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Spectral characteristics of magnetic storm-induced F-region scintillations extending into daytime

H. Chandra,* G. D. Vyas,* B. M. Pathan† and D. R. K. Rao†

* Physical Research Laboratory, Navrangpura, Ahmedabad, India 380 009
† Indian Institute of Geomagnetism, Colaba, Bombay, India 400 005

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Abstract—Magnetic storm-induced F-region scintillations extending into daytime were recorded over Bombay, situated near the anomaly crest region in India, on 12 November 1991. The scintillations at 244 MHz using the radio beacon onboard FLEETSAT (73°E), lasted till 1312 h IST (77.5°E). Observations at Trivandrum, situated close to the magnetic equator also show strong daytime scintillations lasting till 1030 h. The scintillation event followed a sudden commencement at 1748 h UT (2318 h IST) on 11 November 1991 and the ionosonde observations, both over Ahmedabad in the anomaly crest region and Kodaikanal near the magnetic equator, show large upward drift of about 50 m s^{-1} around 0300 h IST. The scintillation index S_4, autocorrelation function and power spectra have been computed from the digital data recorded at Bombay. The time variation of S_4 shows large fluctuations with a periodicity of about half an hour. The 50% decorrelation time of the signal fluctuations is of the order of seconds. The spectral index *n*, of the temporal power spectra, where $P(f) \alpha f^{-n}$, varies between 1.5 and 5.0, with a mean value of 3.0, and shows a dependence on the S_4 index. These features are similar to those reported for night time scintillations recorded over Ahmedabad.

1. INTRODUCTION

The night time equatorial F-region is characterized by the presence of intense plasma density structures, covering a wide range of scale sizes (1000 km to a fraction of a meter). These plasma density irregularities are associated with the phenomena of equatorial spread-F as seen in the ionospheric soundings (occurrence of diffuse F-region traces in ionograms), radio wave scintillations in transionospheric propagation and radar backscatter at VHF/UHF. Several studies of these phenomena have been made ever since the discovery of equatorial spread-F by Booker and Wells (1938). In the last two decades multitechnique investigations involving rocket and satellite borne *in situ* measurements, VHF/UHF radar backscatter measurements, satellite scintillation observations and theoretical/numerical simulation studies have greatly advanced our understanding of the phenomenon of equatorial spread-F. Recent reviews describe these works (Fejer and Kelley, 1980; Ossakow, 1981; Basu and Basu, 1985; Chandra, 1990). It is now believed that a hierarchy of processes is responsible for the generation of the irregularities of different scale sizes, a concept first suggested by Haerendel (1973). The plasma density irregularities associated with equatorial spread-F have been classified into different categories (Livingston *et al.*, 1981). These are the planetary scale (>1000 km), medium scale (10–100 km), intermediate scale (0.1–10 km), transitional scale (10–100 m) and the short wavelength scale (<10 m). The generalized Rayleigh–Taylor instability, which includes the electric field and neutral wind terms along with the gravitational term, is considered to be the primary process for the generation of intermediate scale irregularities. Large scale plasma depletions or bubbles thus generated rise fast to cover entire F-region including the topside. Plasma instabilities, operating at steep plasma density gradients, generate smaller scale structures. Drift waves have been thought to be responsible for the generation of irregularities in the transitional scale wavelength.

The radio wave scintillation technique has been used extensively to study ionospheric irregularities over the last four decades. Earlier observations made use of radio stars (Hewish, 1952). With the advent of satellites, radio beacons on board have provided a powerful means for the study of ionospheric irregularities. Radio waves propagating through the irregularities suffer phase fluctuations due to the random changes in the radio refraction index of the medium. As the waves propagate to ground the distorted wavefront sets up an interference pattern resulting in intensity fluctuations. Due to the motion of the irregularities the diffraction pattern formed moves over the ground, resulting in the temporal fluctuations in the phase and intensity recorded at the ground. In the case of phase coherent radio transmissions from satellites one can record both the phase and intensity scintillations. While the phase fluctuation recorded at the ground are truly representative of the irregularities of various scale sizes, the intensity scintillations are limited to the Fresnel scale size $(\lambda z)^{1/2}$ due to the finite distance between the observer and ground. For the radio frequencies used this scale is about a km. Therefore the recording of the intensity of radio beacons from satellites has become a simple and convenient method of studying sub km size irregularities. The scintillation theories have been reviewed by Yeh and Liu (1982). For weak scintillations (thin screen approximation or single scatter approximation) the temporal power spectrum of phase or intensity contains information on the spatial power spectrum of the electron density fluctuations. Also the amount of phase and intensity fluctuations as defined by the rms phase deviations and the scintillation index S_4 (normalized variance of intensity) are related to the electron density fluctuations. The global morphology of scintillations has been reviewed by Aarons (1982).

At low latitudes scintillations are a night time phenomenon and associated with the occurrence of spread-F (Wright *et al.*, 1956; Bhargawa, 1964). In the Indian zone detailed studies of scintillations began during the ATS-6 phase (Rastogi *et al.*, 1977). Morphological features of scintillations at low latitudes in India have been studied both near the magnetic equator and in the anomaly crest region from observations covering a solar cycle (Dasgupta *et al.*, 1981; Pathan *et al.*, 1991). Spectral features of the night time scintillations associated with spread-F have been studied in the equatorial region in India from observations at Thumba (dip 1°N) by Moorthy *et al.* (1979), Ootacamund (dip 6°N) by Bhattacharya and Rastogi (1985); SHAR (dip 14°N) by Chandra *et al.* (1992), and at Ahmedabad near the anomaly crest (dip 34°N) by Vyas and Chandra (1994). There are occasions of strong daytime scintillations associated with the occurrence of blanketing type of sporadic-E, which is a mid-latitude type of sporadic-E with multiple reflections (Iyer and Rastogi, 1978; Chandra *et al.*, 1979). Bhattacharya and Rastogi (1986) have studied the spectral features of daytime scintillations associated with E-region from observations made at Ootacamund near the magnetic equator.

Strong F-region scintillations extending into daytime at low latitudes have been reported to occur on geomagnetically disturbed days. Vats *et al.* (1978) reported a case of F-region scintillations extending into daytime following a sudden commencement type magnetic storm during the ATS-6 phase of observations at Indian stations. Aarons and Dasgupta (1984) have reported similar events of daytime F-region scintillations at Huancayo near the magnetic equator and Ascension Island near the anomaly crest during the major magnetic storm of April 1981. An event of strong F-region scintillations extending into daytime was recorded over Bombay during 12 November 1991 following a sudden commencement. Digital data recorded over Bombay for the daytime scintillations associated with F-region have been analysed for power spectral characteristics and the spectral features studied for the first time for daytime F-region scintillations at low latitudes are reported in the communication.

2. DATA AND RESULTS

As part of the All India Coordinated Programme on Ionosphere Thermosphere Studies (AICPITS) a chain of about 20 stations recording scintillations at 244 MHz using the beacon from FLEETSAT (73°E) operated. Most of the stations recorded data on paper charts. In the present study scintillation data recorded at Trivandrum (8.3°N, 76.9°E, dip 1°N), Anantpur (14.7°N, 77.6°E, dip 15°N), Bombay (19.0°N, 73.0°E, dip 26°N) and Ahmedabad (23.0°N, 72.4°E, dip 34°N) are examined. The locations of the stations are shown in the map in Fig. 1. The arrows are marked to show the locations of the subionospheric points at 400 km (not to scale). The geographic latitude and longitude, dip angle of the station and of the subionospheric point at 400 km are listed in Table 1. Ionosonde data at Kodaikanal (10.2°N, 77.5°E, dip 4°N) near the magnetic equator and Ahmedabad near the anomaly crest are used to study the F-layer height changes during this event. Geomagnetic data from the observatories at Trivandrum and Alibag near Bombay have been used. The ionosonde and the magnetic observatories are also shown in the map in Fig. 1 which also shows the iso-dip lines computed using the IGRF 1991 model.

2.1. *Scintillation observations*

Regular observations of VHF scintillations at the Indian Institute of Geomagnetism at Bombay were started in 1982. Initially data were recorded on paper charts but during 1991 an IBM PC based digital data logger with a sampling frequency of 10 Hz was added. Generally scintillations at Bombay occur in patches of short duration with an average duration of less than an hour. During the month of November 1991

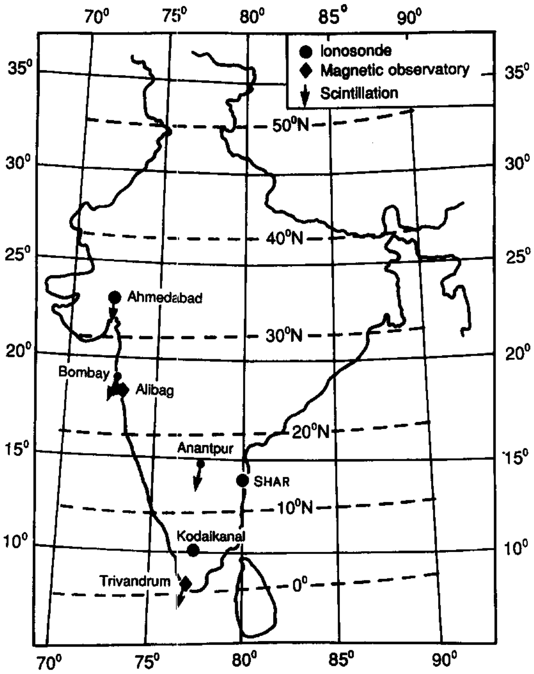

Fig. 1. Map of India showing the locations of the ionosondes, magnetic observatories and the scintillation recording stations for which data have been used in the present study. The arrows indicate the locations of the subionospheric points at 400 km. The iso-dip lines shown are computed from the IGRF 1991 model.

three events of daytime scintillations were recorded. These were on 5 November (0841–0927 h IST), 12 November (0453–1312 h IST) and 22 November (0932–1028 h IST). The scintillations on 12 November were strong and digital data were also available from 0600 h onward. Examples of scintillations on 12 November 1991 from chart recordings over Bombay between 0453–1312 h IST are shown in Fig. 2a,b. The occurrence of the scintillation patches are also marked in Fig. 3 where the depth of scintillation/fading (decibel change of maximum to minimum power levels, which is a simple measure of the strength of scintillations from chart records) and fading period are plotted every 10 min. Scintillations appeared in distinct patches between 2000–2040 h IST, 2130–2354 h IST, 0222–0242 h IST and 0453–1312 h IST. During night time the maximum excursion remained around 20 dB, with no fluctuations as the receiver saturated at this level. After 0530 h IST fluctuations in the peak to peak excursions between 4 dB and 16 dB are observed with a periodicity of about 30 min. The fading was fast in the night time with a period of less than 10 s and could not be estimated due to the limitation of paper chart speed. However, after 0600 h IST fading was comparatively slower and one could estimate the fading period which varied generally between 25 and 90 s. Around 0730 h IST fading became very slow and for about 10 min there were hardly any fluctuations in the signal. This is due to the electric field reversal around this time and the zonal drift velocity becoming westward. Due to the velocity close to zero around 0730 h IST there is no change in the signal strength as the signal pattern (diffraction pattern) was nearly stationary.

Scintillations did not appear at Ahmedabad situated about 500 km north of Bombay. However, strong scintillations extending into daytime were seen at Trivandrum situated near the magnetic equator. Examples of scintillations at Trivandrum between 0624–1027 h IST are shown in Fig. 4. The occurrence of scintillations at Trivandrum during 11–12 November 1991 are shown in Fig. 5 where the peak to peak excursions in dB are plotted every 10 minutes. Scintillations were seen from 2033–0115 h IST and then from 0624 to 1027 h IST. From 0220 to 0600 h IST no data were available due to equipment failure. Therefore the patch that occurred around 0230 h IST over Bombay could not be recorded at Trivandrum. Comparing with the occurrence of scintillations over Bombay in Fig. 3, it is seen that the first patch

Table 1. Locations of the scintillation receivers, ionosondes and magnetic observatories in India for the various data used in the present study

Name of station	Geog. lat. (deg)	Geog. long. (deg)	Dip angle (deg)	Dip angle subionospheric (400 km) (deg)	Data
Trivandrum	8.3 N	76.9 E	1 N	0.9 S	Scintillation Magnetic
Anantpur	14.7 N	77.6 E	15 N	13.1 N	Scintillation
Bombay	19.0 N	73.0 E	26 N	22.9 N	Scintillation
Ahmedabad	23.0 N	72.4 E	34 N	30.7 N	Scintillation Ionosonde
Kodaikanal	10.2 N	77.5 E	4 N		Ionosonde
Alibag (Bombay)	19.0 N	73.0 E	26 N		Magnetic

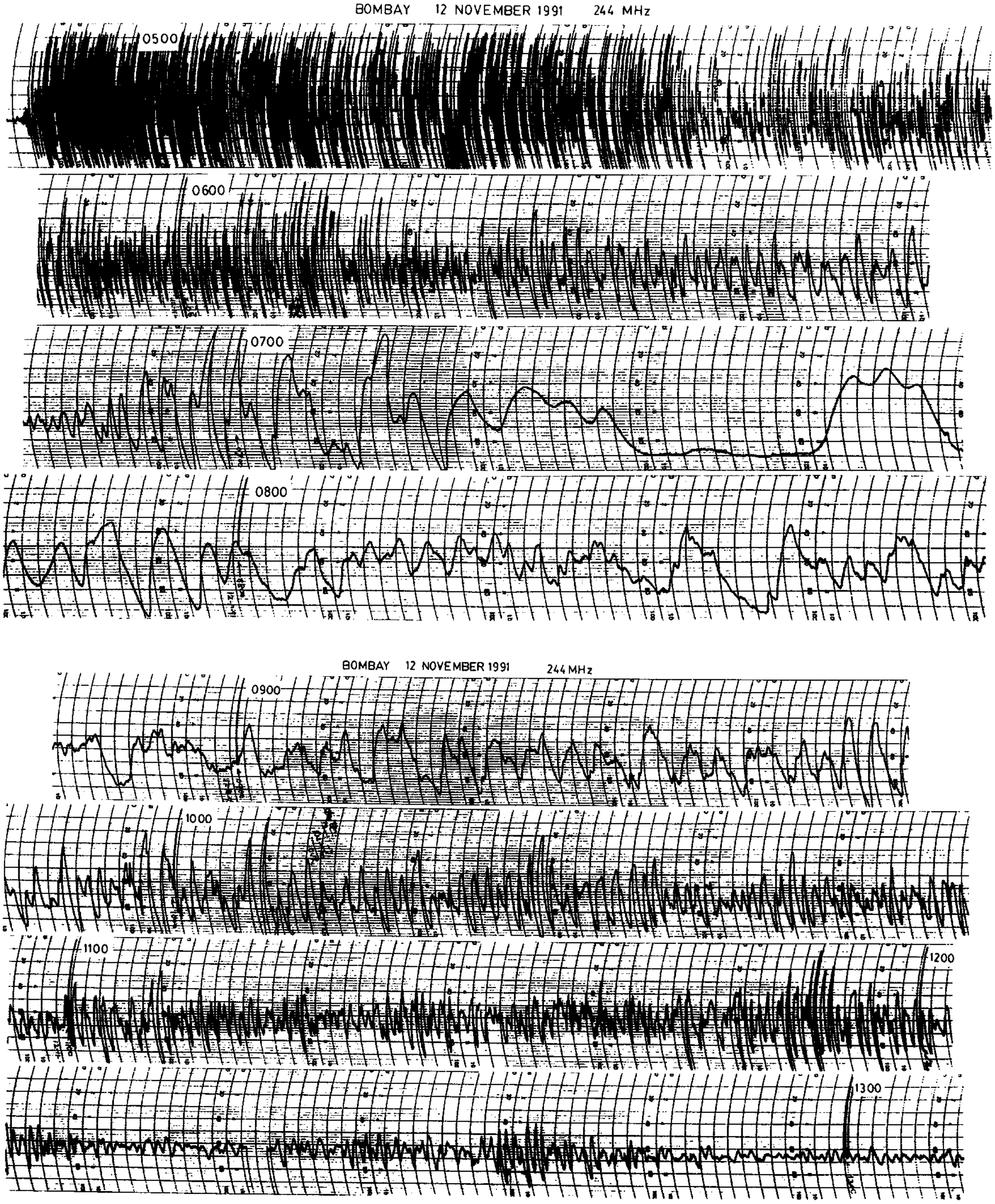

Fig. 2. Examples of the scintillations recorded at Bombay during the period 0453–1312 h IST on 12 November 1991.

appeared 33 min later at Trivandrum. Further, while the scintillations at Bombay were seen in two distinct patches before midnight a single patch is seen at Trivandrum. However, there is a weakening of scintillations at Trivandrum. The depth of scintillations at Trivandrum is lower than at Bombay for daytime

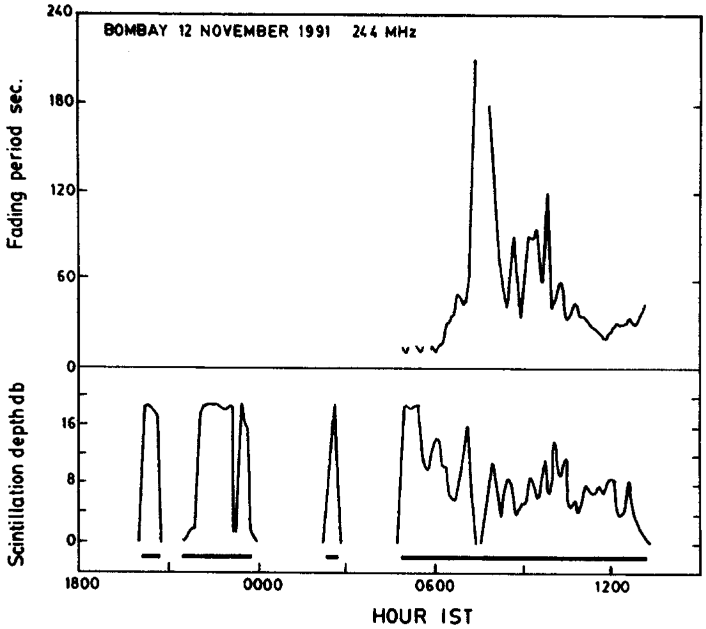

Fig. 3. The occurrence of scintillations at Bombay during 11–12 Nocvember 1991 (time variation of the scintillation depth in dB and of the fading period).

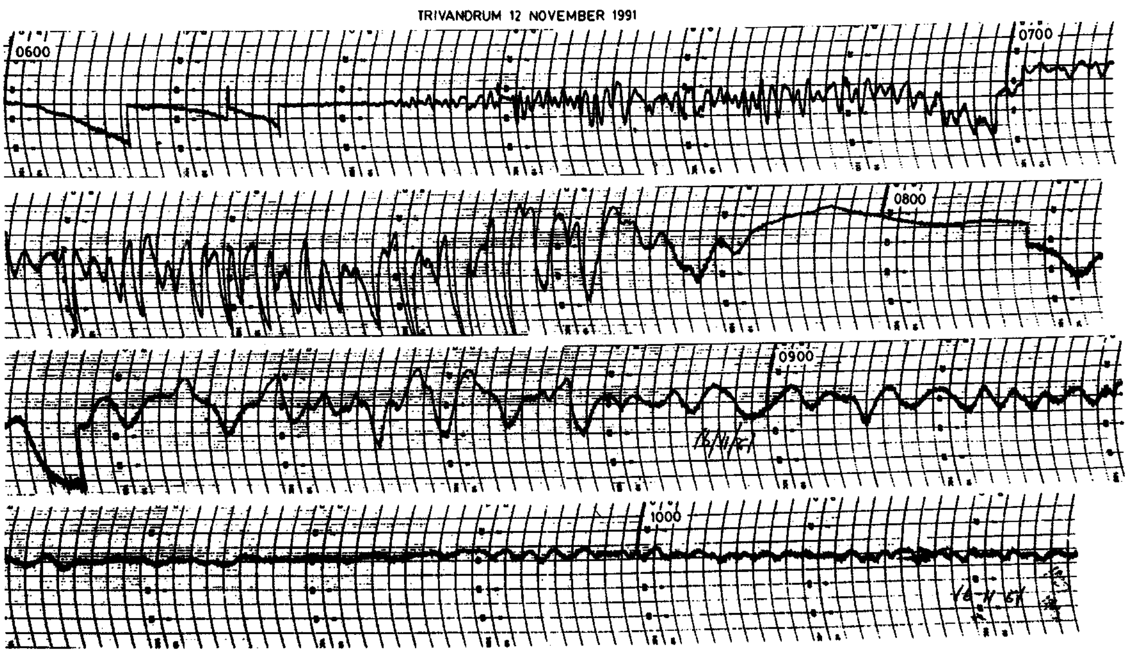

Fig. 4. Examples of scintillations recorded over Trivandrum during the period 0624–1027 h IST on 12 November 1991.

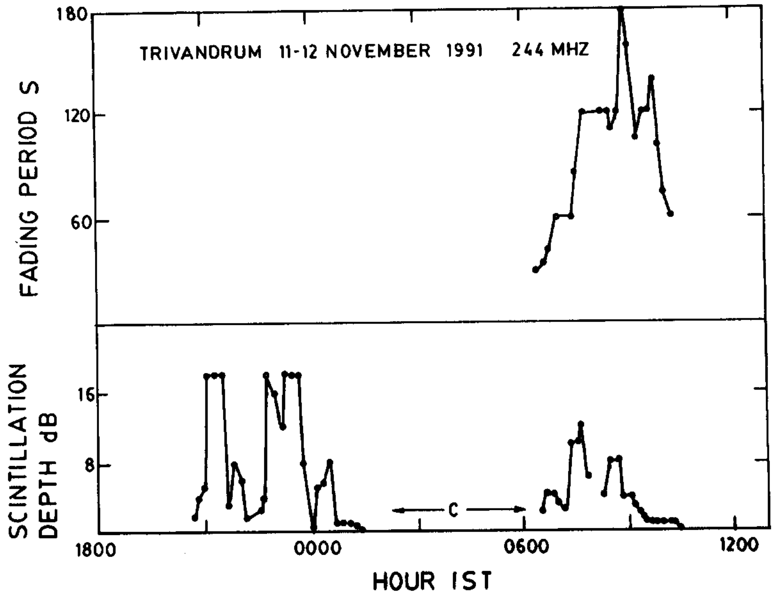

Fig. 5. The occurrence of scintillations at Trivandrum during 11–12 November 1991 (time variation of the scintillation depth in dB and of the fading period).

scintillations. Quasi periodic fluctuations at Trivandrum are not as clear as at Bombay and show a periodicity of about 45 min. The fadings for the daytime scintillations are faster at Bombay, with periods less than 60 s compared with the fading periods of greater than 60 s at Trivandrum. The electric field reversal as inferred from the near constant level of signal occurred around 0800 h IST which is 30 min later than at Bombay.

Scintillation data at Anantpur, situated midway between Bombay and Trivandrum, did not show any daytime scintillations. However, night time scintillations were seen as shown in Fig. 6. Scintillations occurred in three patches between 1943 and 2033 h, 2038 and 0103 h and 0330 and 0440 h IST. Strong scintillations appeared only around 2100 h IST at Anantpur and Trivandrum, about an hour later than at Bombay.

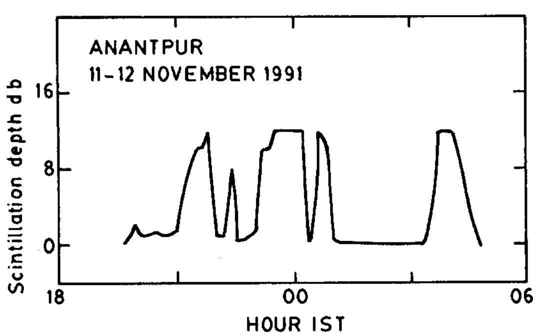

Fig. 6. The occurrence of scintillations at Anantpur during 11–12 November 1991 (time variation of the scintillation depth in dB).

2.2. *Ionosonde observations*

An examination of the ionograms recorded over Ahmedabad did not show the presence of spread-F or blanketing type of sporadic-E. The satellite to receiver (for Bombay) raypath intersection point (subionospheric point) for an altitude of 400 km lies about 150 km south which is about 600 km south of the ionosonde location. Therefore the patch of irregularity extended at the most up to 150 km south of Ahmedabad in the northward direction. The minimum virtual height of the F-layer, h'F (minimum height of reflection of the F-layer echoes obtained from the time delay of the echoes, assuming the group velocity of radio waves to be equal to the velocity of light), over Ahmedabad showed sudden increases. The variation of h'F obtained from quarter hourly ionograms at Ahmedabad is shown in Fig. 7a. For comparison the monthly mean values of h'F are also plotted in the figure. A rapid rise of the F-layer is noted around 2300 h, 0200 h and 0445 h IST. It is interesting to note that the uplift of the F-layer around these times coincides with the onset times of the scintillation patches over Bombay as shown in Fig. 3. The

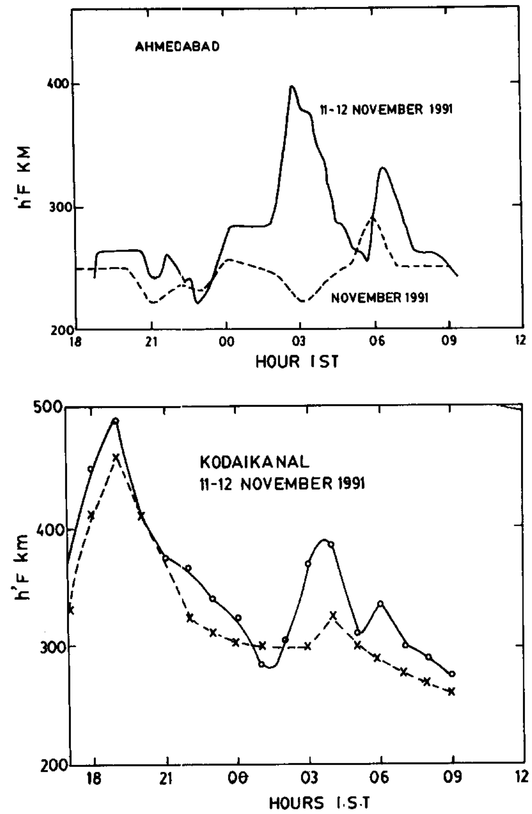

Fig. 7(a). The daily variation of the minimum virtual height of the F-layer, h'F, over Ahmedabad during the night of 11–12 November 1991 (full line). The monthly mean variation of h'F for the month of November 1991 is also shown (dashed line). (b) The daily variation of the minimum virtual height of the F-layer, h'F, over Kodaikanal during the night of 11–12 November 1991 (full line). The monthly mean variation of h'F for the month of November 1991 is also shown (dashed line).

night time changes in h'F can be used to calculate the vertical drift velocity of the F-layer. The increases shown in Fig. 3 amount to a vertical drift velocity of about 50 ms^{-1}). Vertical drifts at the location near the anomaly crest could arise due to electric fields or meridional neutral winds.

The published hourly ionospheric data for Kodaikanal, situated near the magnetic equator, have been examined to study the h'F variations during the night of 11–12 November 1991 and for the monthly mean; these are shown in Fig. 7b. There is a large post sunset height rise up to 490 km during this night which is associated with the onset of spread-F in the post sunset period. There is another big height rise around 0300 h IST which appears to be associated with the scintillation event that persisted till 1030 h IST. Comparing with the monthly mean variation of h'F during November 1991, the variations are similar in the post sunset period. However, the height rise around 0300 h IST on 11–12 November is unusual. A comparison with the variation of h'F over Ahmedabad does show the maximum in h'F in the post-midnight period appearing about 30 min earlier at Ahmedabad than at Kodaikanal. The vertical rise of the F-layer however are of equal magnitude, about 100 km, both at Ahmedabad and Kodaikanal.

2.3. *Geomagnetic variations*

The geophysical conditions during this event were of a moderately quiet period with an *Ap* value of 20 and *Kp* sum value of 26 on 11 November 1991. However, there were sudden commencements recorded on both 10 November at 1353 UT (1923 h IST) and 11 November at 1748 UT (2318 h IST). The quarter hourly values of the horizontal component of the geomagnetic field, H, at Alibag, near Bombay, and Trivandrum are plotted in Fig. 8 to show the daily variations on 11 and 12 November 1991. The difference in H at Trivandrum and Alibag ($H_{\text{Trivandrum}} - H_{\text{Alibag}}$) is also plotted in the figure. The amplitudes of the sudden commencements in H at Alibag and Trivandrum are 25 nT and 27 nT, respectively, on 10 November 1991 (not shown in the figure) and 30 nT and 32 nT, respectively, on 11 November 1991. One notable feature is that there are periodic fluctuations in H at both Alibag and Trivandrum on the morning of 12 November 1991. These are seen up to about 0900 UT (1430 h IST). The sudden commencement around 2318 h IST appears to be coincident with the rise of the F-layer over Ahmedabad.

The difference in the geomagnetic H component at Trivandrum and Alibag is an index of the equatorial electrojet currents. During daytime the currents are eastward as indicated by the positive values of ($H_{\text{Trivandrum}} - H_{\text{Alibag}}$) with a peak near 1000 h IST. There is a clear indication of eastward currents during the post midnight period. The variations of H at Alibag and Trivandrum show marked positive gradients (dH/dt) between 2300 and 0000 h IST and again between 0100 and 0200 h IST. These times coincide with the onset of scintillation patches over Bombay around 2300 h and 0300 h IST. Since the h'F variations show large increases at Kodaikanal and Ahmedabad around 0300 h IST, it appears that the electric fields responsible for the F-layer rise around 0300 h IST are associated with the sudden commencement and could be of high latitude origin.

2.4. *Scintillation results from digital data*

Scintillation data at Bombay were also recorded on a digital data logger from 0600 h IST onward. Each

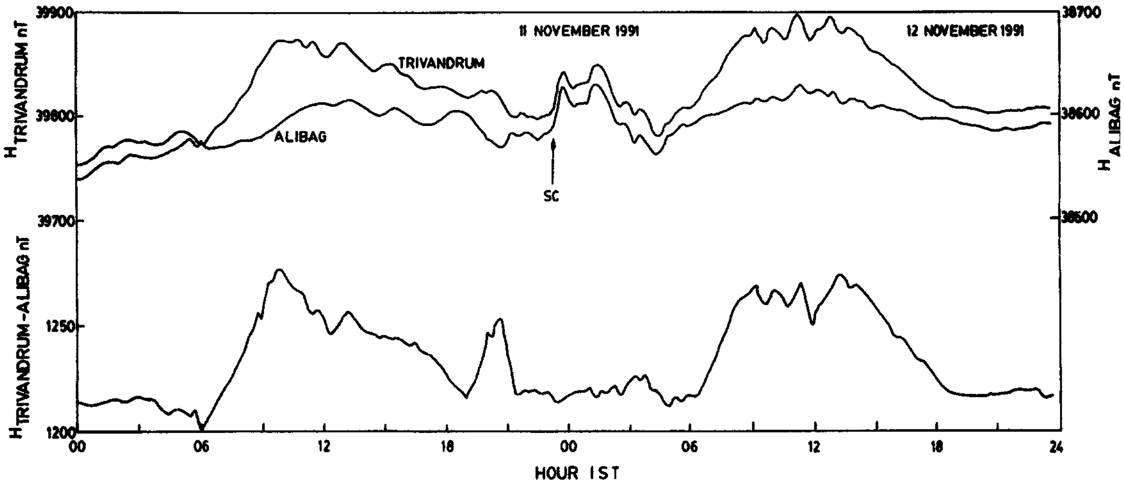

Fig. 8. Daily variations of the geomagnetic H component over Trivandrum and Alibag and of the difference ($H_{\text{Trivandrum}} - H_{\text{Alibag}}$) on 11 and 12 November 1991.

data block was of 400 s duration with 4000 data samples. The scintillation index S_4 has been computed for each data block. The temporal variation of the scintillation index S_4 between 0600 h and 1312 h IST is shown in Fig. 9. Large fluctuations with a periodicity of about 25 min are seen with S_4 varying between 0.1 and 0.7. Comparison with the time variation of the depth of scintillation in Fig. 3 shows a similar periodicity.

Scintillation data were further subjected to power spectral analysis. Autocorrelation functions were first computed for 512 lags. This was later Fourier transformed into power spectral estimates using a standard FFT routine. For smoothing a Hanning window was employed to the autocorrelation function. Two examples of the autocorrelation function are shown in Fig. 10. The first example at 1000 h IST shows a 50% decorrelation time of 8.2 s. The second example at 1130 h IST shows 50% decorrelation time of 4.6 s. The 50% decorrelation time varied between 4.6 s and 8.2 s, with a mean value of 6 s. This value is little higher than the value reported for the night time scintillations from Bombay and Rajkot. The spatial correlation length can be estimated from the 50% decorrelation time once the velocity is known.

The spectral resolution for an autocovariance

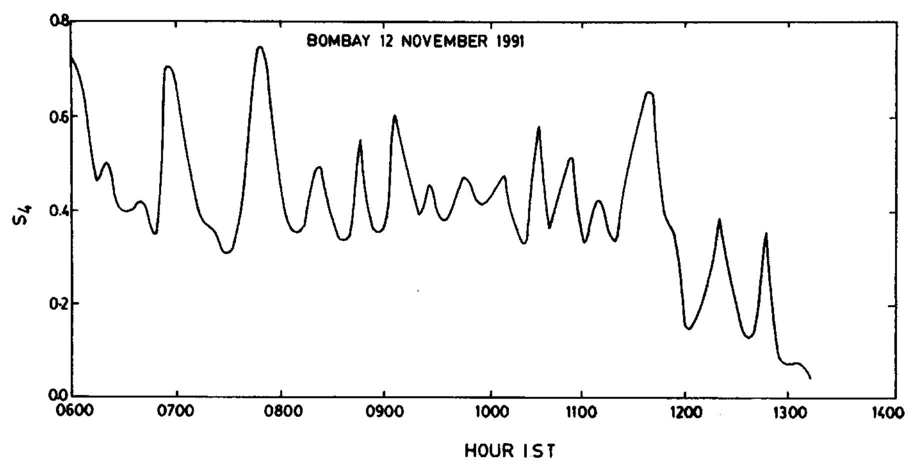

Fig. 9. Time variation of the scintillation index S_4 obtained from the digital data recorded from 0600–1312 h IST on 12 November 1991 over Bombay.

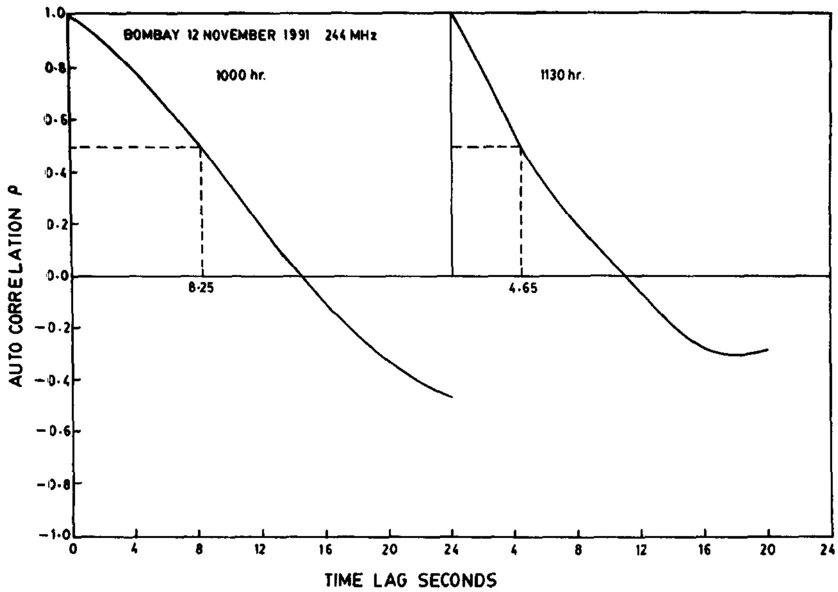

Fig. 10. Examples of the autocorrelation function obtained from the daytime scintillation records at 1000 h IST and 1130 h IST over Bombay.

length of 51.2 s is 0.02 Hz. However, for intensity scintillations the spectra are limited by Fresnel filtering at lower wavelengths. Examples of power spectra for daytime scintillations are shown in Fig. 11. The sampling rate of 10 Hz limits the spectral information to <5 Hz on the high frequency side. Due to the Fresnel filtering effect the part of the spectrum at the lower frequency side is not suitable to study the spectral slope. The Fresnel frequency can be identified from the portion of the spectrum where roll-off begins. Beyond 2 Hz estimates are contaminated by noise. Therefore spectral slopes have been determined by fitting a straight line between 0.1 Hz and 2 Hz. Since there are no velocity measurements, spatial scales cannot be obtained from the temporal spectra. Assuming the drift velocity of irregularities to be between 50 and 100 ms^{-1}, the spatial scales corresponding to 0.1 and 2 Hz would be 25–50 m and 500–1000 m, respectively. Thus the spectral slopes in the irregularity scale size of a few tens of meters to a few hundreds of meters could be studied. The spectral index n defines the spectral form of type $P(f) \alpha f^{-n}$. Power spectra were computed for all data blocks with S_4 index greater than 0.1. Of the 23 samples analysed for power spectra the spectral index varied between 1.5 and 5.0, with a mean value of 3.0 and a median value of 2.9. This is in close agreement with the mean value of 2.8 obtained for night time scintillations at Ahmedabad (Vyas and Chandra, 1994) but less than the mean value of 4.0 for the night time scintillations recorded at SHAR (Chandra *et al.*, 1992).

Scintillation studies both at high latitudes (Kersley and Chandra, 1984) and at low latitudes (Basu and Whitney, 1983; Chandra *et al.*, 1992) show a dependence of the spectral index on the scintillation index. To examine whether such a dependence exists for daytime scintillations the spectral index is plotted against the scintillation index in Fig. 12. The spectral index does show a dependence on scintillation index S_4 similar to the night time scintillations.

3. DISCUSSION

Generally the occurrence of spread-F or scintillations is inhibited at low latitudes on geomagnetically disturbed days and particularly in the pre-midnight period. This has been related to the reduction in the post sunset rise of F-layer in the equatorial region. However, there have been reports of severe spread-F or scintillations present on some magnetic storm days. Rastogi and Woodman (1978) reported instances of the reversal of the electric fields in the post midnight periods from the VHF backscatter radar measurements at Jicamarca. Strong range type of spread-F was shown to develop following the rise of F-layer. The events were related to the southward turning of the interplanetary magnetic field. Rastogi and Aarons (1980) have also observed

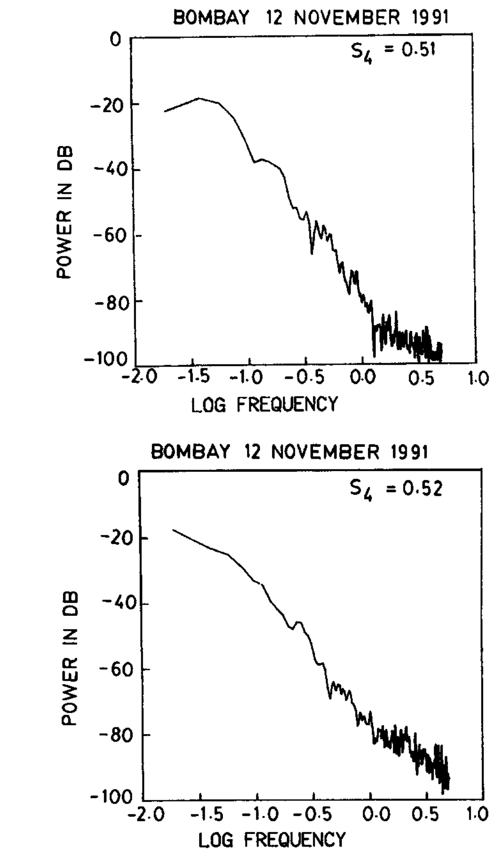

Fig. 11. Examples of the power spectra obtained from the daytime scintillations recorded over Bombay on 12 November 1991.

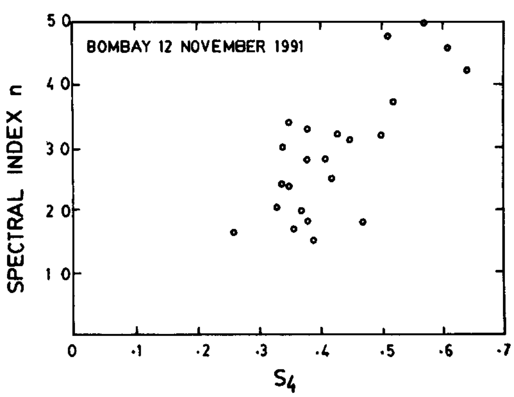

Fig. 12. Variation of the spectral index n with the scintillation index S_4 obtained from the daytime scintillation recorded over Bombay on 12 November 1991.

the reversal of vertical drift to upward during night followed by instances of scintillations in the post midnight period on geomagnetic storm days.

Vats *et al.* (1978) reported an event of daytime scintillations in the anomaly crest region in India following a magnetic storm that occurred with a sudden commencement around midday on 10 January 1976. The results were based on the polarization scintillations (fluctuations in the Faraday rotation or the plane of polarization as seen in the Faraday rotation measurements) made at a chain of stations in India during the ATS-6 phase. During the night time, polarization scintillations were seen right from the magnetic equator to well beyond the anomaly crest region. However, during daytime (midday) the scintillations were seen only at latitudes near the anomaly crest and North of it. The magnetogram at Kodaikanal, near the magnetic equator, on 11 January 1976 showed periodic fluctuations superimposed on the storm time variation. It was concluded that the daytime scintillations over the anomaly crest region were due to the northward movement of the irregularity patch. Similar events of daytime scintillations have been reported by Aarons and Dasgupta (1984) at other longitude region. They studied the scintillation events generated in the post midnight period and extending into daytime at Huancayo near the magnetic equator and at Ascension Island near the anomaly crest region during the major magnetic storm event of April 1981. They suggested that the probability of occurrence of the post-midnight scintillations is enhanced if a positive dH/dt following a negative excursion maximum of H is obtained in the post midnight to dawn sector with the local magnetogram. Dasgupta *et al.* (1985) studied a number of scintillation events extending into daytime and related them to the maximum negative excursion of the horizontal intensity of the geomagnetic field occurring in the 0000–0600 h local time interval. Aarons (1991) examined a large number of magnetic storms, primarily in the high solar flux period during 1971—1981, and concluded that, if the maximum ring current energy as shown by Dst occurred during the midnight to post midnight period, irregularities were generated. If the maximum Dst occurred in the early afternoon, irregularities were inhibited. In the case that the maximum occurred around sunset or shortly after sunset, then there was no effect on the generation of the irregularities that night. The study was based on scintillation data at different longitude zones. Woodman *et al.* (1985) detected spread-F like irregularities during daytime (1400–1600 h local time) extending from 600 km to 1000 km in the topside from the VHF backscatter radar at Jicamarca.

Rastogi and Woodman (1978) showed electric field reversals in the post midnight period associated with the southward turning of the interplanetary magnetic field (IMF). Fejer *et al.* (1979) studied the correlations between the anomalous changes in the equatorial electric fields and IMF, and concluded that it is the changes in the magnetospheric electric fields and auroral zone electric field which alter the world wide ionospheric current flow and electric field pattern. They also concluded that the equatorial electric field perturbations usually occur at the onset of a substorm or at the onset of a substorm recovery phase. Gonzales *et al.* (1979) examined simultaneous auroral and equatorial electric field data along with magnetic field data to study the anomalous electric field patterns during disturbed conditions. During some substorms the world wide equatorial zonal electric field reverses. In several cases the zonal equatorial electric field component was nearly identical in form to the zonal auroral component, indicating the close electrical coupling between these regions. It is known observationally that the substorm related electric fields at high latitudes penetrate to low latitudes (Reddy *et al.*, 1981). Recently Reddy *et al.* (1994) reported from VHF backscatter radar, ionosonde and magnetometer measurements at Trivandrum large amplitude ionospheric and magnetic field fluctuations associated with a Pc5 micropulsation event which occurred during an intense magnetic storm on 24 March 1991. The fluctuations were dominated by a near sinusoidal oscillation of 10 min period. Simultaneous fluctuations in magnetic field (100 nT) were also observed at high latitude stations in Denmark and Greenland. The observations were interpreted in terms of a compressional cavity mode resonance in the inner magnetosphere and the associated ionospheric electric field penetrating from high latitude to the magnetic equator.

The present observations of the F-region scintillations extending into daytime, both at Bombay near the anomaly crest and at Trivandrum near the dip equator, appear to be associated with the electric fields of high latitude region penetrating to low latitudes. This is supported by the positive dH/dt in the post-midnight period and the oscillatory changes in the geomagnetic H component at Alibag and Trivandrum following the sudden commencement that occurred during the night of 11 November 1991. Large vertical drifts of about 50 ms^{-1} around 0300 h IST observed both at Kodaikanal near the magnetic equator and at Ahmedabad near the anomaly crest also lead us to believe that these effects are of high latitude electric field origin rather than of local origin. The maximum in $h'F$ in the post midnight period occurred about 30 min earlier at Ahmedabad. This time delay of 30 min cannot be accounted in terms of equatorwind neutral winds, which are typically of the order of 100–200 ms^{-1}. Further, the meridional winds, though efficient in the vertical lifting of the F-layer for latitudes close to the anomaly crest, will not be effective at the dip equator. Equal magnitudes of vertical drift at the dip equator and at the anomaly crest can only be explained in terms of the electric fields of high latitude origin.

The onset of scintillations in the post-sunset period during this night is as usual associated with the post-sunset rise of the F-layer near the dip equator as seen from the large rise of $h'F$ over Kodaikanal. The absence of scintillations from observations recorded over Ahmedabad shows that the northern limit of the equatorial belt of scintillations during this night was at least 150 km south of Ahmedabad. Simultaneous observations of scintillations made at the chain of stations in India, during the campaign of March–April 1991, have shown that scintillations appear first in the equatorial region and with a systematic time delay at higher latitudes (Chandra *et al.*, 1993). This is consistent with the concept of rising plasma depletions or bubbles which are generated in the postsunset equatorial F-region. As the bubbles rise, the field-aligned depleted regions extend to latitudes farther and farther from the dip equator. However, on this particular night, the scintillations appeared about an hour earlier at Bombay than at Trivandrum in the equatorial region. This feature is difficult to understand as there was no height rise in the post sunset period in the anomaly crest region as seen from the observations over Ahmedabad.

The patch of scintillations which extended into daytime appeared first at Bombay, then at Trivandrum, and lasted for a much longer time than at Trivandrum. This shows that the generation of this particular patch was in the anomaly crest region itself. The absence of scintillations at Anantpur, situated midway between Bombay and Trivandrum is also difficult to explain. If the effect is related to electric fields of high latitude origin penetrating to low latitudes we would expect a rising F-layer, and therefore the generation of irregularities to be present at different latitudes. Thus other factors must be responsible for the generation of irregularities. The presence of large scale plasma density gradients and neutral winds could be factors explaining the variability in the occurrence of scintillations. Monitoring of the large scale plasma depletions from all sky imaging camera and the neutral wind measurements from the Fabry–Perot spectrometer observations using 630 nm night airglow emission along with the VHF scintillations and ionosonde observations at sites in the equatorial and anomaly crest regions are important to understand the different aspects of the F-region irregularities associated with the phenomena of equatorial spread-F and scintillations.

The scintillation index S_4 during the period of observations from 0600 h to 1312 h IST showed large fluctuations between 0.1 and 0.7, with a periodicity of about 30 min. Spectral slopes of the power spectra varied between 1.5 and 5.0 with a mean value of 3.0. This is in agreement with the mean value of 2.8 obtained from the night time scintillations recorded over Ahmedabad (Vyas and Chandra, 1994) in the anomaly crest region, but less than the mean value of 4.0 for the night time scintillations recorded over SHAR (Chandra *et al.*, 1992) in the equatorial region. The period of observations for the power spectral studies reported for Ahmedabad and SHAR were, however, for different periods. The spectral index shows a linear increase with the scintillation index which is in accordance with the earlier results from the night time scintillations recorded over SHAR and Ahmedabad and also with the increase in the spectral index (one dimensional) of the rocket-borne Langmuir probe measurements of the *in situ* electron density fluctuations, over SHAR, with the spectral power of fluctuations in the irregularity scale size of 20–200 m (Prakash *et al.* 1991). The reversal of the electric field as inferred from the increase of fading period and near absence of signal fluctuations for a short time in the morning (around 0730 h IST at Bombay and 0800 h IST at Trivandrum) does not seem to have any effect on the nature of scintillations at either of the stations. Once generated, the role of the electric field appears to be only in the drift motion of the irregularity patch.

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