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Power spectral characteristics of ESF irregularities during magnetically quiet and disturbed days

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Amplitude scintillations on 251 MHz signal recorded by spaced receivers at Tirunelveli (8.7°N, 77.8°E, dip latitude 0.6°N) for eight months during 1995–2005 are utilized in present work. Power spectral analysis of weak scintillations ($0.15 \leq S_4 \leq 0.5$) is carried out and spectral index, m of ESF irregularities, is computed for quiet and disturbed days. Maximum cross-correlation, $C_I(x_0,t_m)$, of intensity variations between two receivers is used to identify the fresh generation of EPBs resulted from magnetic activity. Increase in F-region height is seen prior to the generation of these fresh EPBs and associated ESF irregularities found to possess shallower power spectrum.

1. Introduction

Generation of ESF irregularities through Rayleigh–Taylor (R–T) plasma instability in the post sunset hours is a known nighttime equatorial F region phenomenon. Movement of equatorial F-region to higher altitude with $\mathbf{E} \times \mathbf{B}/B^2$ drift and the presence of steep vertical electron density gradient at the bottom side of equatorial F-region favor the growth of R–T plasma instability. Although, these conditions are present every day in the post sunset hours, ESF irregularities are not generated every day. Exact triggering or seeding mechanism for the generation of ESF irregularities is still unknown. The presence of these electron density irregularities causes scintillations or fluctuations on radio signal passing through ionosphere. Many of earlier studies have been carried out using spaced receiver scintillation data recorded at equatorial station to get information about ESF irregularities (Wernik et al., 1983, 2007; Bhattacharyya et al., 1989, 2001; Basu et al., 1991, 1996; Valladares et al., 1996, 2002, 2004; Kil et al., 2002; Ledvina et al., 2004). Once the generation of ESF irregularities is initiated, the ambient ionospheric parameters like height of F layer, background electric field, perturbation electric field associated with R–T instability, ion-neutral collision frequency and neutral wind might be playing an important role in the structuring and evolution of these ESF irregularities. The information on the evolution of equatorial plasma bubbles (EPBs) and spatial scales of associated ESF irregularities is useful, as sometimes radio signal can be completely degraded due to the presence of fast moving small scale irregularities.

Effect of magnetic disturbance on night time equatorial F region is reported in many studies (Fejer et al., 1991; Fejer and Scherliess, 1995, 1997; Sastri et al., 2000; Basu et al., 2001; Dymond et al., 2004). On some magnetically disturbed nights ambient ionospheric electric field gets modulated either due to the disturbance dynamo (DD) (Blanc and Richmond, 1980) or prompt penetration of the electric field of magnetospheric origin (Spiro et al., 1988; Fejer et al., 1990) or combination of both (Maruyama et al., 2005; Kakad et al., 2007), which results in the generation or inhibition of EPBs in the post sunset hours (Sastri, 1981, 1999; Abdu et al., 1997; Martinis et al., 2005; Prasad et al., 2005). In such studies of cause–effect relationship, the identification of magnetic activity linked fresh generation of EPBs is a crucial task. It should be noted that ESF irregularities generated freshly as a result of magnetic activity or ESF irregularities generated few hours earlier at some location west to the observation site and drifting eastward at later time, both can cause scintillations on incoming radio signal. This issue has been addressed by Bhattacharyya et al. (2002), and suggested that maximum cross-correlation of intensity variations between two spaced receivers, $C_I(x_0,t_m)$ can be used to identify the freshly generated EPBs during periods of enhanced magnetic activity. Recently, Kakad et al. (2007) statistically studied the local time occurrence pattern of freshly generated EPBs for different seasons using the estimates of $C_I(x_0,t_m)$ from spaced receiver scintillation records.

As background ionospheric conditions change substantially during magnetically active periods, structuring and evolution of

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freshly generated ESF irregularities, resulted from magnetic disturbance might be different than that on quiet days. Using three dimensional computer simulations Keskinen et al. (2006) have shown that the evolution of EPB on magnetically disturbed day is different as compared to its evolution during quiet time, in the post sunset hours. Thus, the present work is carried out to investigate difference in the spectral characteristics of ESF irregularities on magnetically disturbed and quiet days using spaced receiver scintillation data. The focus is to study separately, the magnetically disturbed days "with fresh generation" and "without fresh generation" of EPBs. Data used and analysis technique are described in Section 2. Details of information retrieved from the power spectral analysis of scintillation data are given in Section 3. Identification of freshly generated EPBs as a result of magnetic activity is described in Section 4. Results are discussed and summarized in Sections 5 and 6 respectively.

2. Data used and analysis technique

Amplitude scintillations on 251 MHz signal transmitted from geostationary satellite and recorded by two spaced receivers closely aligned along magnetic E–W at equatorial station Tirunelveli (8.7°N, 77.8°E, dip latitude 0.6°N) during December 1995, January 2000, July 2000, November 2001, October 2002, March 2003, March 2004 and February 2005 are used here. The data used in the present study is a subset of the long period (1996–2006) amplitude scintillation data recorded at the same station. Here we have considered only eight magnetically disturbed days ($Ap>$ 20) from this long term data such that four days show the fresh generation of EPBs and other four days do not show the fresh generation of EPBs. These magnetically disturbed days are chosen such that the S_4 index on these days is ≤ 0.5 for considerable time during the night in order to carry out power spectral analysis. Signal transmitted from geostationary satellite FLEETSAT (UFO2) located at 73°E (71.2°E) is used till (after) December 2000. The zenith, θ, and azimuth angle, A, of signal path for UFO2 (FLEETSAT) are 12.8° and 216.9° (11.4° and 209°) respectively. Distance between two receivers, x_0, is 540 m which is of the order of Fresnel scale length and scintillations are sampled at every 0.1 s. In addition to this, single receiver scintillations on the same frequency recorded at Mumbai (19.09°N, 72.85°E, dip latitude 13.6°N) with 10 Hz sampling frequency and simultaneous ionosonde observations at Trivandrum (77°E, 8.5°N, dip latitude 0.5°N) are utilized. Local time variation of base height of F layer at Trivandrum is obtained for quiet and disturbed days. If Earth's magnetic field is assumed to be dipolar, then the magnetic field line is govern by a equation; $r=L\cos^2(\theta)$, where L is equatorial crossing point of field line, θ is magnetic latitude (Kelley, 1989). A simple calculation reveals that ESF irregularities situated at an altitude of $\sim$456 km near to dip equator can map down to Mumbai at $\sim$250 km. It should be noted that Tirunelveli and Mumbai do not lie on the same magnetic longitude, but the separation between magnetic longitude is small ($\sim$4.1°). Hence the single receiver scintillations recorded at Mumbai are used to get information about the altitudinal extent of equatorial F layer.

Spaced receiver scintillations are analyzed using full cross-correlation technique introduced by Brigg (1984) in which space time correlation function of intensity variations in the ground scintillation pattern is assumed to have a following form:

$$C_I(x,t)=f[(x-V_0t)^2+V_C^2t^2] \quad (1)$$

where f is a monotonically decreasing function of its argument with $f(0)=1$. Parameters S_4, V_0, V_C and $C_I(x_0,t_m)$ are estimated for every 3 min from spaced receiver scintillation measurements. S_4 gives information about the strength of scintillation and defined as standard deviation of normalized intensity variation. In order to remove the noisy signal, scintillation events with $S_4 \geq 0.15$ are subjected to full cross-correlation analysis technique. Random velocity, V_C, is the measure of random changes in the irregularity characteristics. V_0 is the drift of the ground scintillation pattern in the receivers plane, which is determined by the drift of the irregularities across signal path. V_0 and V_C are estimated only when $C_I(x_0,t_m)\geq 0.5$, because in this regime assumed form of space time correlation function of intensity variations (Eq. (1)) has greater validity.

ESF irregularities drift with the background plasma after $\sim$22 : 00LT, when perturbation electric field associated with R–T plasma instability decays considerably (Bhattacharyya et al., 1989) and estimated, V_0, is close to the background plasma drift (Bhattacharyya et al., 2001; Retterer, 1999; Basu et al., 1996; Valladares et al., 1996). Considering the geometry of the incoming radio signal, we have $V_0=V_X-V_Z\tan(\theta)\sin(A)$, where V_X and V_Z are eastward and vertical drift of irregularities. The values of zenith angle θ and Azimuth angle A of a signal transmitted from UFO2 and FLEETSAT satellite are substituted in above expressions. This reveals that the amount of $-0.13V_Z$ ($-0.1V_Z$) contributes to V_0 when signal is transmitted from UFO2 (FLEETSAT) satellite. This contribution is very small after 22:00LT, hence calculated V_0 can be considered as a representative of zonal plasma drifts i.e. $V_0 \approx V_X$ after 22:00LT. It is observed that for magnetically quiet nights, estimated V_0 follows a well-defined pattern after 22:00LT for a given month (Engavale et al., 2005). However, on some magnetically disturbed days, estimated V_0 shows a clear departure from monthly quiet time pattern of zonal plasma drift (Bhattacharyya et al., 2002).

3. Power spectral analysis

It is known that ESF irregularities follow a power law spectrum $\Phi_{\nabla N}(k)\propto k^{-p}$, where p is three dimensional power spectral index of irregularity, which is valid between some inner (r_0) and outer scale (R_0) (Rufenach, 1972; Fejer and Kelley, 1980). In the power spectrum of weak amplitude scintillations, the broad maxima is seen around Fresnel frequency ($\nu_F=V_0/\sqrt{2\lambda Z_{AVG}}$) and higher frequencies falls off as a power law (Yeh and Liu, 1982). The magnitude of the slope of the power spectrum on log–log scale gives two-dimensional power spectral index m of ESF irregularities (where $p=m+1$). Many studies of ESF irregularities have been carried out in past using power spectral analysis of amplitude and phase scintillations (Basu et al., 1986; Bhattacharyya and Rastogi, 1985). Sometimes ESF irregularity exhibits two component power law spectrum, which has a break in slope. It means two regions with different spectral slopes exist in the power spectrum at the same time (Bhattacharyya and Rastogi, 1986; Basu et al., 1983; Franke and Liu, 1983). When small scale ESF irregularities are not present, there is no sufficient power to higher frequencies (or small scale lengths) and power spectrum falls off rapidly giving rise to steep spectral slopes. On the other hand when small scale length irregularities are present, considerable power is associated with higher frequencies and hence power spectrum has shallower slope.

The power spectral analysis is carried out for weak ($0.15 \leq S_4 \leq 0.5$) scintillation events occurred during eight disturbed days namely; 23 March 2003, 1 October 2002, 14 July 2000, 9 March 2004, 7 November 2001, 23 January 2000, 7 February 2005, 24 December 1995, and quiet days of corresponding months, using east receiver data from Tirunelveli. Spectral index of ESF irregularities, $m=$–spectral slope are computed for these quiet and disturbed days. In the case of strong scintillations drift speed and strength of irregularities influence power spectrum and the form of the power spectrum is close to Gaussian (Spatz et al., 1988; Wernik et al., 1990). Thus, power spectral slopes are estimated only for weak scintillations. Occasionally, the break in slope is observed in the power spectrum but such data points are fewer and not considered in the study.

Simultaneous single receiver scintillation data from Mumbai, is available for 1 October 2002, and 7 February 2005, which is subjected to spectral analysis together with their monthly quiet days. It should be noted that simultaneous ionosonde data recorded at Trivandrum is available for March 2003, July 2000, February 2005 and March 2004. Also no scintillations were observed during the night of 6 November 2001 and 15 July 2000 although geomagnetic activity index *Ap* was 142 and 164 respectively for those days.

4. Identification of freshly generated EPBs

Fig. 1 shows LT variation of (a) V_0, (b) V_C and (c) $C_I(x_0,t_m)$ for the quiet days of August 2002 along with a disturbed day, 2 August 2002 ($Ap=42$). S_4 index for this disturbed day is depicted in Fig. 1(d) as a function of LT. Characteristics of ESF irregularities like spectral index, drift speed change rapidly in the initial phase of generation of ESF irregularities, due to the presence of perturbation electric field associated with R–T instability. This gives rise to rapidly changing scintillation pattern on ground, and hence parameters derived from spaced receiver scintillation measurements; V_0, V_C and $C_I(x_0,t_m)$ are highly variable in the initial phase of scintillation in post sunset hours. However, once initiated approximately 2 h later the perturbation electric field associated with R–T instability dies down considerably (Bhattacharyya et al., 1989, 2001) and signals from two spaced receivers are in good correlation after 22:00LT. Thus, $C_I(x_0,t_m)$ shows less variability and remains close to 1 after 22:00LT for all quiet days in a given month (see Fig. 1c).

The scenario for the disturbed day is different from that on quiet day, low values of $C_I(x_0,t_m)$ are observed even after 22:00LT on disturbed day. This feature is seen on many of disturbed days and used to identify the fresh generation of EPBs (Bhattacharyya et al., 2002; Kakad et al., 2007) resulting from magnetically disturbed time electric field. Scintillation periods with $C_I(x_0,t_m) \leq 0.5$ are considered as a proxy for freshly generated EPBs. However, this method is applicable only after 22:00LT when usual post sunset perturbation electric field associated with R–T plasma instability is eroded. Thus, magnetically disturbed days considered in the present study are separated in two categories as days “with fresh” and “without fresh” generation of ESF irregularities.

5. Results and discussion

Fig. 2 shows the LT variation of V_0, $C_I(x_0,t_m)$, m and S_4 for days with the fresh generation of EPBs namely; 23 March 2003, 1 October 2002, 14 July 2000 and 9 March 2004 along with their monthly quiet time pattern. The monthly quiet time average of V_0 is estimated for every 10 min after 22:00LT and its LT variation is plotted with disturbed time V_0 in the first horizontal panel (Fig. 2a–d). Secondly, $C_I(x_0,t_m)$ and power spectral index, m, are plotted as a function of LT, for quiet days of a given month, superimposed with their disturbed time variation, in the second (Fig. 2e–h) and third (Fig. 2i–l) horizontal panels respectively. S_4 is plotted as a function of LT for disturbed days in the fourth horizontal panel (Fig. 2m–p). Similar plots are made for four magnetically disturbed days without the fresh generation of EPBs namely; 7 November 2001, 23 January 2000, 7 February 2005 and 24 December 1995, and shown in Fig. 3.

It should be noted that the effect of magnetic disturbance on V_0 is clearly observed on all eight disturbed days (see Figs. 2 and 3a–d), however, the fresh generation of EPBs is triggered only on four days; 23 March 2003, 1 October 2002, 14 July 2000 and 9 March 2004 (see, Fig. 2e–h). Low values of maximum cross-correlation of intensity variations ($C_I(x_0,t_m) < 0.5$) are observed even after 22:00LT on these days, which implies the presence of freshly generated EPBs. On the other hand, 7 November 2001, 23 January 2000, 7 February 2005 and 24 December 1995, $C_I(x_0,t_m)$ do not show deviation from monthly quiet time pattern (see, Fig. 3e–h). This indicates that on these magnetically disturbed

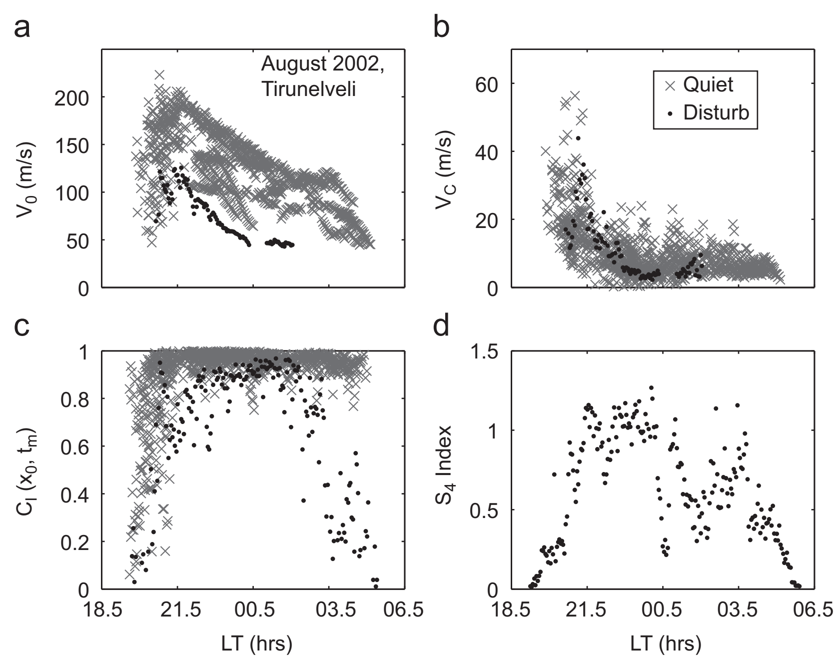

Fig. 1. LT variation of (a) drift speed, V_0, (b) random velocity, V_C, (c) maximum cross-correlation, $C_I(x_0,t_m)$, and (d) S_4 index for disturbed day, 2 August 2002 along with their monthly quiet time pattern.

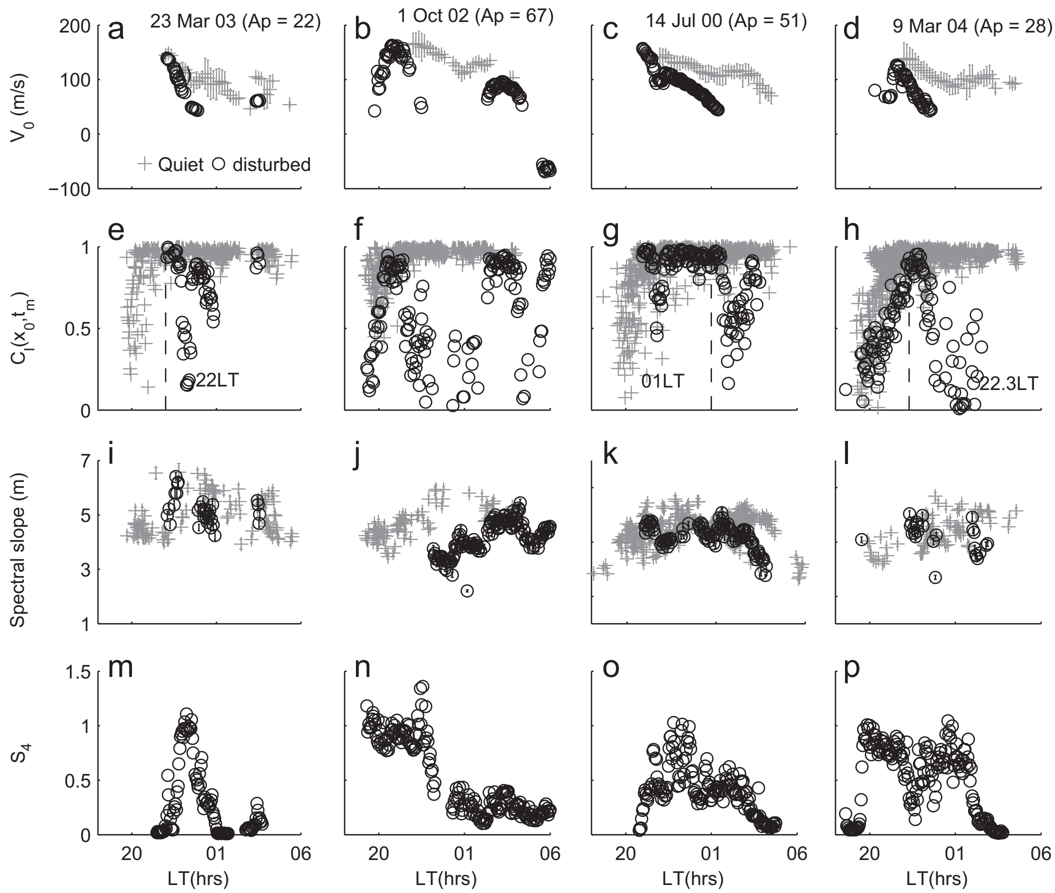

Fig. 2. (a–d) Irregularity drift speed V_0, (e–h) maximum cross-correlation $C_I(x_0,t_m)$, (i–l) power spectral index m and (m–p) S_4 index are shown as a function of LT for magnetically disturbed days with the fresh generation of EPBs; 23 March 2003, 1 October 2002, 14 July 2000 and 9 March 2004, respectively. Monthly quiet time variations of these parameters are shown in background for corresponding months (gray color, a–l).

days the fresh generation of EPBs is not triggered. All disturbed days considered here are having $Ap > 20$, except for the 7 November 2001, which is a following day of strongly magnetically disturbed day. Sometimes the effect of magnetic activity may be seen on the following day of magnetically disturbed day (Scherliess and Fejer, 1997; Fuller-Rowell et al., 1996, 2002) and 7 November 2001 is one example of such case.

Monthly quiet time pattern of power spectral index m shows considerable day-to-day variation with shallower slopes in the initial phase of development of ESF irregularities, which becomes steeper with time. This happens because small scale irregularities decay faster living behind large scale irregularities. If so, then spectral index, m, associated with ESF irregularities should increase with time through the night. But, monthly quiet time mass plot of spectral index, m, indicates that sometimes small values of m are found in post-midnight hours as well. Spatz et al. (1988) reported that power spectral slope associated with weak scintillations increase with time approximately till midnight, however, on some occasions it decreases after midnight. These authors have suggested that sometimes strong irregularities leave behind the trail of small scale irregularities, which may give rise to this midnight notch observed in the LT variation of power spectral index. The monthly quiet time pattern of m observed here is in agreement with the study by Spatz et al. (1988).

Interesting thing which is noted here is that the power spectral slopes associated with freshly generated EPBs on magnetically disturbed nights are found to be much shallower than that on quiet days. This feature is consistent and observed on all four disturbed days, which shows the fresh generation of EPBs (see, Fig. 2i–l). Whereas magnetically disturbed days without freshly generated EPBs do not show any considerable difference in the power spectral index as compare to that on quiet days (see, Fig. 3i–l). Example of power spectrum for weak scintillation event on quiet and disturbed nights of October 2002 is shown in Fig. 4. It is clearly seen that the irregularity power spectrum on magnetically disturbed night is shallower as compared to quiet time irregularity power spectrum. It should be noted that maximum contribution to weak amplitude scintillations comes from the irregularities of the order of Fresnel scale length. Thus, the peak in the power spectrum is decided by the Fresnel frequency ($\nu_F = V_0/\sqrt{2\lambda Z_{AVG}}$), which depends on drift speed and height of irregularity. Fresnel frequency ν_F is found to be 0.14 and 0.016 for power spectrum shown in Fig. 4a and b respectively. On disturbed day, 1 October 2002, the drift speed of the irregularities is smaller than quiet time average drift speed. Hence there is shift in the frequency linked with maximum power, which is apparent in power spectrum shown in Fig. 4a and b. Fresnel scale can be estimated from $d_F = V_0/\nu_F$ when the drift speed V_0 of irregularity is known. The average zonal drift speed $V_0 \sim 130$ m/s during the time of power spectrum is shown in Fig. 4a. Thus, the Fresnel scale d_F comes out to be ~ 920 m for Fig. 4a. Whereas we could not compute d_F for Fig. 4b, as information of V_0 is not available due to the presence of low (<0.5) values of $C_I(x_0,tm)$ during that time.

It is observed that mostly small values of spectral slopes are associated with low values of $C_I(x_0,t_m)$ after 22:00LT, for magnetically disturbed days with fresh generation. For magnetically disturbed days with freshly generated EPBs, spectral index m is

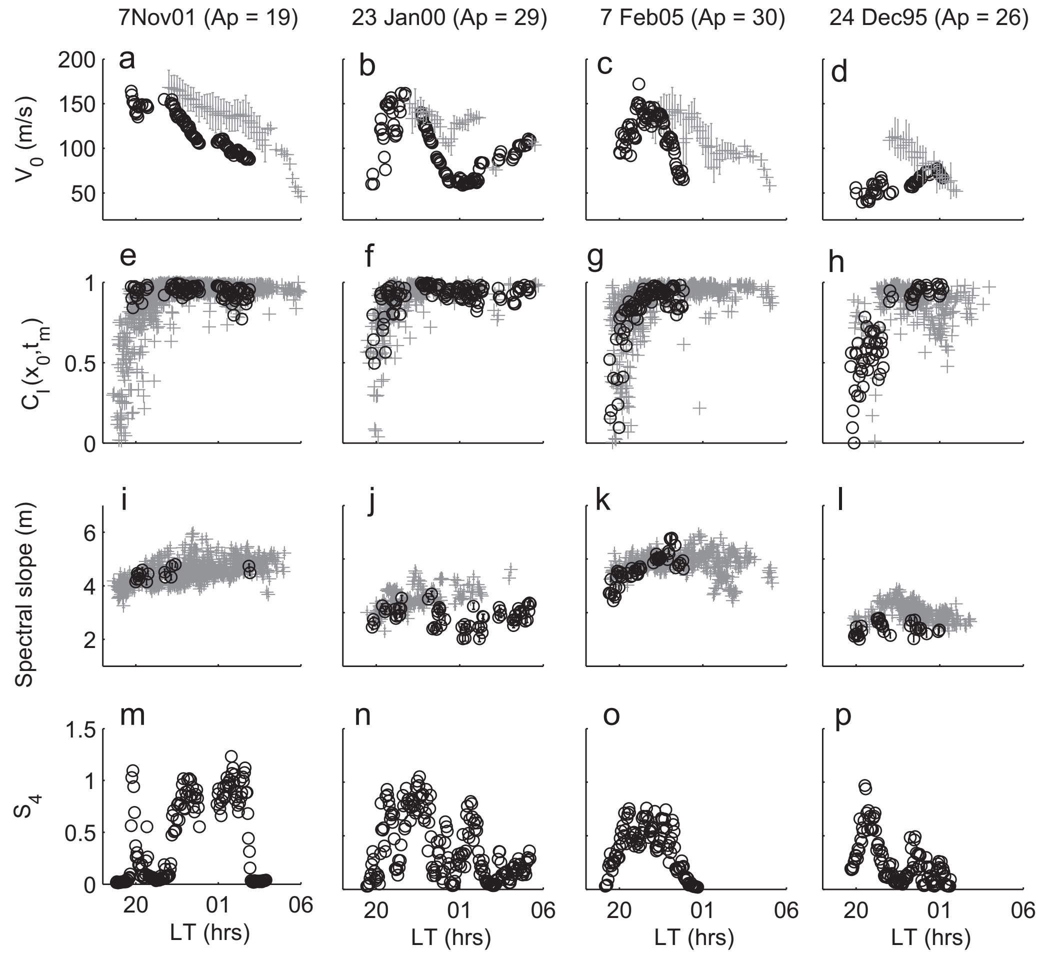

Fig. 3. (a–d) Irregularity drift speed V_0, (e–h) maximum cross-correlation $C_I(x_0,t_m)$, (i–l) power spectral index m and (m–p) S_4 index are shown as a function of LT for magnetically disturbed days without the fresh generation of EPBs; 7 November 2001, 23 January 2000, 7 February 2005 and 24 December 1995 respectively. Monthly quiet time variations of these parameters are shown in background for corresponding months (gray color, a–l).

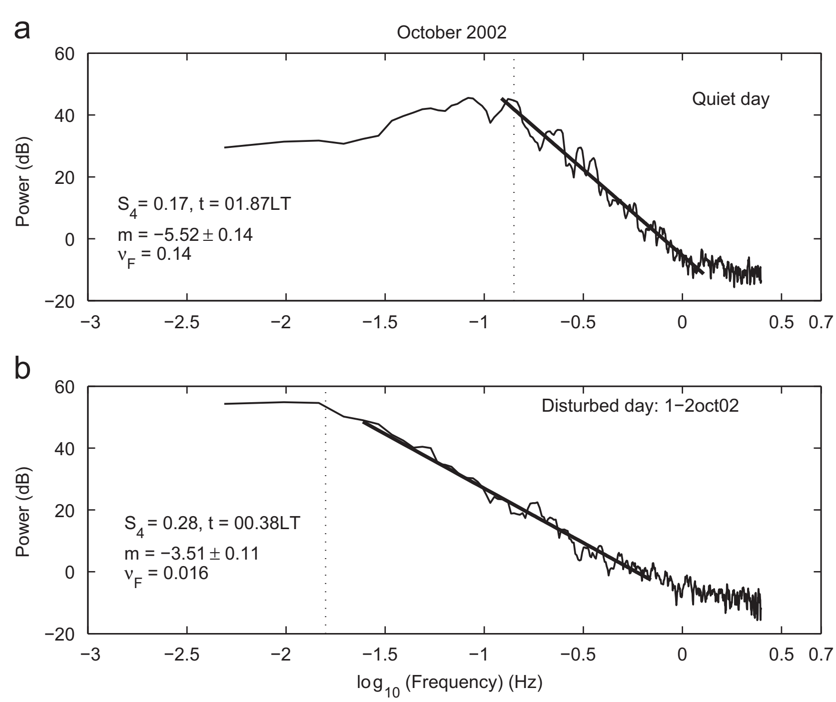

Fig. 4. Power spectrum of weak scintillation event occurred on (a) quiet and (b) disturbed night of October 2002.

plotted as a function of its corresponding value of $C_I(x_0,t_m)$ after 22:00LT and illustrated in Fig. 5. It is seen that power spectral slope has tendency to decrease with decreasing $C_I(x_0,t_m)$, nevertheless correlation is not very good due to scatter in the plot. It should be marked that when $C_I(x_0,t_m)$ starts decreasing after 22:00LT, spectral index m do not decrease simultaneously, but small spectral indices are observed after some time lag. Likewise, when $C_I(x_0,t_m)$ increases and moves towards 1, spectral index do not increase simultaneously, but remains small for some time. As a result, plot of m as a function of $C_I(x_0,t_m)$ shows scatter and gives rise to low correlation coefficient. This behavior is expected, as electron density perturbations generated due to instability sustains, even after the decay of perturbation electric field associated with instability. Moreover, when plasma instability is triggered, irregularities are not formed immediately, but it takes some time to grow and generate small electron density perturbations. Nevertheless, the tendency of having shallower slopes during the period of fresh generation of EPBs is clearly seen on all four days, which suggest that small scale irregularities are likely to generate during the periods of freshly generated EPBs on magnetically disturbed days.

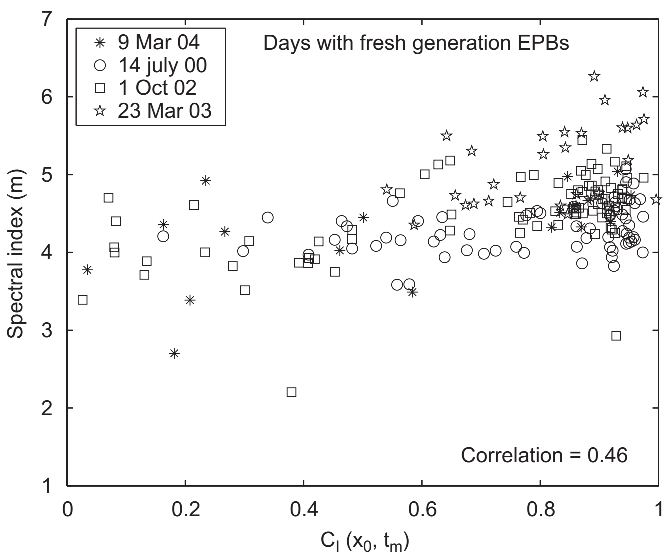

Fig. 5. Plot of m as a function of corresponding value of $C_I(x_0,t_m)$ for magnetically disturbed days with freshly generated EPBs.

If magnetic disturbance results in a net eastward electric field, which is superimposed on ambient electric field, which is westward after 22:00LT, then F layer moves upward, where R–T plasma instability is more likely to take place. Thus, the fresh generation of EPBs may be seen on those disturbed days even after 22:00LT. The presence of perturbation electric field associated with the freshly triggered R–T instability causes correlation between signals recorded by two spaced receivers, to fall below 0.5 even after 22:00LT. In order to get the information about the height of F layer on disturbed days, ionosonde data from Trivandrum is used. Virtual base height of F layer, h'F is plotted as a function of LT of Tirunelveli for four magnetically disturbed days together with their monthly average quiet time pattern in Fig. 6. It should be noted that Fig. 6 (a) 23 March 2003, (b) 14 July 2000, and (d) 9 March 2004 are the days with the fresh generation of EPBs and (c) 7 February 2005 is a day without the fresh generation of EPBs. It is found that days with fresh generation; 23 March 2003, 14 July 2000 and 9 March 2004 show increase in height, which initiates at 22, 01 and 22.3$LT_{Tirunelveli}$ respectively. This start time of increase in h'F is indicated by vertical dotted line in Fig. 6a, b, and d and 1e–h. It is interesting to note that on these days, the fresh generation is initiated just after the time of start of increase in h'F. The maximum cross-correlation $C_I(x_0,t_m)$ starts falling below 0.5 at 22.95, 01.65 and 23.25$LT_{Tirunelveli}$ for 23 March 2003, 14 July 2000, 9 March 2004 respectively. It should be noted that, even if the increase in h'F on disturbed day is not very large, it is sufficiently above the monthly quiet time variability of h'F.

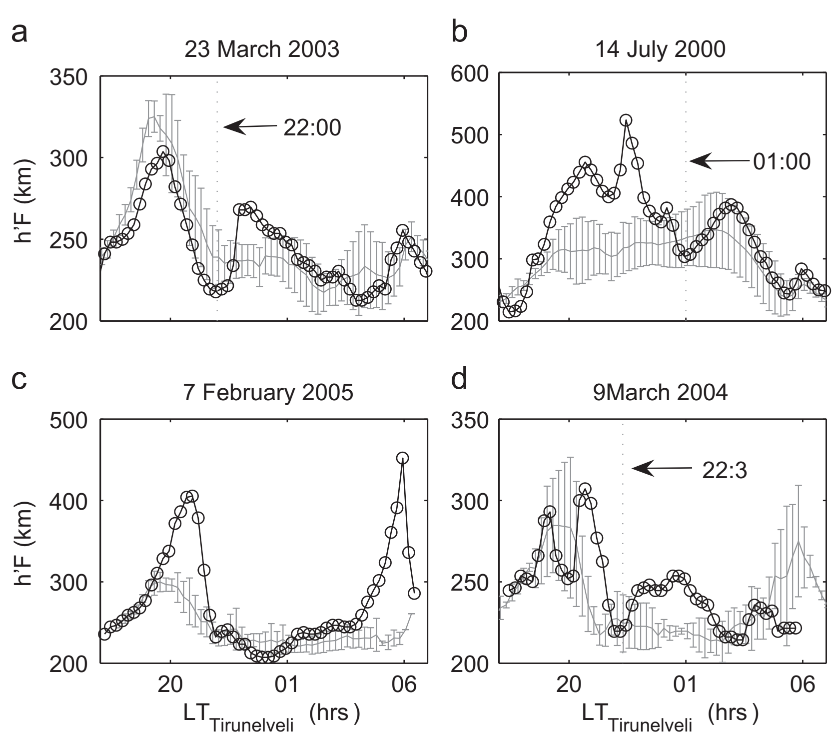

Fig. 6. Variation of virtual base height of F layer, h'F for disturbed days (a) 23 March 2003, (b) 14 July 2000, (c) 7 February 2005 and (d) 9 March 2004 at Trivandrum with their monthly quiet time average of h'F as a function of LT of Tirunelveli. $LT_{Trivandrum}$=IST-0.39 (h).

Magnetically disturbed days without fresh generation; 7 February 2005 do not show any increase in height between 22-04LT. Also no fresh generation is observed on this day between 22-04LT. However, increase in height is seen after 04:00LT, which can trigger fresh generation at Tirunelveli. Scintillation data from Tirunelveli after 04:00LT is not available, hence we could not confirmed the generation of fresh EPBs associated with this height rise after 04:00LT. Secondly, on 1 October 2002, $C_I(x_0,t_m)$ shows decrease twice $\sim$ at 21.32 and 03.7LT, which indicate the fresh generation of EPBs. But ionosonde data from Trivandrum is not available to get the information of F-region heights.

ESF irregularities generated at equatorial station can map down to off equatorial stations through magnetic field lines, depending on their altitude. Occurrence of scintillations at Mumbai can be used as proxy for altitudinal extent of ESF irregularity at Tirunelveli. So, single receiver scintillation measurements are used to get the better insight of the evolution of ESF irregularities on these magnetically disturbed days. S_4 and power spectral index, m as a function of $LT_{Tirunelveli}$, for 1 October 2002 and 7 February 2005 for Mumbai is depicted in Fig. 7a and c and b and d respectively. In the post-midnight hours, equatorial F layer comes down considerably and height of the F layer is not sufficient to map the irregularities to off equatorial station. Thus, on quiet days scintillations are generally not seen after $\sim 02:00$ h at Mumbai station. Whereas on 1 October 2002 and 7 February 2005, scintillations are observed till 08:00 h. Quiet time variation of m for corresponding months is shown in the background of Fig. 7c and d. It should be noted that, on 7 February 2005 spectral index follows their monthly quiet time pattern between 20-01LT, and low values of m are seen after 04:00 h, which continues till 08:00LT. It is interesting to note that on none of the quiet days of February 2005 scintillations are observed after 02:00LT at Mumbai. But, on 7 February when virtual height of F layer increases after 04:00LT at Trivandrum, scintillations are seen which are linked with irregularities with shallower power spectrum. This indicates that increase in height might have triggered the fresh generation of EPBs, at Tirunelveli and height of the bubble was sufficient to map these irregularities at off equatorial station Mumbai through magnetic field lines. It should be noted that on disturbed day 1 October 2002 strong scintillation are observed at Mumbai till 08 LT, which is not seen on quiet days of October 2002 and m associated with these scintillations are found to be low. This implies that on 7 February 2005 and 1 October 2002, F layer was sufficiently high to produce the fresh generation of EPBs and map them to off equatorial station Mumbai even after 01 LT.

The present study reveals that on magnetically disturbed days when F layer is raised to higher altitudes after 22:00LT, as a result of magnetic activity, R–T plasma instability may be triggered to initiate the fresh generation of EPBs, which give rise to the low values of $C_I(x_0,t_m)$ and associated ESF irregularities are more likely to have small scale size at these higher heights. Study by Tiwari et al. (2006) using simultaneous radar and scintillation measurements has shown that lower values of $C_I(x_0,t_m)$ are associated with higher heights in the initial phase of the development of bubbles. Thus, low values of $C_I(x_0,t_m)$ associated with F-region height rise observed after 22:00LT on magnetically disturbed days with fresh generation supports the finding of these authors. It should be noted that higher altitudes favor the generation of R–T plasma instability, but that is not the only condition which decides the occurrence of ESF irregularities through R–T plasma instability. Recently using three-dimensional nonlinear evolution of EPB, Keskinen and Vadas (2009) have shown that nearly zonal propagating gravity waves are needed to excite equatorial ionospheric bubbles in the presence of zonal tidal winds. The magnetically disturbed days without the fresh generation of EPBs do not show considerable difference in power spectral characteristics of ESF irregularities as compared to their quiet time pattern.

6. Summary and conclusions

In order to get information about structuring and evolution of ESF irregularities during magnetically disturbed and quiet days, power spectral analysis of weak scintillations ($0.15 \leq S_4 \leq 0.5$) for

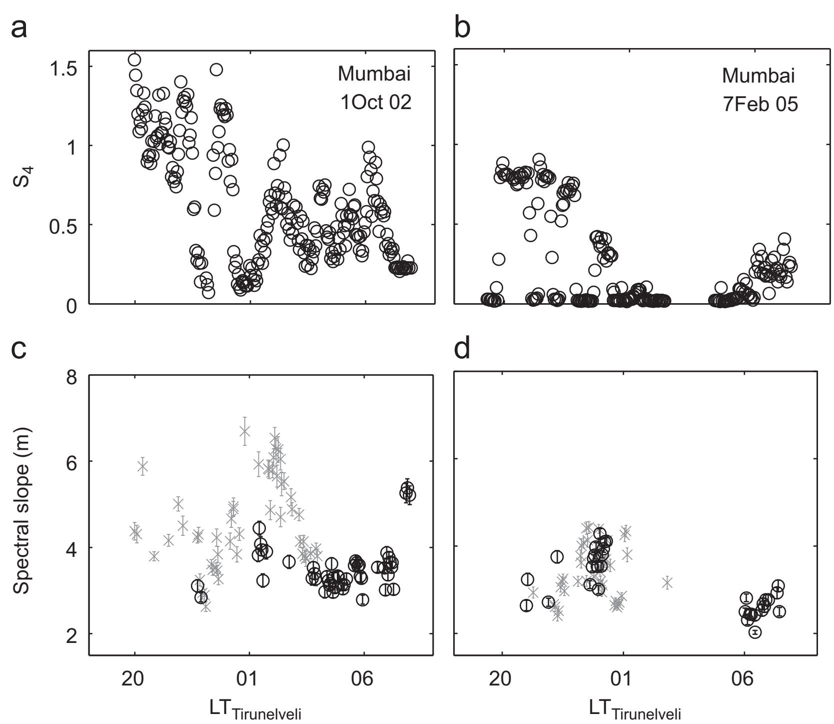

Fig. 7. (a, b) S_4 index, (c, d) power spectral index, m for disturbed days; 1 October 2002 and 7 February 2005 for off equatorial station Mumbai as a function of LT of Tirunelveli. LT_{Mumbai}=IST-0.66 (h). Monthly quiet time variation of spectral index, m, is shown by gray color in background.

eight magnetically disturbed days namely; 23 March 2003, 1 October 2002, 14 July 2000, 9 March 2004, 7 November 2001, 23 January 2000, 7 February 2005, and 24 December 1995 together with their monthly quiet days is carried out. For this purpose (i) spaced receiver scintillation on a 251 MHz signal recorded at dip equatorial station Tirunelveli, (ii) single receiver scintillation measurements recorded at Mumbai on same frequency and (iii) ionosonde data recorded at Trivandrum are utilized. It is reported earlier that sometimes EPBs are triggered in the post sunset hours as a result of magnetic activity. Identification of these freshly generated EPBs is extremely important, when the effects associated with geomagnetic disturbances are studied. The maximum cross-correlation of intensity variations of ground scintillation pattern $C_I(x_0,t_m)$ is used to identify the freshly generated EPBs (Bhattacharyya et al., 2002). Scintillation events with $C_I(x_0,t_m)<0.5$ occurring after 22:00LT are considered as a proxy for the freshly generated ESF irregularities. Magnetically disturbed days are separated into two categories as, days "with" and "without" fresh generation of EPBs. Some of the main outcomes of present study are summarized below:

1. It is found that drift of ground scintillation pattern V_0, which is close to zonal plasma drift after $\sim 22:00$LT, deviates significantly from their monthly quiet time pattern on all eight disturbed days studied here.
2. Although effect of magnetic activity on V_0 is clearly observed for all eight nights, the altered ionospheric electric field resulted from magnetic activity has triggered the fresh generation of EPBs only on four disturbed days.
3. The monthly quiet time power spectral index, m, follows a well defined pattern with a midnight notch, which is in agreement with the earlier reports by Spatz et al. (1988).
4. It is found that freshly generated ESF irregularities, as a result of magnetic activity, are likely to have small scale lengths.
5. Enhancement in F layer base height, h'F, is seen prior to the fresh generation of EPBs on magnetically disturbed days.
6. It is found that increase in h'F is followed by decrease in $C_I(x_0,t_m)<0.5$ approximately after average time of 0.85 h.
7. Two-dimensional power spectral index m shows tendency to decrease with decreasing $C_I(x_0,t_m)$ for the magnetically disturbed days with the fresh generation of EPBs.
8. Power spectral index may be used to identify the freshly generated EPBs triggered by magnetic activity, when values of $C_I(x_0,t_m)$ computed from spaced receiver scintillation data are not available.

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