The combined effects of electrojet strength and the geomagnetic activity on the post sunset height rise of the F-layer and its role in the generation of ESF during high and low solar activity periods.

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Abstract

In this paper, we present a linear relationship that exists between the day-time integrated equatorial electrojet (IEEJ) strength and the maximum elevated height of the F-layer during post-sunset hours (denoted as peak h'F). An inverse relationship that exists between the 6-hour average Kp-index prior to the local sunset and the peak h'F of the F-layer is also presented. From this study, it has been found that the threshold base height of the F-layer at the equator for the development of plasma bubbles is reduced from 405 km to 317 km as the solar activity decreases from March 2001 (mean Rz = 113.5) to March 2005 (mean Rz = 24.5). This decrease in threshold height with the decreasing solar activity is explained on the basis of changes in the local linear growth rate of collisional Rayleigh-Taylor instability due to the variability of various terms such as inverse density gradient scale length (L^{-1}), ion-neutral collision frequency (ν_{in}) and recombination rate (R) with the changes in the solar activity.

Introduction

Several earlier suggest that the daytime EEJ strength contributes positively for the post sunset height rise of the equatorial F-layer thereby creating conditions favorable for the development of ESF, while the average Kp-index acts as a suppressant for the post sunset height rise of the equatorial F-layer during equinoxes and winter solstices. In this paper, the presence of a linear relationship that exists between a function that involves both these parameters (day-time integrated electrojet (IEEJ) strength and the 6-hour average Kp-index) and the post sunset peak height of the F-layer (peak h'F) at the equator is presented. Fejer et al. (1999) have reported that the threshold drift velocity for the generation of strong early night irregularities varies from 50 m/s during solar maximum to a value of 20 m/s during solar minimum. Tulasi Ram et al. (2006) have shown that the threshold value of this upward ExB drift at the equator should be ≥ 30 m/s for the onset of strong scintillations over Waltair (17.7°N, 83.3°E) during the high sunspot year 2001, while it reduces to 20 m/s during the low solar activity year, 2004. Further, Jyoti et al. (2004) have clearly shown that the critical height $(h'F)_c$ of the F-layer for the onset of ESF increases/decreases linearly with solar flux. However, the rationale for this solar activity dependence of the critical/threshold height of the post sunset F-layer for the onset of ESF still remains unexplained. Here, in this paper, this result is explained, for the first time, on the basis of changes in the local linear growth rate of collisional Rayleigh-Taylor instability.

Data and Method of Analysis

The details of the observations made using various instruments are given in Table.1.

Station	Geographic Co-ordinates		Dip	Parameter(s)
	Latitude	Longitude		
Ionospheric sounders				
Trivandrum	8.5°N	76.5°E	0.5°N	h'F, Spread-F
SHAR	13.7°N	80.2°E	10.8°N	h'F, Spread-F
Waltair	17.7°N	83.3°E	20°N	h'F, Spread-F
VHF and L-band scintillations				
Waltair	17.7°N	83.3°E	20°N	Scintillation occurrence
Magnetometers				
Tirunelveli	8.7°N	77.7°N	0.6°N	EEJ Strength (ΔH_{T-A})
Alibagh	18.5°N	72.9°E	23°N	

Results and Discussion

In order to examine the effect of Integrated Equatorial ElectroJet (IEEJ) strength and the average Kp-index on the post sunset peak height of the equatorial F-layer, the peak h'F for the month of March 2001 as a function of IEEJ and the 6-hour average Kp-index prior to the local sunset are plotted and presented in Figs. 1(a) and 1(b), respectively.

From Fig. 1(a), it is clearly seen that the peak h'F increases with increasing IEEJ and there exists a linear relationship between these two parameters. The least-squares straight line fit gives a relation between IEEJ and the peak h'F as

$$peak\ h'F = 366.2 + 0.2 * IEEJ \quad ---- \quad (1)$$ with a correlation coefficient, r = 0.7.

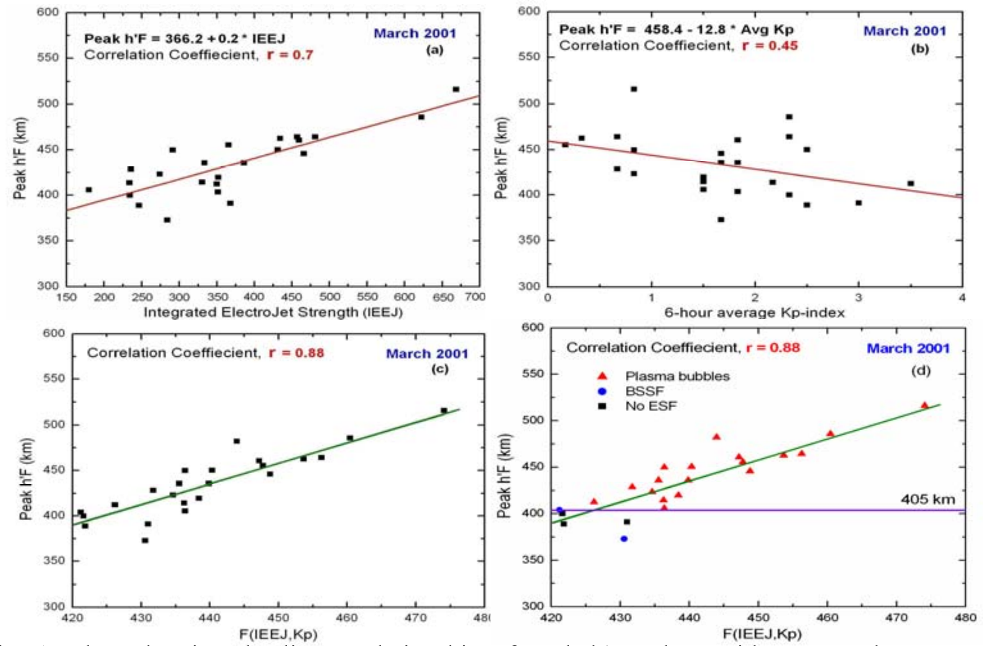

Fig. 1: Plots showing the linear relationship of peak h′F values with IEEJ and average Kp-Index the combined parameter *F(IEEJ, avg Kp)*

Further, it is also seen from Fig. 1(b) that there exists an inverse linear relationship between the 6-hour average Kp-index and the peak h′F. The least-squares straight line fit equation can be given as

$$peak\ h'F = 458.4 - 12.8 * avg\ Kp \quad \text{----} \quad (2)$$

The correlation is poor in this case (correlation coefficient r = 0.45) as may be seen from the large spread of points on either side of the straight line fit. But, the decreasing trend of peak h′F with increasing average Kp-index is clearly evident. Thus, the results shown in Figs. 1(a) and 1(b) clearly suggest that the IEEJ contributes positively for the increase of the post sunset peak h′F, whereas the average Kp-index appears to suppress the post sunset peak height of the F-layer.

It is widely accepted that the post sunset enhancement of F-region upward drift is basically due to the contribution from the electric fields produced by the F-region dynamo action. The major ingredients of F-region dynamo action is thermospheric zonal wind (***U***) at equatorial and low latitudes, which can be effectively modulated by the spatial distribution of F-region plasma density (EIA) through ion-neutral drag, which acts as a resistive force for the thermospheric wind dynamics. The intensification of EIA reduces plasma density over the magnetic equator (trough) and simultaneously increases the plasma density over ± 15 – 20 dip latitudes (crest regions). The decrease in the plasma density over the equator reduces the ion-drag (which acts as a resistive force) on neutrals and hence enhances the zonal wind (***U***) prior to sunset. Further, the enhanced plasma fountain, in addition, will increase the ratio of F to E-region flux tube integrated Pederson conductivity due to the increased plasma content along the flux tubes with high apex altitudes over the magnetic equator. Both of these changes in the properties of the equatorial ionosphere constitute favorable conditions for a very efficient F-region dynamo action, which in turn produces large eastward electric field thereby causing the large post sunset height rise of equatorial F-region. The disturbance dynamo electric fields, which are driven by the enhanced energy deposition into the high-latitude ionosphere during the magnetically disturbed periods, cause large reduction of the evening upward drifts at the equator thereby suppressing the post-sunset height rise of the F-layer. Since the layer height at the post-sunset hours bears a relation with the IEEJ and the average Kp-Index, the effects of these two parameters can be combined in the form of a function that involves both IEEJ and average Kp-index. Thus, combining the equations (1) and (2), a new equation can be written, as

$$F(IEEJ, Kp) = peak\ h'F = \frac{0.2 * IEEJ - 12.8 * avg\ kp}{2} \quad \text{----} \quad (3)$$

Now, the peak h′F is plotted against F(IEEJ, Kp) and is presented in Fig. 1(c). As may be seen from this figure, the peak h′F holds a good linear relationship with this function and the correlation coefficient is significantly improved (r = 0.88). Thus, using this relationship, one can estimate the height of the equatorial F-layer during the post sunset hours (1900 – 1930 hrs LT) using the IEEJ strength and the 6-hour average Kp-index by 1700 hrs LT with reasonable accuracy.

Fig. 1(d) is similar to that of Fig. 1(c), except that the data points are color coded with red triangles representing the peak h′F values for the days on which plasma bubbles were observed, while the blue circles represent the days on which only bottom side spread-F (BSSF) was observed and the black squares represent the days on which no ESF was observed. In the present study, the presence of plasma bubbles are designated to be on those days when the spread-F is present simultaneously at all stations Trivandrum (dip. lat. 0.5°N), SHAR (dip. lat. 10.8°N) and Waltair (dip. lat. 20°N) and also the VHF scintillations over Waltair. For those days on which spread-F was observed only at equatorial stations Trivandrum and/or SHAR without any ESF over Waltair were designated as BSSF. It may also be observed from this figure, that the plasma bubbles were observed when the base height of the post- sunset equatorial F-layer is sufficiently high and also there exist a threshold height of 405 km for the development of plasma bubbles during this high solar activity period, March 2001. Here, the threshold height is defined as the minimum height at which the plasma bubble event is observed during that month.

The variation of the peak h′F values against the combined function defined earlier, F(IEEJ, Kp) were plotted for March 2002, 2004 and 2005 and are presented in Figs. 2(a), 2(b) and 2(c), respectively. As may be seen from these figures, the peak h′F values hold a good linear relationship with the combined function that involves both IEEJ and average Kp-index during both high (March 2001, 2002) as well as low (March 2004, 2005) solar activity periods. However, the threshold heights for the development of plasma bubbles are found to decrease with decreasing solar activity from the years 2001 to 2005. In Fig. 2(d), the variation in the threshold heights of the F-layer as a function of the monthly mean sunspot (mean Rz) number for the months of March 2001, 2002, 2004 and 2005 is presented. The decreasing trend of the threshold height with decreasing solar activity is clearly evident from this figure.

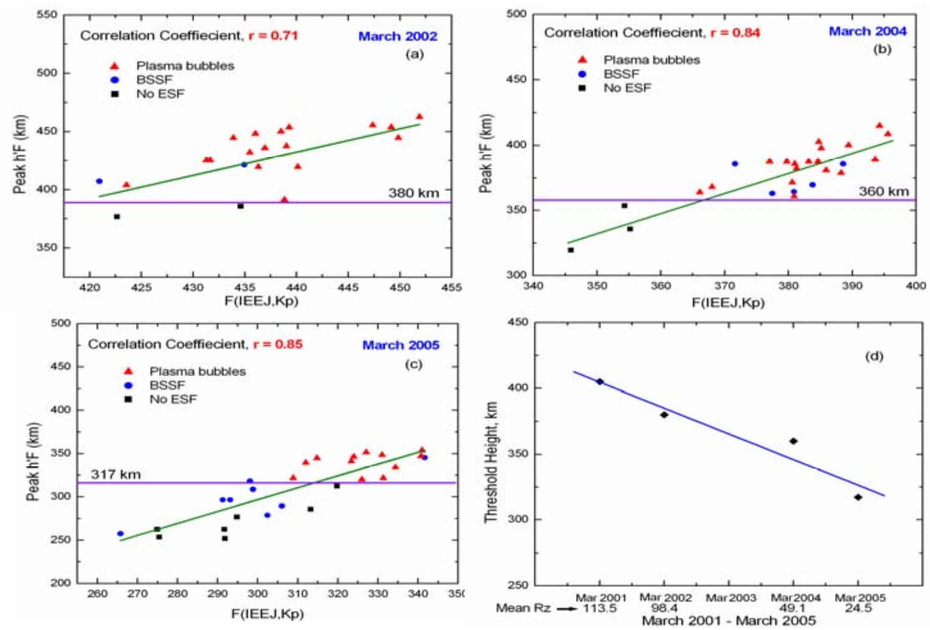

Fig.2: Plots showing the linear relationship between the peak h′F and the combined function *F(IEEJ, avg Kp)* during the months of (a) March 2002, (b)2004 and (c) 2005 while fig.2(d) presents the variation of the threshold heights as a function of the monthly mean sunspot (mean Rz) number, that are needed for the generation of plasma bubbles.

Using the ionogram data of an equatorial station, Trivandrum during the years from 1993 to 1998, Jyoti et al. (2004) have also reported that the threshold height $(h'F)_c$ for the onset of bottom side spread-F (BSSF), irrespective of the polarity of meridional wind, follows a linear relationship with the solar activity. However, the basis for this solar activity dependence on the threshold height has not been explained. With a view to investigate the rationale behind the effect of the solar activity on the threshold height, we have examined the effects of different parameters on the local linear growth rate (γ) of collisional Rayleigh-Taylor instability. The linear growth rate of CR-T instability is estimated by the equation given by Ossakow et al., (1979), as

$$\gamma = \frac{1}{n_o} \cdot \frac{dn}{dh} \cdot \frac{g}{\nu_{in}} - R \quad s^{-1} \qquad \text{---- (4)}$$

where n_o is the background electron density, h is the altitude, ν_{in} is the ion-neutral collision frequency, g is the gravity (positive downward), and R is the local recombination rate. The term $(1/n_o)$ (dn/dh) is called the inverse density gradient scale length (L^{-1}) of the background electron density profile. The values of $L^{-1} = (1/n_o)(dn/dh)$ in equation (4) are calculated from the electron density profile over Trivandrum derived from IRI 2001 model by giving the inputs of sunspot number, foF2 and hmF2 values obtained from the ionogram data of Trivandrum. The ion-neutral collision frequency (ν_{in}) and the recombination rate (R) in the equation (4) are calculated using the equations given by Strobel and McElroy, 1970; McFarland et al. 1973)

Further, in order to examine the variability of L^{-1}, ν_{in}, R and γ with changes in the solar activity, the monthly mean altitudinal profiles for the months of March 2001, 2002, 2004 and 2005 are computed and presented in Fig. 3 as (a), (b), (c) and (d) respectively. It is seen from Fig. 3(a) that the altitudinal profiles of inverse density gradient scale length (L^{-1}) during the equinox month (March) of four years closely follow each other between the altitudes of 360 and 380 km. However, between the altitudes of 380 and 500 km, the L^{-1} profiles exhibit a lower value during March 2001 and increases with decreasing solar activity, reaching a maximum during March 2005.

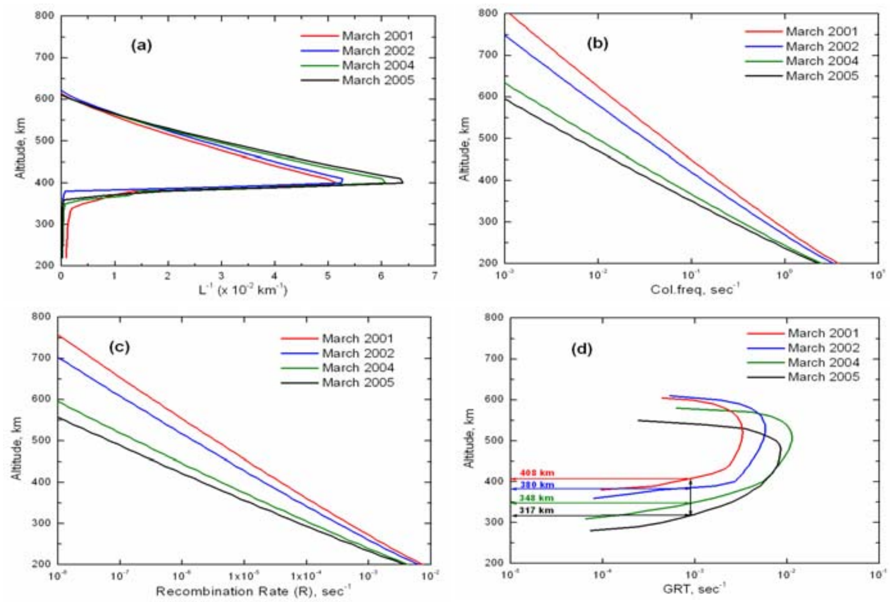

Fig. 3: Monthly mean altitudinal profiles of (a) inverse density gradient scale length, L^{-1}, (b) ion-neutral collision frequency, ν_{in}, (c) recombination rate, R, and (d) the local linear growth rate of collisional Rayleigh-Taylor instability γ for the months of March 2001 (red), 2002 (blue), 2004 (green) and 2005 (black)

From Figs. 3(b) and 3(c), it is observed that at any given altitude, both the ion-neutral collision frequency (ν_{in}) and the recombination rate (R) are higher during high solar activity periods and decreases with decreasing solar activity from March 2001 to March 2005. In Fig. 3(d), is presented the altitudinal profiles of linear growth rate of collisional Rayleigh-Taylor (γ) instability for the months of March 2001, 2002, 2004 and 2005. It is seen from this figure that the growth rate (γ) increases exponentially with altitude (up to the altitudes of about 500 – 550 km) during all these four periods. However, for any given growth rate (γ), the corresponding altitudes are lower during the low solar activity periods and higher during the high solar activity periods. For example, from Figs. 2(c) and 2(d), it may be recalled that the threshold height for a plasma bubble event to occur during the low solar activity period of March 2005 is 317 km. From Fig.3(d), if we consider the growth rate at 317 km during March 2005 is the required growth rate for the development of the plasma bubbles, the same growth rate is obtained at an altitude of 348 km during March 2004, at 380 km during March 2002 and at 408 km during March 2001. In other words, the altitudes at which the necessary growth rate exists for the development of a plasma bubble are 408 km, 380 km, 348 km and 317 km during the periods March 2001, 2002, 2004 and 2005, respectively. Hence, it is inferred from the present study that the altitude at which the necessary growth rate occurs for a plasma bubble to develop decreases linearly with the decreasing solar activity. Also, these values are in good agreement with the measured threshold height values of 405 km, 380 km, 360 km and 317 km, respectively, obtained during the periods March 2001, 2002, 2004 and 2005 as seen in Fig. 2(d). Thus, the linear increase/decrease in the threshold post sunset peak height (peak h′F) for the development of plasma bubbles may be explained on the basis of the necessary growth rate that attains at low altitudes during the low solar activity periods and this altitude increases linearly with the increase in solar activity.

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