 4(a) that shows the seasonal variation of Vzp.

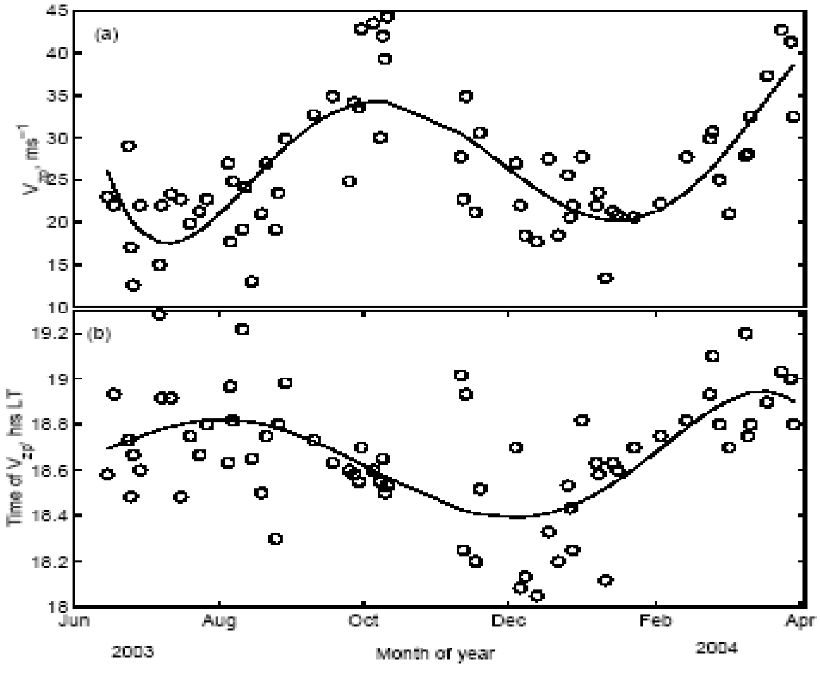

Fig 5 Variation of PRE using HF radar data

Seasonal variation of Velocity at PRE (Vzp) and reflection height
During Winter

The variation of vertical velocity at PRE and the corresponding reflection height during winter is shown in the figure. From the figure it is clear that the value of Vzp lies between 5 to 20 m/s. The corresponding reflection height lies between 280 – 320 km. As the season advances there is gradual increase in both the velocity and reflection height.

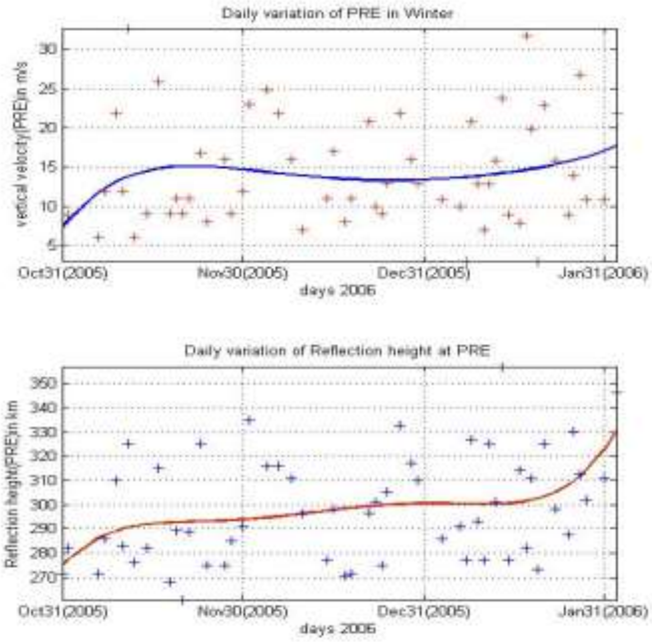

Figure 6: Daily variation of vertical velocity and reflection height at PRE in winter.

During March equinox

The variation of vertical velocity at PRE and the corresponding reflection height during March equinox is shown in the figure. From the figure we can found that the velocity and corresponding reflection height are low during this season. The velocity lies between 10 – 15 m/s and the reflection height is 280 – 300 km. During the month of March, the vertical velocity is a little higher compared to other months in this season.

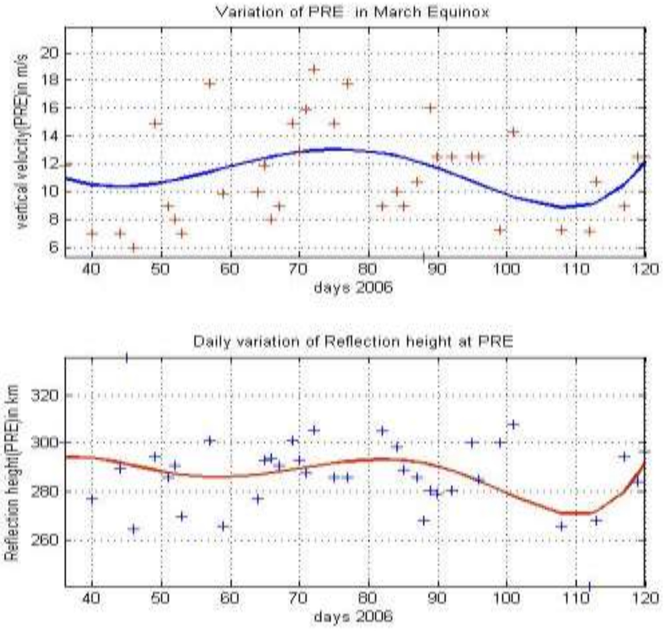

Fig 7: Daily variation of vertical velocity and reflection height at PRE in March equinox

During Summer

The variation of vertical velocity at PRE and the corresponding reflection height during summer is shown in the figure. In the beginning of this season velocity was relatively large (30 m/s) and after that velocity value gradually decreases and reaches a minimum (< 10 m/s) at the end of this season. The reflection height during summer varies about 240–320 km.

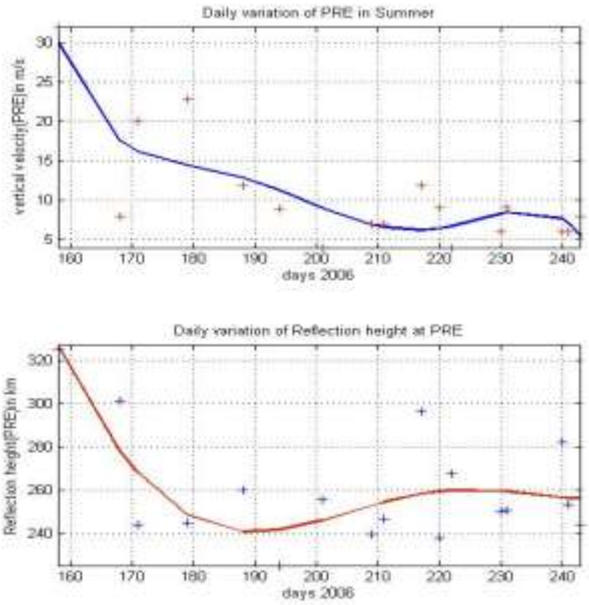

Fig 8: Daily variation of vertical velocity and reflection height at PRE in summer

During September equinox

The variation of vertical velocity at PRE and the corresponding reflection height during September equinox is shown in the figure. The vertical velocity varies between 6 – 15 m/s. During this season the reflection height is relatively low.

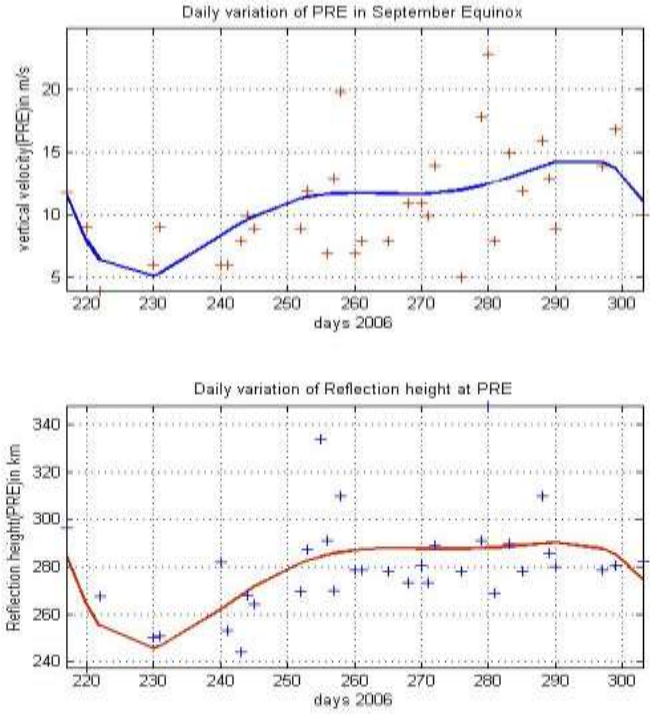

Fig 9: Daily variation of vertical velocity and reflection height at PRE in September equinox

Conclusions

1. The magnitude of vertical velocity during PRE is greater August- September
2. The reflection height during PRE lies above 250 km
3. The variation of Vzp and the reflection height are almost similar
4. If the PRE occurs at an early local time, the magnitude of Vzp will be large and vice versa.

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