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Co-ordinated multistation VHF scintillation observations in India during March-April 1991

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A number of VHF scintillation stations are currently operating in India as part of the All India Co-ordinated Programme of Ionospheric and Thermospheric Studies (AICPITS). The chain covers latitudes right from the magnetic equator to beyond the anomaly crest region. During March-April 1991 co-ordinated observations were made at all the stations of the chain and the data collected analysed jointly. The quarter-hourly values of the occurrence of scintillations along with the start and end times of the patches of scintillations during each night form the data base. Nocturnal variations of the percentage occurrence of scintillations, histograms of percentage occurrence of the number of patches of scintillations during the course of a night and of the patch duration have been computed for each station. Scintillations generally start between 1930 and 2000 hrs IST. The stations close to the magnetic equator show strong scintillations which last till early morning in a single patch or sometimes with a weakening or absence of scintillations for a short time duration. For the stations in the anomaly crest region or beyond, scintillations occur in small patches with periods of no scintillations in between. The nocturnal variations show maximum scintillation activity of about 50 per cent in the equatorial region which drops to about 30 per cent in the anomaly crest region and further reduces to 10 per cent at Delhi, the Northern-most location in the chain. From the latitudinal variations of the percentage occurrence of scintillations, the half width of the equatorial belt of scintillations has been found to vary with local time. It extends right up to Bombay or even beyond it around 2000-2200 hrs but is much narrower after midnight. The occurrence of spread-F during March-April 1991 from ionosonde data at Thumba, Waltair and Ahmedabad representing stations in the equatorial zone, intermediate zone and the anomaly crest zone have been studied. There is a fairly good agreement between the nocturnal variations of spread-F and scintillations.

1 Introduction

Nighttime magnetic equatorial F-region is a seat of intense plasma density irregularities encompassing scales from about 1000 km to a fraction of a metre. These plasma density irregularities give rise to the phenomenon of equatorial spread-F as seen in ionospheric sounding, intense radiowave scintillations in transionospheric propagation and radar backscatter signals. Several studies of these phenomena have been made ever since the discovery of equatorial spread-F by Booker and Wells[1] in 1938. Early studies, primarily based on ionosonde data, had shown the equatorial spread-F occurring in the post-sunset period, following a rapid rise of the F-layer and inhibition due to magnetic activity[2,3]. The solar cycle variation of the equatorial spread-F is longitude dependent with a negative correlation in American zone and a positive correlation in the Indian and African zones[4]. Over the last two decades multitechnique measurements such as rocket-borne and satellite-borne *in situ* measurements of the plasma density fluctuations, satellite radio beacon studies of scintillations, coherent and incoherent backscatter radar and other ground-based experiments like ionosonde and airglow measurements have been made extensively. These measurements along with modelling/simulation studies have greately added to our knowledge of the phenomenon of equatorial spread-F. Recent reviews[5-9] cover these aspects. It is believed that large scale plasma depletions are generated first in the post-sunset period through Rayleigh-Taylor instability and then these depleted regions rise fast to cover the entire F-region including topside ionosphere. Plasma processes then give rise to instabilities acting on the steep gradients available and generate smaller and smaller scale sizes in a cascade process[10]. Since the equatorial spread-F irregularities extend along the field lines, higher the altitude of plasma depletions, wider the latitudinal extent of the irregularities. However, there are still a number of points not understood yet. These include the day-to-day variability in the occurrence of spread-F, the characteristics of the plasma density fluctuations in different scale sizes, and the mechanisms of generation.

Monitoring of the radio beacons onboard satellites provides a simple and convenient way of studying the irregularities associated with equatorial spread-F. The fluctuations in the signal strength, often characterized by some form of scintillation index, are directly related to the fluctuations in electron density. Scintillations therefore provide a unique method of studying the temporal spectral behaviour of the electron density fluctuations. Knowledge of the velocity of irregularities enables conversion of the temporal information into a spatial one. India provides a unique geographical feature of covering latitudes right from magnetic equator to well beyond the anomaly crest region. Thus a chain of scintillation receivers distributed closely can provide both the temporal and spatial variations in the occurrence patterns of scintillations. With this aim a number of scintillation recording stations were set up under the All India Co-ordinated Programme of Ionospheric and Thermospheric Studies (AICPITS). A specific campaign was conducted during the months of March-April 1991 for co-ordinated observations using the 244 MHz radio beacon from Fleetsat (73°E). The data collected at sixteen stations covering dip equator to 40° dip were analysed jointly at a workshop held at Kolhapur during 3-8 June 1991. The features of scintillation at Indian stations for this period are summarized in this paper.

2 Observations and data

The stations with scintillation recordings in this period are shown in Fig. 1. Table 1 lists the geographical latitude and longitude, dip angle and also the dip angle of the subionospheric point computed at 400 km for these stations. The receivers at the majority of stations were developed at the Indian Institute of Geomagnetism, Bombay, with recording on chart papers. Apart from chart recording, digital data recordings were available at Ahmedabad and Delhi. In the present study, however, the analog chart data at all the stations have been used. On examination of the records following information has been compiled for each day of the data collected at various staions: (i) start time and end time of every patch of scintillations, and (ii) presence of scintillations every quarter hourly (± 7.5 min).

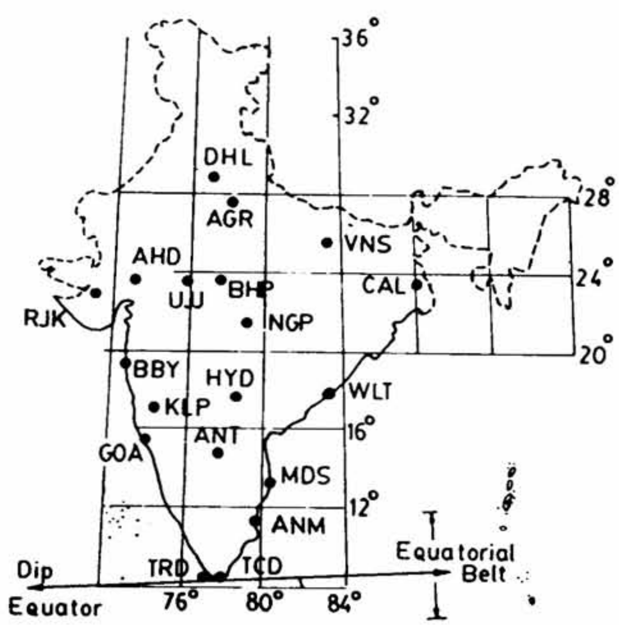

Fig. 1—Locations of stations in India recording VHF scintillations under AICPITS (TRD, Trivandrum; TCD, Tiruchendur; ANM, Annamalainagar; MDS, Madras; ANT, Anantpur; GOA, Goa; KLP, Kolhapur. BBY, Bombay. HYD, Hyderabad; WLT, Waltair; RJK, Rajkot; AHD, Ahmedabad; UJJ, Ujjain; BHP, Bhopal; NGP, Nagpur; CAL, Calcutta; VNS, Varanasi. AGR, Agra; and DHL, Delhi).

Table 1—Locations of the scintillation recording stations in the Indian region

Name of station	Geog. lat. deg	Geog. long. deg	Dip angle deg	Dip angle of subionospheric point at 400 km deg
Trivandrum	8.3	76.9	−0.6	−0.6
Tiruchendur	8.3	78.1	−0.7	−0.5
Annamalainagar	11.4	79.4	7.6	6.0
Goa	15.2	74.0	17.2	14.9
Kolhapur	16.7	74.2	20.6	18.1
Waltair	17.7	83.3	21.9	19.3
Bombay	19.0	73.0	25.7	22.9
Nagpur	21.1	79.1	29.5	26.6
Rajkot	22.3	70.7	32.6	29.6
Calcutta	22.6	88.4	31.9	28.7
Ujjain	23.2	75.8	33.9	30.8
Ahmedabad	23.0	72.4	33.8	30.7
Bhopal	23.2	77.6	33.8	30.7
Varanasi	25.3	83.0	37.3	34.0
Agra	27.2	78.0	41.0	37.7
Delhi	28.6	77.2	43.7	40.2

3 Results

3.1 Characteristics of scintillations

The characteristics of scintillations occurring at the stations along the entire chain can be broadly classified into two types. The one occurring at stations close to the magnetic equator with onset of scintillations in the post-sunset period and strong scintillations lasting throughout the night. Figure 2 shows one such example with recordings at Tiruchendur during the night of 18-19 Mar. 1991. Scintillations started around 2030 hrs and lasted beyond 0500 hrs in the morning as shown in the figure. Though there were brief periods when scintillations weakened for a while, namely, between 2040 and 2047, around 2115, 0225 to 0237 and 0315 to 0325 hrs. Later after 0400 hrs scintillations were observed to be comparatively weaker. In contrast Ujjain, a station situated at the anomaly crest region, showed on the same night scintillations intermittently lasting for an hour or even for a smaller period with patches in between (Fig. 3). The scintillations started around 2040 hrs for a minute or so and then reappeared again around 2050 hrs. This patch lasted till around 2200 hrs. There were three more patches till 0200 hrs. In the pre-sunrise period (after 0300 hrs) scintillations were weaker. One point of interest, however, is that both at Tiruchendur and Ujjain the onset or disappearance of scintillations was abrupt.

The occurrence characteristics of scintillations at Tiruchendur in the equatorial region, at Bombay situated in between the equatorial zone and the anomaly crest zone, and at Ahmedabad situated in the anomaly zone are also shown in Figs 4(a), (b) and (c) respectively for the entire period of the campaign. The length of the lines denotes the time period for which scintillation activity was present. It is apparent that the number of days with scintillation activity was maximum at Tiruchendur, less at Bombay and least at Ahmedabad. Another point worth noticing is that on days when scintillations lasted continuously for a longer duration at Tiruchnendur, one sees long duration of scintillations at Bombay also. While on days when scintillations at Tiruchendur occurred in small patches of duration, there was very likelihood of the absence of scintillations at Bombay, for example, on 10 March, 12 March, 27-28 March. Comparing the scintillation characteristics at Ahmedabad one notices that the number of patches of smaller duration was more than those of longer duration seen at Tiruchendur and Bombay.

3.2 Characteristics of patches at different stations

From the examination of the scintillation records at different stations of the chain and tabulation of the scintillation patches, following two parameters of the scintillation patches have been compiled for each station: (i) number of patches during a night, and (ii) time duration of each patch.

Histograms of the percentage occurrence of the number of patches over a night and the time duration of each patch were made for each station. However, we show here the results after grouping the stations in the following four different latitude zones:

(I) Magnetic equatorial zone consisting of the stations Trivandrum, Tiruchendur, and Annamalainagar.

(II) Zone intermediate to the equatorial zone and the anomaly crest zone consisting of the stations Goa, Kolhapur, Waltair, and Bombay.

(III) Anomaly crest zone consisting of the stations Nagpur, Rajkot, Ahmedabad, Bhopal, Ujjain, and Calcutta.

(IV) Zone beyond the anomaly crest consisting of the stations Varanasi, Agra, and Delhi.

The histograms of percentage occurrence of the number of patches during a night for the four latitudinal zones are shown in Fig. 5. For the equatorial zone I, the number of patches is five or less with a median value between 2 and 3 on about 85 per cent of the nights. For zone II, the number of patches is six or less on about 88 per cent of nights with a median value of 3. In the anomaly crest zone III, the number of patches is six or less on about 90 per cent of nights with a median value close to 3. In zone IV, the number of patches is three or less on 90 per cent of the

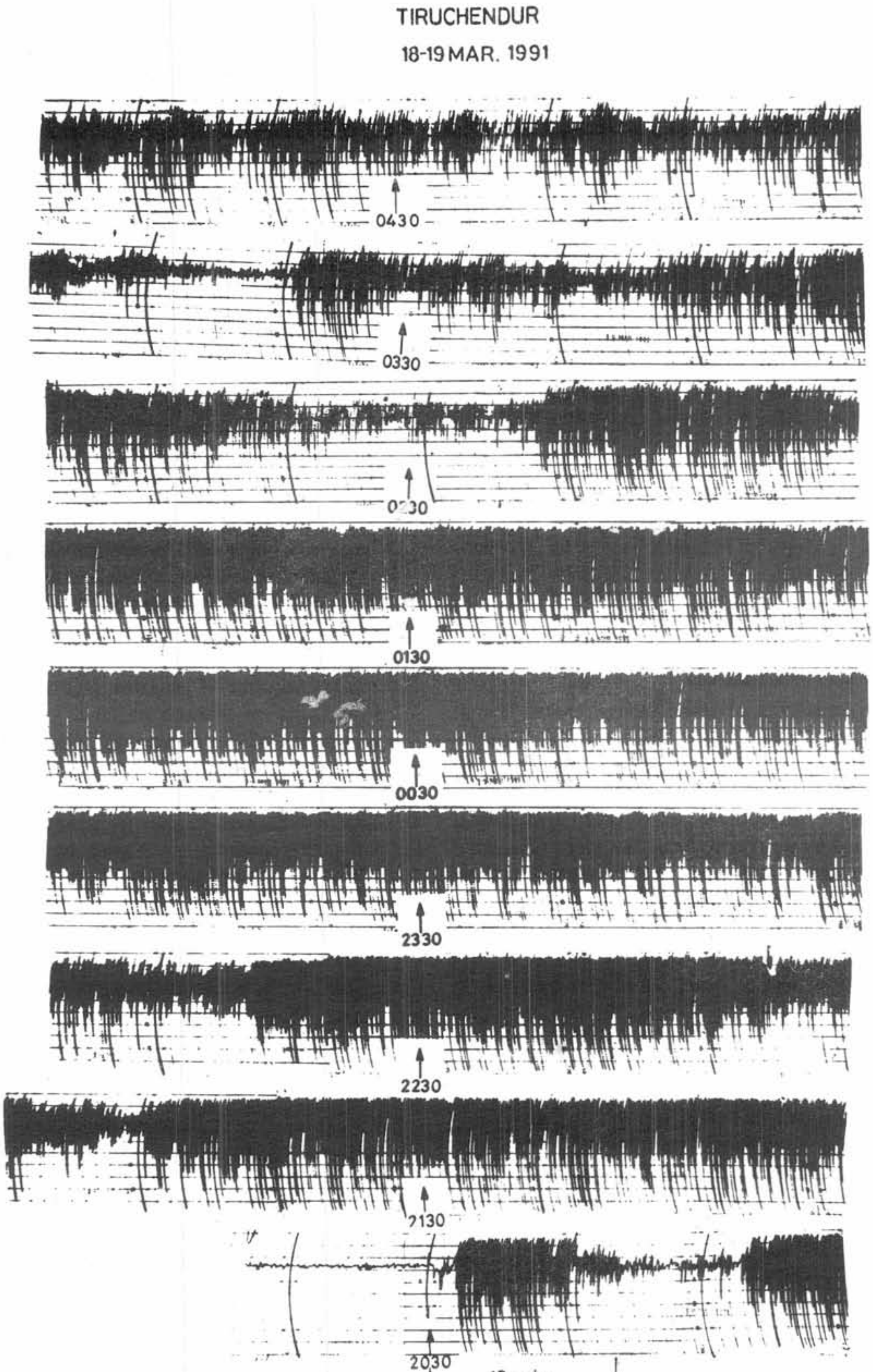

Fig. 2—Typical nighttime long duration scintillation record at an equatorial station, Tiruchendur

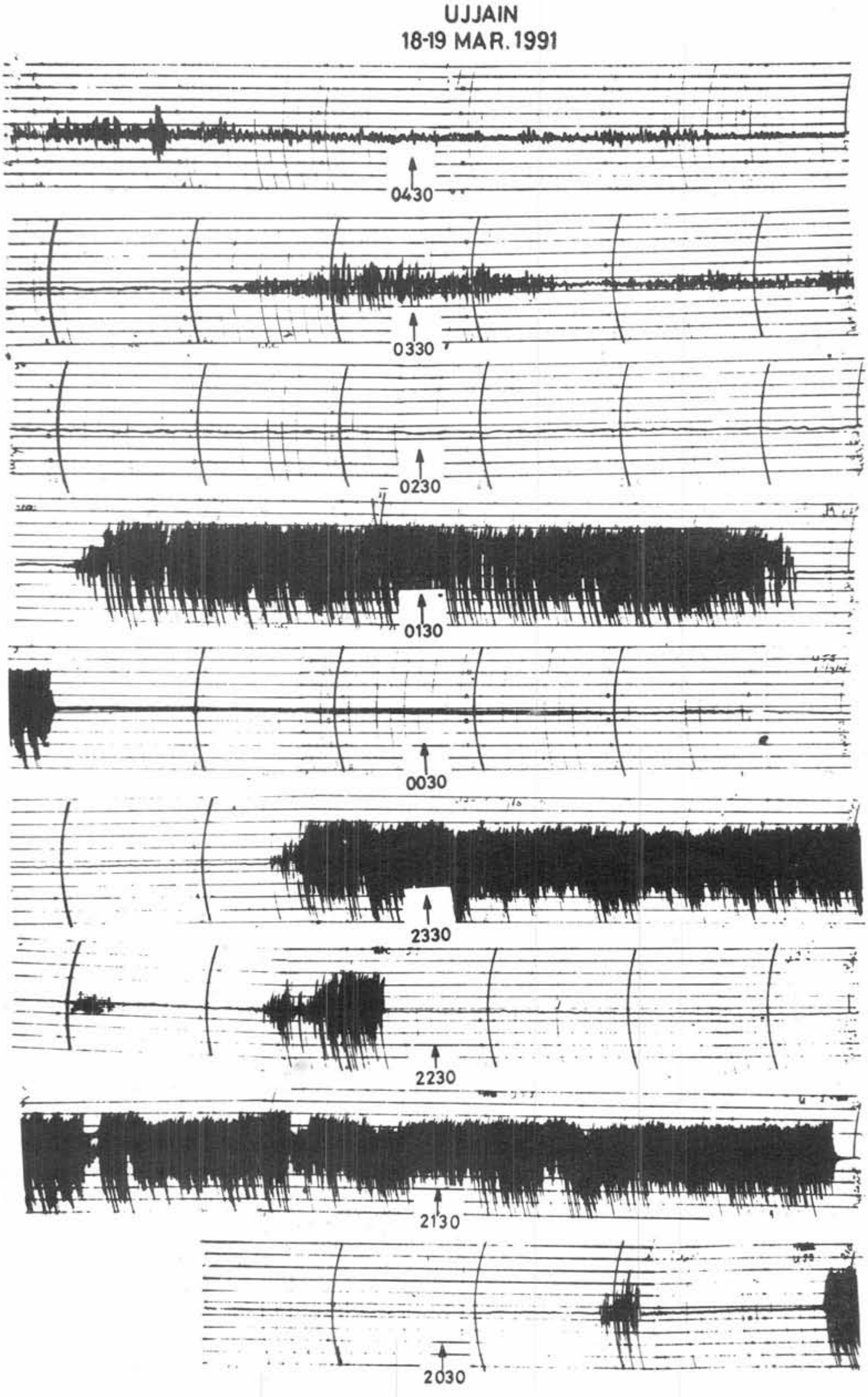

Fig. 3—Typical nighttime scintillation record at Ujjain, a station in the anomaly crest region.

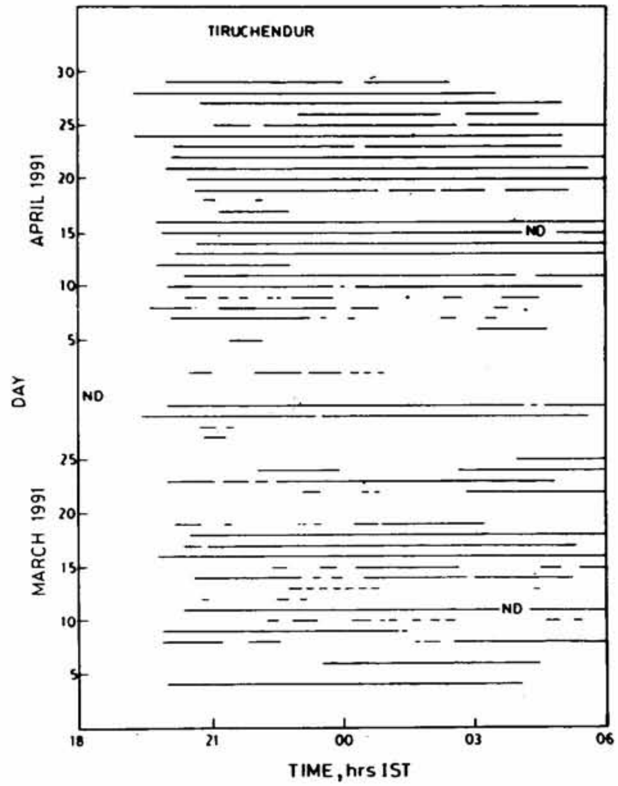

Fig. 4(a)—Daily occurrence of scintillations at an equatorial station, Tiruchendur, during March-April 1991 (ND, No data).

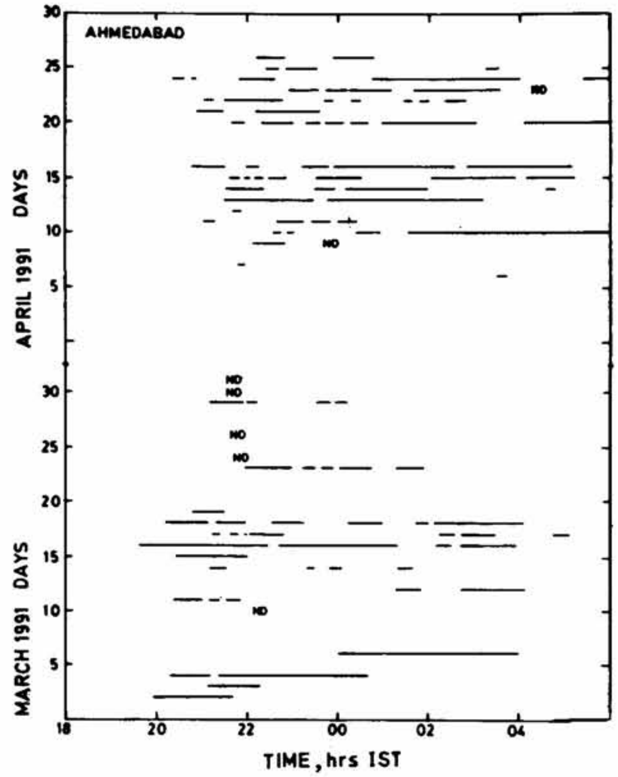

Fig. 4(c)—Daily occurrence of scintillations at Ahmedabad in the anomaly crest region during March-April 1991 (ND, No data).

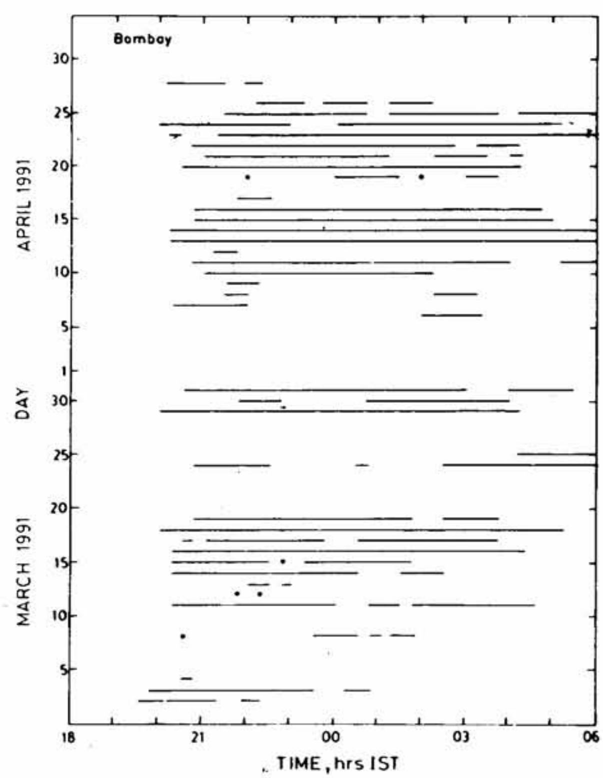

Fig. 4(b)—Daily occurrence of scintillations at Bombay during March-April 1991.

nights. But one must note here that at stations in zone III and zone IV, the occurrence of scintillations is less, and it is absent in these two zones particularly when scintillations do occur in small patches in the equatorial F-region.

The histograms of the percentage occurrence of the patch duration are shown in Fig. 6. In the equatorial zone I, patch duration extends up to 10 h. In zone II, patch duration extends up to 5 h which is again the case in the zones in the anomaly peak region and beyond.

3.3 Onset of scintillations at different latitudes

An examination was made to study the latitudinal variation, if any, on the onset time of the occurrence of scintillations. Figure 7(a) shows an example of the scintillations recorded at a few stations during the night of 11 Mar. 1991. The scintillations started at 2015 hrs at Tiruchendur, at 2028 hrs at Kolhapur, at 2037 hrs at Rajkot, and at 2046 hrs at Ujjain. Thus there is a delay of about half an hour in the onset time of scintillations from magnetic equator to the onset time in the anomaly peak regions. Another example is shown in Fig. 7(b) from the scintillations recorded during the night of 8 Mar. 1991. During this night scintillations started at 2019 hrs at Tiruchendur, at 2139 hrs at Kolhapur, and at 2147 hrs at Bombay,

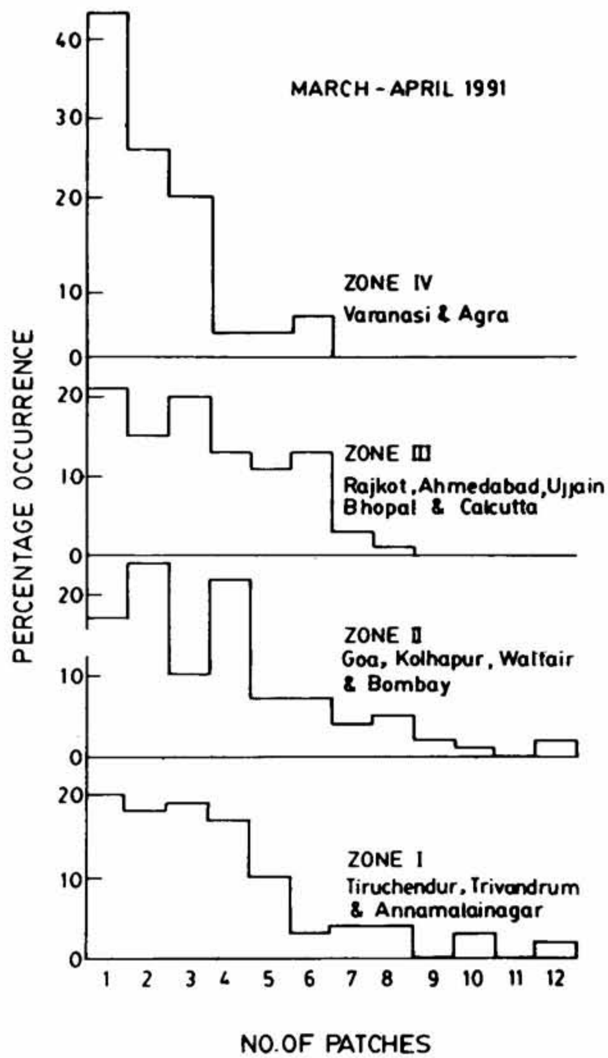

Fig. 5—Distribution of the occurrence of scintillation patches during a night at four different latitudinal zones, namely, (I) Equatorial, (II) Intermediate between equatorial and anomaly crest, (III) Anomaly crest, and (IV) Beyond the anomaly crest.

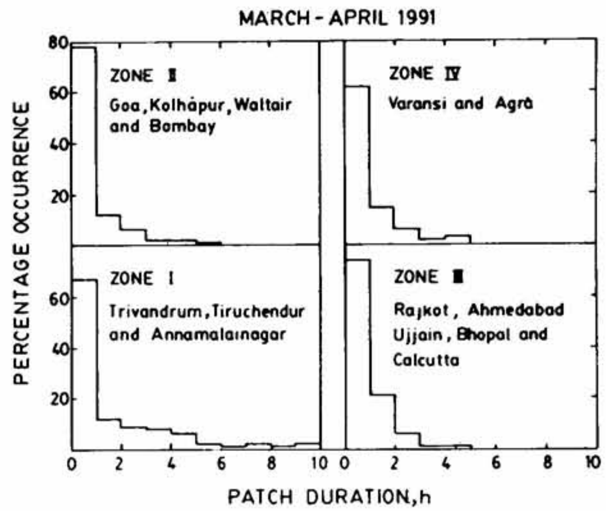

Fig. 6—Distribution of the occurrence of duration of the patches of scintillations at four different latitudinal zones, namely, (I) Equatorial, (II) Intermediate between equatorial and anomaly crest, (III) Anomaly crest, and (IV) Beyond the anomaly crest.

showing a delay of about an hour and a half between Tiruchendur and Bombay. In both the examples the onset of scintillations was sudden. On some occasions the onset of scintillations was slow. Such an example is shown in Fig. 7(c). On 13 Apr. 1991 scintillations started building up slowly from around 1950 hrs at Tiruchendur and strong scintillations set in around 2000 hrs. Similar types of onsets were seen at Goa and Bombay with strong scintillations from 2030 hrs at Goa and at 2045 hrs at Bombay which were preceded by slow scintillations. At Ujjain strong scintillations started around 2200 hrs rather abruptly.

Thus it is clear from the above examples that scintillations start earlier at the equatorial stations and later at latitudes away from the equator.

3.4 Daily variations in scintillation occurrence

From the quarter-hourly occurrence of scintillations during the campaign period of March and April 1991, average quarter-hourly percentage occurrences have been computed for each month. The monthly averaged daily variations of the scintillation occurrence at all the sixteen stations for the month of March 1991 are shown in Fig. 8. Similar daily variations are noted for the three equatorial stations of Tiruchendur, Trivandrum and Annamalainagar with peak occurrence between 50 and 60 per cent which drops to less than 50 per cent at Goa and Waltair and to less than 40 per cent at Bombay and Kolhapur. For stations Nagpur, Rajkot, Ahmedabad, Calcutta and Ujjain in the anomaly peak region., peak occurrence rate is close to 30 per cent, while for Varanasi and Agra it further reduces to less than 20 per cent. At Delhi peak occurrence is only 10 per cent. Another systematic difference noted is the scintillation occurrence in the post-midnight period which drops considerably with increasing latitude. It must be noted here that the daily variations are shown in hrs IST for all the stations. Therefore the onset times show differences due to longitudinal differences. This is clearly seen in the case of stations close to the anomaly crest where five stations lie from Rajkot to Calcutta covering a longitudinal extent of 1°. The onset of scintillations over Calcutta occurred about one hour earlier than at Rajkot.

3.5 Latitudinal variations in scintillation occurrence

To study the latitudinal variations in scientillation occurrence during the course of night, three-hourly

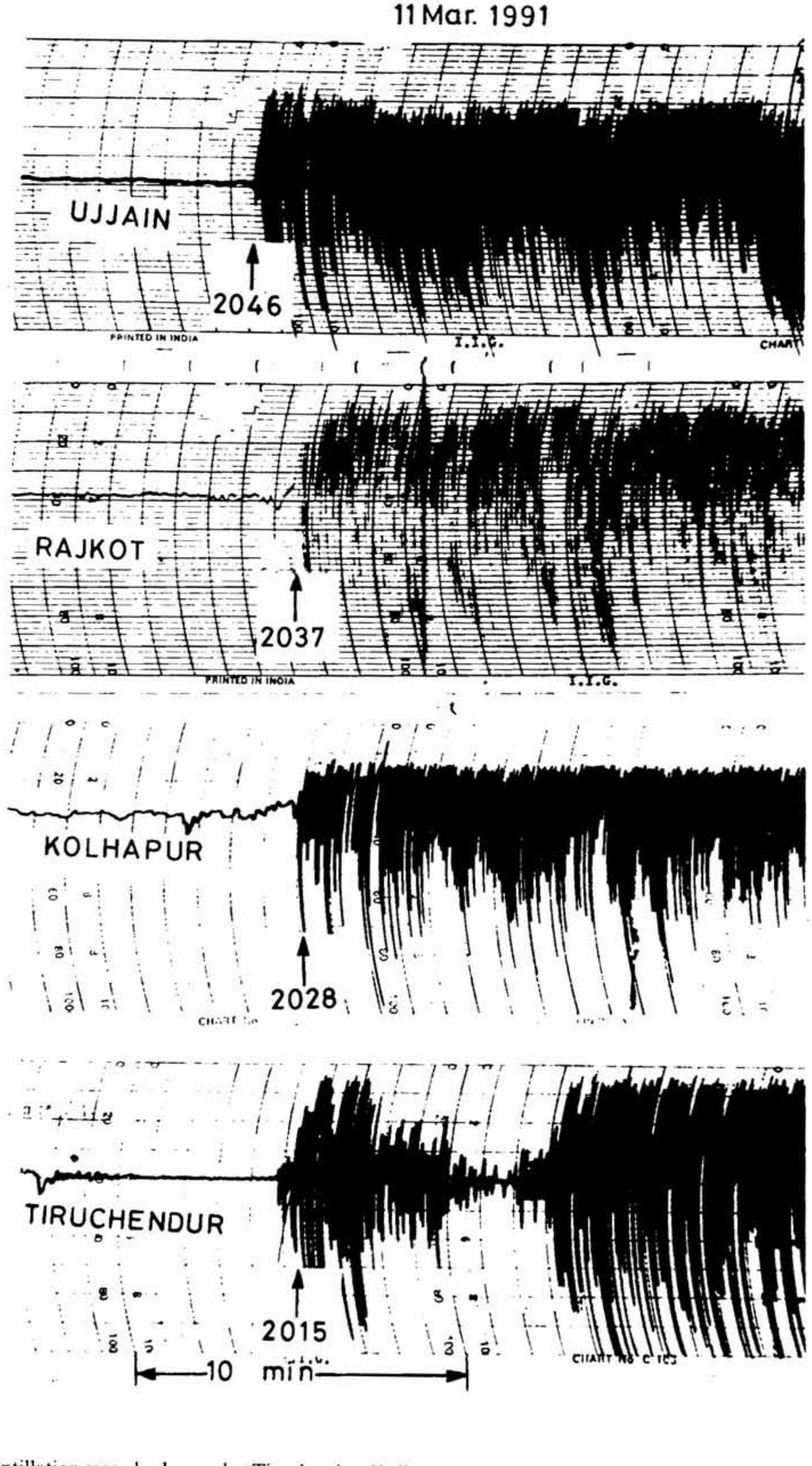

Fig. 7(a)—Scintillation records observed at Tiruchendur, Kolhapur, Rajkot and Ujjain on 11 Mar. 1991 showing the time delays in the onset of scintillations

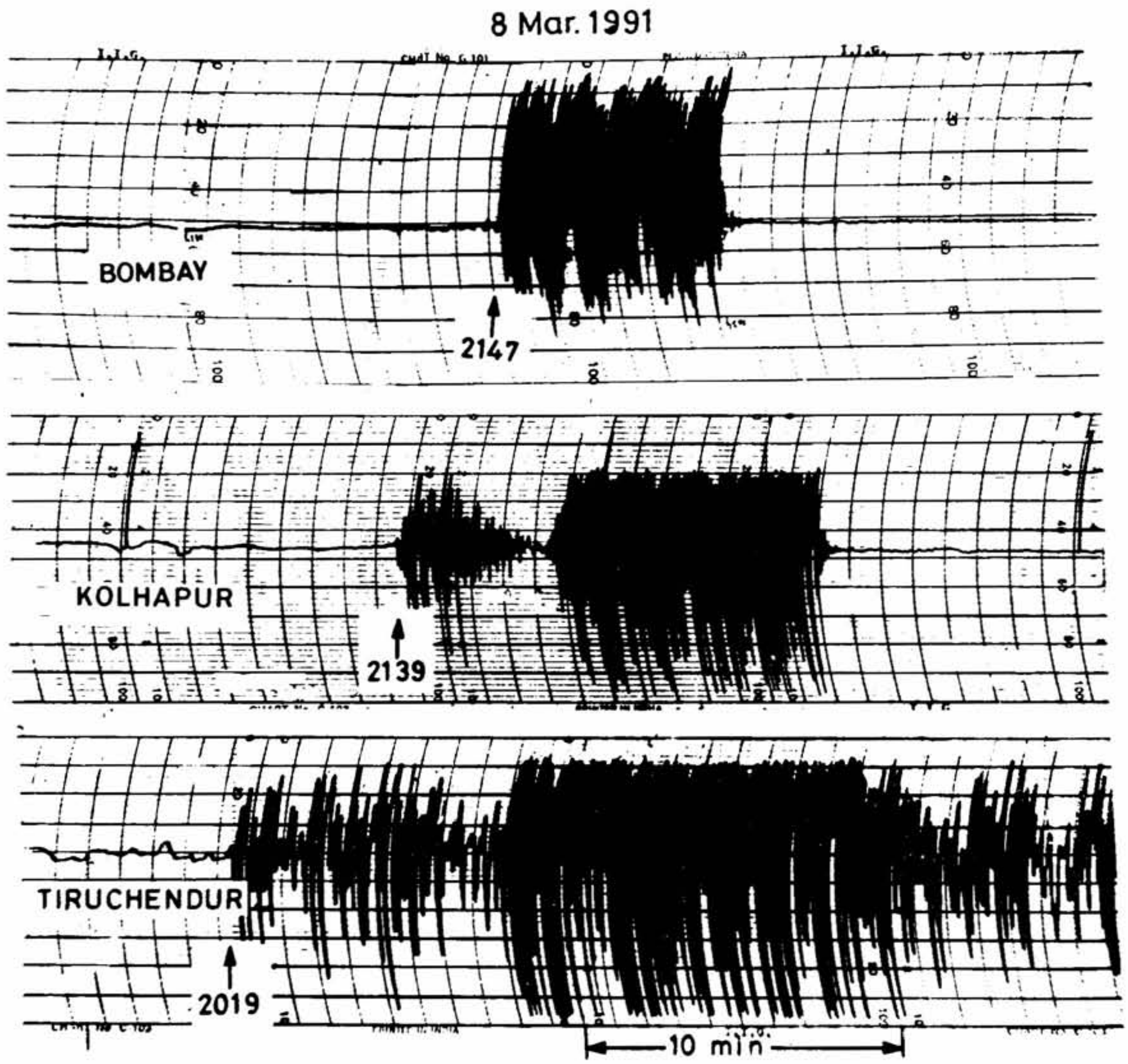

Fig. 7(b)—Scintillation records observed at Tiruchendur, Kolhapur and Goa on 8 Mar. 1991 showing the time delays in the onset of scintillations.

groupings of the data were made. These were the post-sunset (1900-2100 hrs), pre-midnight (2200-0000 hrs), post-midnight (0100-0300 hrs), and pre-sunrise (0400-0600 hrs) periods. The mean occurrence of scintillations during these four groups has been plotted as a function of latitude (Fig. 9). During the evening hours scintillation occurrence remains between 20 and 27 per cent at latitudes up to 20° and then decreases with increasing latitude. The half width of the scintillation belt (considered as the latitude at which occurrence reduces to half of the values at magnetic equator) appears to be 15° for this period of the night. For the pre-midnight hours the maximum occurrence is 50 per cent at equator and the half width comes out to be 14°. During post-midnight period the peak occurrence is once again 50 per cent at equator which drops to half in a latitude width of 6° only. Similarly the half width for early morning hours is again 6° though peak occurrence of scintillation has dropped to 30 per cent at equator. Thus the belt of equatorial region of scintillations is widest during onset phase which decreases with the progress of night in the post-midnight period. For the epoch of March 1991, the width estimated is about 30° in the pre-midnight period and 12° in the post-midnight period.

3.6 Spread-F occurrence during March 1991

The occurrence of scintillations in the nighttime equatorial region is well correlated with the occurrence of equatorial spread-F. During the campaign period ionosonde data were available at Thumba, Waltair, and Ahmedabad, which represent three distinct zones—equatorial, edge of the

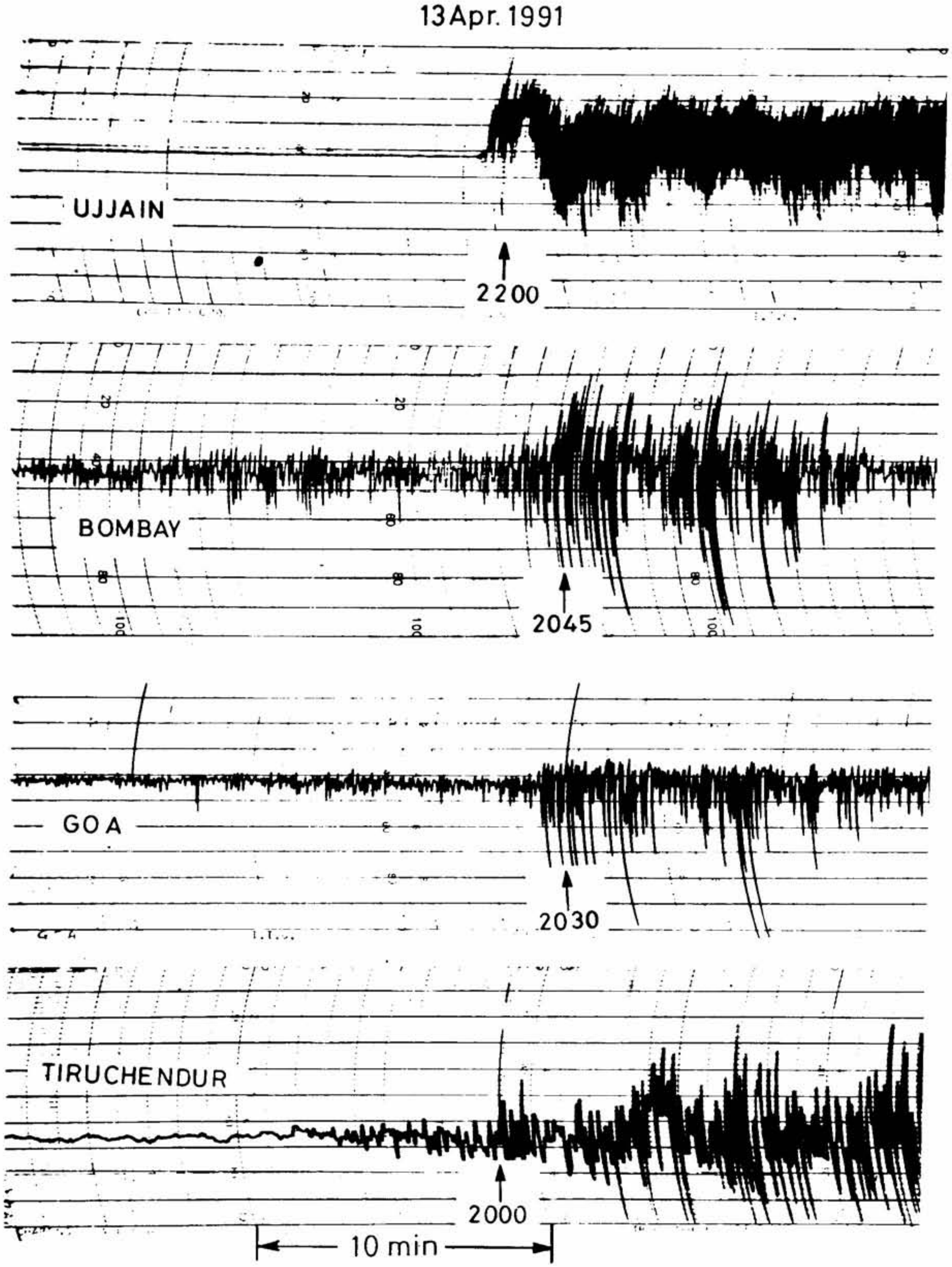

Fig. 7(c)—Scintillation records observed at Tiruchendur, Goa, Bombay and Ujjain on 13 Apr. 1991 showing the time delays in the onset of scintillations.

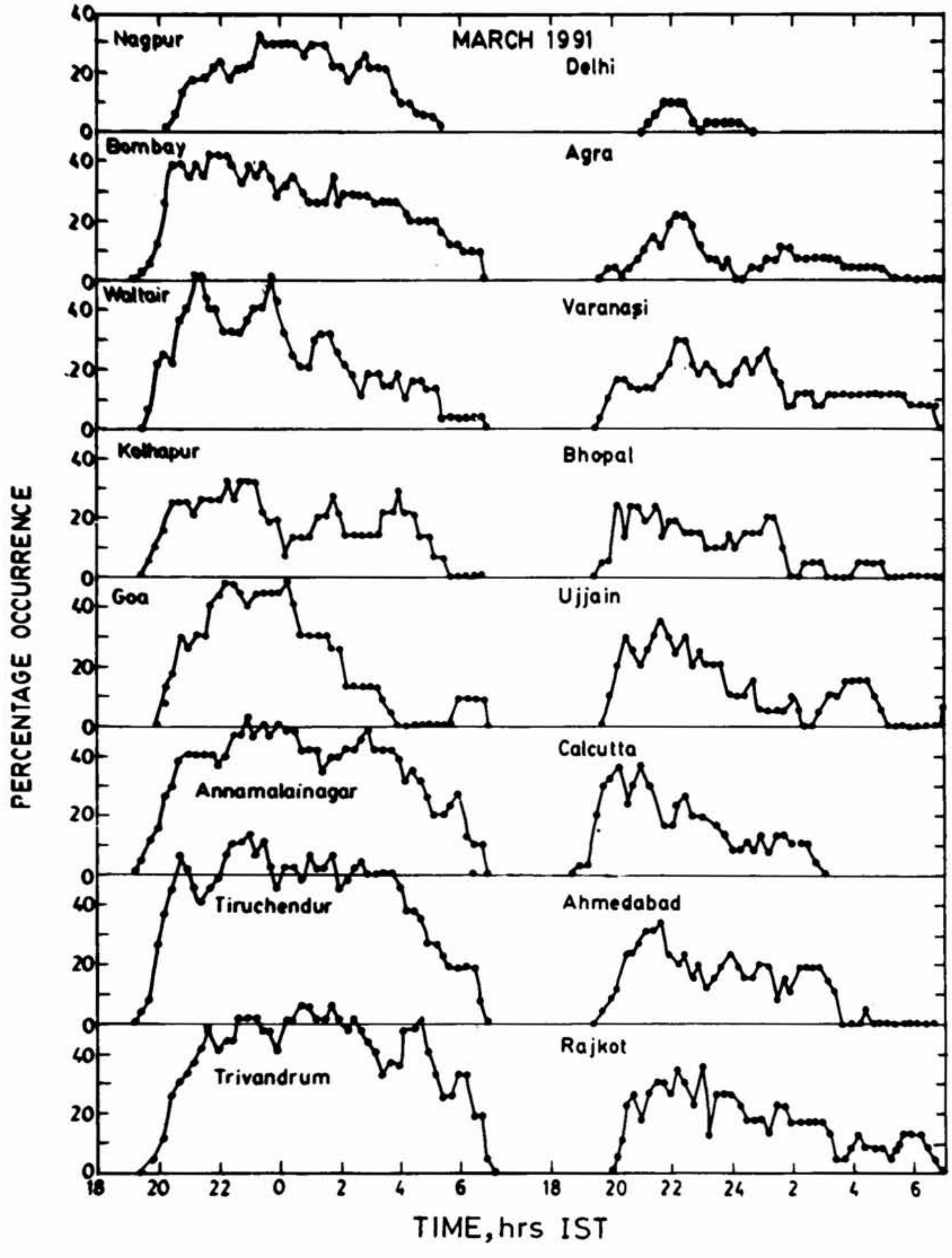

Fig. 8—Nocturnal variations in scintillations at all the stations of the chain covering a latitude belt of 8°N-29°N during March 1991.

equatorial zone, and anomaly peak region. The daily variations based on quarter-hourly values in the percentage occurrence of spread-F at these three stations is shown in Fig. 10. The onset of spread-F is seen to occur around 1900 hrs at Waltair and about 15-20 min later at Thumba which is likely due to the longitudinal difference. The maximum occurrence rate exceeds 80 per cent at Thumba, 70 per cent at Waltair and 35 per cent at Ahmedabad. The peak occurs around 2100 hrs at Ahmedabad. There is a decrease in the occurrence rate after 2200 hrs to about 40 per cent at Thumba and to about 20-25 per cent at Waltair. For Ahmedabad the occurrence rate decreases continuously and there is no spread-F seen

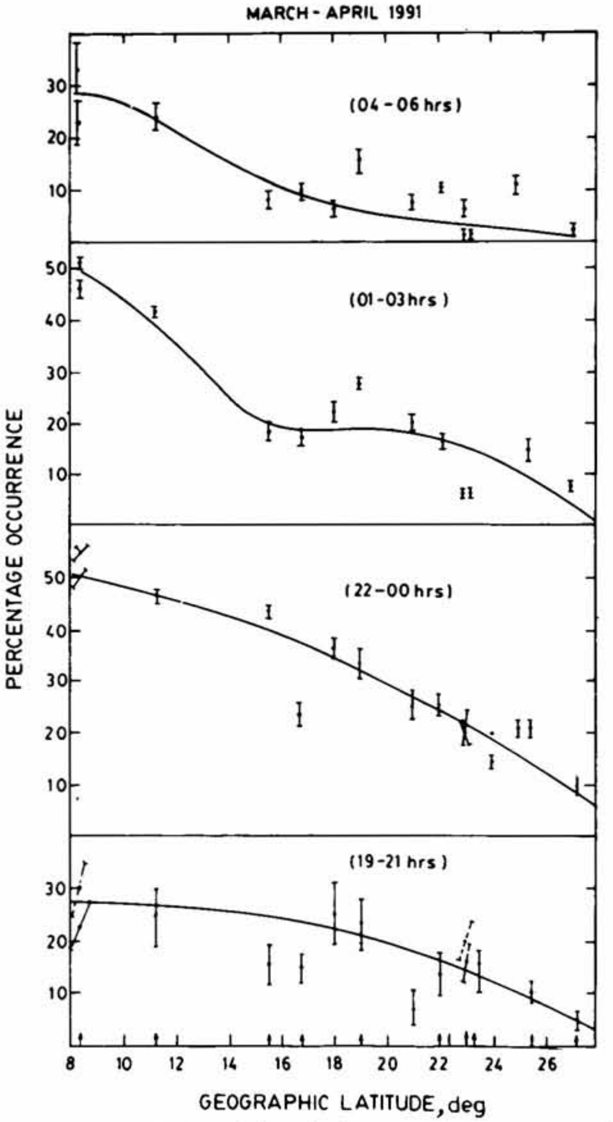

Fig. 9—Latitudinal variations in the percentage occurrence of scintillations at four different time periods of the night.

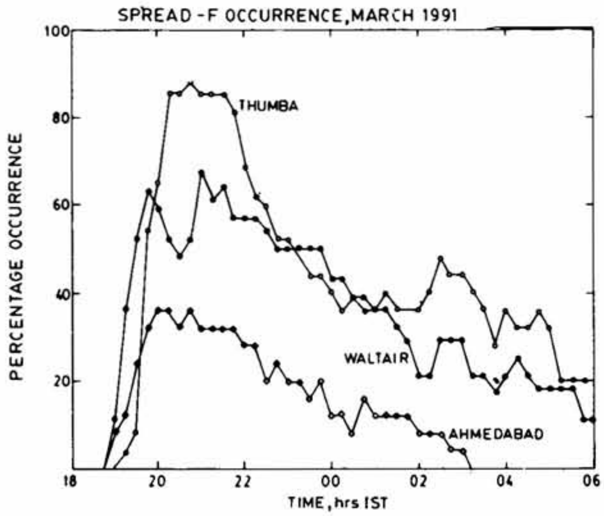

Fig. 10—Nocturnal variations in the percentage occurrence of spread-F at Thumba, Waltair, and Ahmedabad, representing respectively equatorial, low latitude, and anomaly crest regions in India.

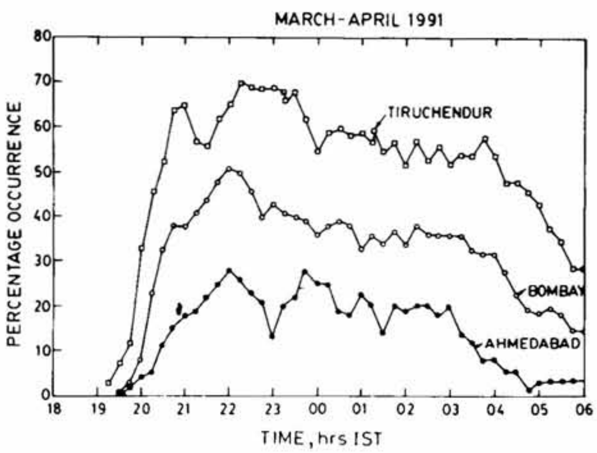

Fig. 11—Nocturnal variations in the percentage occurrence of scintillations at Tiruchendur, Bombay, and Ahmedabad, representing respectively equatorial, low latitude, and anomaly crest stations in India.

after 0300 hrs. For comparison the nocturnal variations in the percentage occurrence of scintillations at three stations, namely, Tiruchendur, Bombay and Ahmedabad, representing the three latitudinal zones are shown in Fig. 11. The maximum occurrence at the three stations is 70, 50 and 30 per cent respectively around 2200 hrs. Unlike rapid decrease in spread-F occurrence after midnight the scintillation occurrence decreases rather slowly. The occurrence characteristics of spread-F are consistent with the occurrence of scintillations observed at the three latitudinal zones.

4 Discussion and conclusions

The salient features emerging out of this study based on scintillation observations at a chain of stations extending from equator to about 40°N dip in India for the first time are:

(a) Scintillation occurs continuously throughout the night in the equatorial zone while it breaks up into more discrete patches at anomaly peak region and beyond.

(b) The duration of scintillation patches is longer at equator compared to those at other latitudes.

(c) There is a systematic time delay in the onset of scintillations as one goes away from the equator.

(d) The percentage occurrence consistently decreases away from the equator with peak occurrence in the pre-midnight period.

(e) The half width of the equatorial scintillation belt is 15°, 14° and 6° at the pre-midnight, midnight and post-midnight periods respectively.

(f) The occurrence patterns of scintillation and spread-F are well correlated in the equatorial as well as anomaly crest latitudes. A noteworthy feature is that if the irregularities are already broken up into patches at the equator itself, then **scintillation** is less likely to be observed at the crest latitudes and beyond.

The above result of the consistent time delay conforms to the belief that the scintillation-producing irregularities are generated at the bottomside F-region above the equator under favourable conditions and are lifted up by $\mathbf{E} \times \mathbf{B}$ forces and then extended to farther latitudes along field lines. Radar observations[11,12] indicate that at altitudes below about 500 km there are strong irregularity layers which trigger weaker irregularities in between, while above this altitude the weaker irregularity regions disappear. At the equator the integrated effect of all these vertically displaced irregularity regions gives almost continuous scintillation, while the vertically drifting striated irregularity regions at higher altitudes when mapped to higher latitudes give discontinuous patches of scintillation. The decrease in the width of the scintillation belt during midnight and post-midnight may also be due to the reduction of vertical drift velocities during these periods. The general chracteristics of scintillation occurrence reported here are consistent with the previous observations at the magnetic equator and at the anomaly crest region for similar levels of solar activity. Further studies using a larger data base covering low and high sunspot conditions will be necessary to bring out the seasonal and solar activity dependence and their comparison with other longitude sectors so that a better understanding of the irregularity generation mechanism can be obtained. This will be possible only with the complete data set for the whole AICPITS project duration.

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