

Co-ordinated observations of VHF scintillations in India during February-March 1993

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The VHF scintillation observations made at a chain of stations in India during February-March 1993 under AICPITS (third campaign), using the 244 MHz radio beacon from FLEETSAT, and analysed jointly by all participating investigators at a workshop held at Rajkot are described. The occurrence features of scintillations during the third campaign were similar to those observed during the first campaign of March-April 1991. The maximum occurrence was, however, reduced to some extent due to the lower solar activity. The latitudinal variations showed an increased occurrence in the region of about 17-18° latitude. The data during the night of 19-20 Feb. 1993 when an extensive 'Ionisation Hole Campaign' was undertaken showed scintillations marked by earlier onset and longer duration at stations Waltair and Nuzvid than at the stations close to the magnetic equator. However, based on the average variations during February-March 1993 the onset at Tiruchendur, Anantpur and Waltair was at nearly the same time. The vertical rise velocity of the plasma depletions, estimated from the time delays in the onset of scintillations at latitudes away from the dip equator, was found to range from 40 m/s to 420 m/s in the altitude region 300-1350 km.

1 Introduction

Monitoring of satellite radio beacons provides a simple method to study the ionospheric irregularities. The fluctuations in the signal strength, characterized by some form of scintillation index are related to the fluctuations in electron density. The amplitude fluctuations can also be used to derive the temporal spectra of the electron density fluctuations in the ionosphere and can be converted into spatial spectra if the velocity of the irregularities is known. Radio beacons on-board orbiting or geo-stationary satellites

have been used extensively to study the temporal and spatial variations of scintillation index, power spectral features and the velocity of the irregularities (in case of spaced receiver recordings). Globally there are two regions of strong scintillations—one centred at the magnetic equator with a width of 20° and another at high latitudes (Aarons¹ and references therein).

India provides a unique location for studying scintillations at low latitudes covering a region right from the magnetic equator to beyond the F-region ionization anomaly crest region. Detailed studies on

scintillations in the equatorial region were made during the ATS-6 phase II from Thumba² and Ootacamund^{3,6} from the multi-frequency measurements. Scintillation studies covering a chain of stations in India were attempted during the total solar eclipse event of February 1980 by Somayajulu *et al.*⁷. However, an extensive study on scintillations at equatorial and low latitudes in India was possible when a network of nearly 20 stations was established under the All India Co-ordinated Programme of Ionospheric and Thermospheric Studies (AICPITS). The observations were made at 244 MHz using the radio beacon on-board FLEETSAT (73°E). The scintillation data were recorded using identical systems at most of the locations, consisting of a simple 11-element Yagi-Uda antenna, VHF receiver and single channel chart recorder which were established with the help from the Indian Institute of Geomagnetism, Colaba, Bombay. However, there were a few locations with data recorded in digital form also. As part of the co-ordinated studies, campaigns were conducted which were followed by joint data analysis workshops. The first of such campaigns was conducted during March-April 1991 and the salient features of the scintillations at low latitudes in the Indian longitude region during the campaign have been described by Chandra *et al.*⁸. The scintillations were generally found to occur in a continuous patch or in patches of longer duration near the magnetic equator, while away from the equator there is a systematic delay in its onset (they occur in smaller patches with a smaller duration). The half widths of the equatorial belt of scintillations, as determined from the latitudinal variations, were found to be about 15° before midnight and 6° in the post midnight period.

In the present paper, the results obtained from the third 'satellite scintillation network' campaign, conducted during February-March 1993, have been reported. The period covered the 'Ionisation Hole Campaign', undertaken by the Physical Research Laboratory, Ahmedabad, to study the equatorial spread-F. The 'Ionisation Hole Campaign' involved the launching of two RH-560 rockets on 19 Feb. 1993. The first of the rockets released active chemicals at four altitudes for measuring the electric fields and neutral winds. This was followed by another rocket instrumented with plasma probes and mass spectrometers⁹. A number of complementary ground-based radio and optical experiments were also

conducted during the rocket campaign. The scintillation data collected at the AICPITS network of stations during the campaign of February-March 1993 were jointly analysed by the participating investigators at the workshop held at Rajkot, Gujarat, during April 1993.

2 Observations and data analysis

The locations of the stations operated during the campaign are shown in Fig. 1. The geographic coordinates of the stations along with the dip angle at the sub-ionospheric point of the satellite-to-receiver path (at 400 km) are also provided in the Table 1. The chain covers the region from dip equator to about dip angle of 44°N. The sub-ionospheric points corresponding to an altitude of 400 km cover from dip equator to about 40°N. The two new stations included in this campaign are Nuzvid and Udaipur. Data recorded on charts have been used in the present study. On examination of the chart recording the following information were compiled: (i) start time and end time of each patch of scintillations and

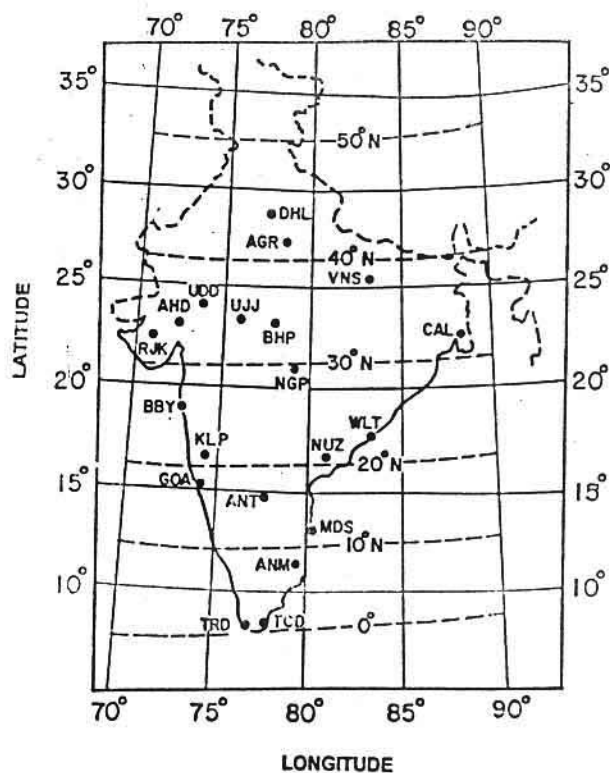


Fig. 1—Map of India showing the locations of the stations recording the 244 MHz radio beacon from FLEETSAT for scintillation studies during the AICPITS

Table 1—Locations of the scintillation recording stations in India during the campaign of February-March 1993

Name of station	Geog. lat deg	Geog. long. deg	Dip angle deg	Dip angle at sub-ionospheric point deg
Trivandrum*	8.4	76.9	0.6	-0.6
Tiruchendur	8.5	78.2	0.7	-0.5
Annamalainagar*	11.4	79.4	7.6	6.0
Madras	13.1	80.3	11.6	9.5
Anantpur	14.7	77.6	15.7	13.4
Goa*	15.2	74.0	17.2	14.9
Kolhapur	16.7	74.2	20.6	18.1
Nuzvid	16.8	80.8	19.9	18.0
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	70.8	32.6	29.6
Calcutta	22.6	88.4	31.9	28.7
Ahmedabad	23.0	72.4	33.8	30.7
Ujjain	23.2	75.8	33.9	30.8
Bhopal	23.2	77.6	33.8	30.7
Udaipur	24.0	73.7	35.3	32.3
Varanasi*	25.3	83.0	37.3	34.0
Agra	27.2	78.1	41.1	37.7
Delhi	28.8	77.2	43.7	40.72

*Stations operated during AICPITS but data not available for the present study.

(ii) every quarter-hourly (± 7.5 minutes) presence of scintillations.

3 Results

The mean nocturnal variations of the percentage occurrence of scintillations at 14 of the total stations during the period February-March 1993 are shown in Fig. 2. The stations Tiruchendur, Madras and Anantpur situated in the magnetic equatorial zone show onset around 1900 hrs IST (77.5° EMT) with peak occurrence of about 40%. It must be noted that the occurrence rates are higher at Madras and Anantpur, situated a few degrees away from the magnetic equator, than at Tiruchendur, situated at the magnetic equator. The stations Kolhapur, Nuzvid, Waltair and Bombay, situated in the zone intermediate to equatorial and the anomaly crest zones, are characterized by onset around 2000 hrs IST and scintillations lasting till sunrise with maximum occurrence of about 30% (occurrence are little higher at Nuzvid). The stations situated in the anomaly crest zone (Rajkot, Calcutta, Ahmedabad, Ujjain and Bhopal) show onset of scintillations at around 2000

hrs IST and lasting till 0600 hrs IST with maximum occurrence of 20%. In the zone beyond the anomaly crest (Agra and Delhi), the onset time is around 2100 hrs IST with peak occurrence of only 10%. The onset times are not different from those reported for the campaign period of March 1991. However, the maximum occurrence were slightly higher for the campaign of March 1991 with values of 50%, 40%, 30% and 20% for the four zones. The decrease in the maximum occurrence rates of scintillations is due to the lower sunspot activity during 1993.

The latitudinal variations of the percentage occurrence of scintillations for different local time plotted against the geographic latitude are shown in Fig. 3. The local time groupings are the post-sunrise (1900-2100 hrs IST), pre-midnight (2200-0000 hrs IST), post-midnight (0100-0300 hrs IST) and pre sunrise (0400-0600 hrs IST). The occurrence does not seem to be maximum at the magnetic equator, but a few degrees away. In the first campaign, the maximum occurrence of scintillations was observed at the magnetic equator. However, one has to consider the fact that during the present campaign there is no

data available from Trivandrum and Annamalainagar. Another point of interest is that there is an increase in the occurrence around $17-18^\circ$ latitude. This feature was also observed in campaign of March-April 1991.

The scintillation data recorded at all the stations of the chain during the night of 19-20 Feb. 1993 have been plotted in Fig. 4 to show the duration of scintillations as a function of the dip angle. The

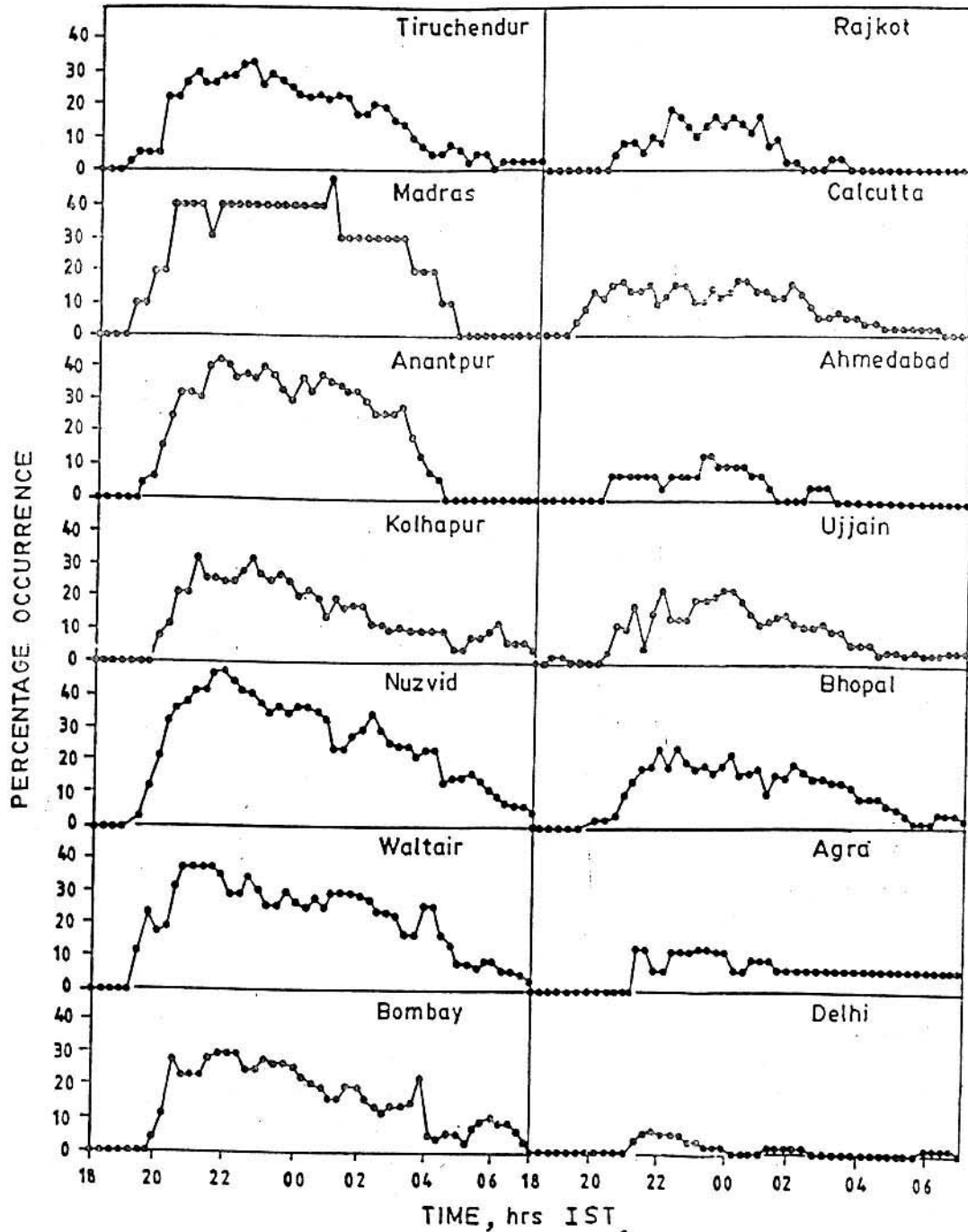


Fig. 2—Nocturnal variations of the percentage occurrence of scintillations at 14 locations averaged over the campaign period February-March 1993

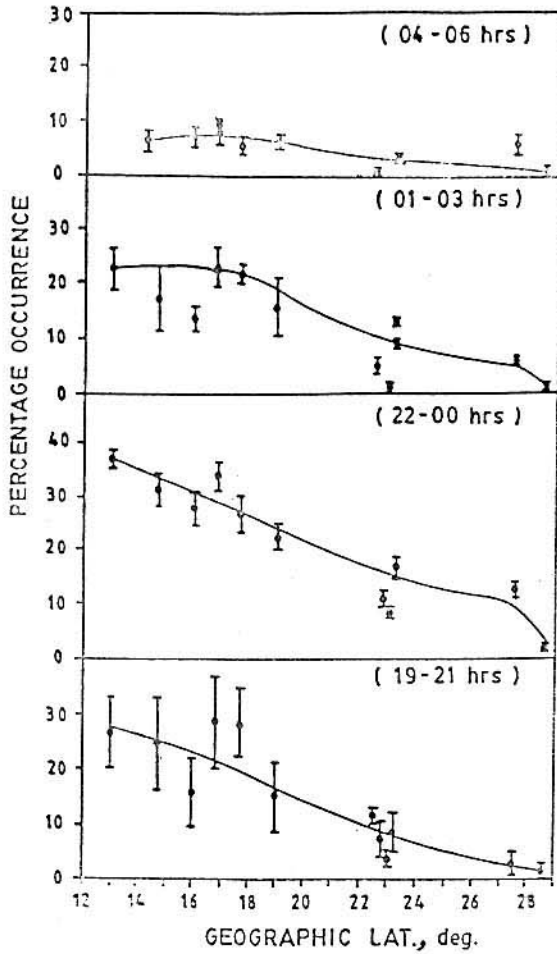


Fig. 3—Variation with geographic latitude of the mean percentage occurrence of scintillations at different local times for the period February-March 1993

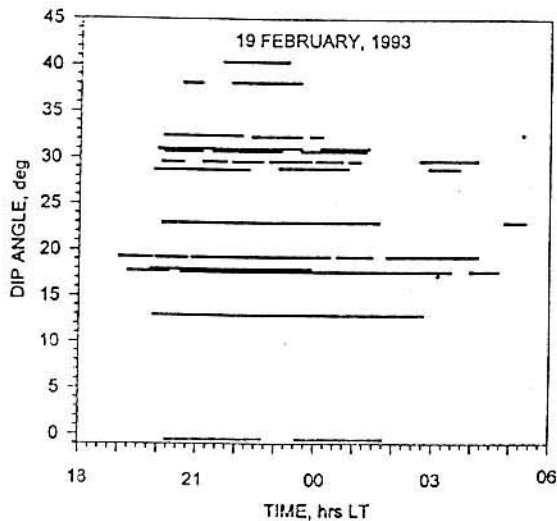


Fig. 4—Time duration of scintillations during the night of 19-20 Feb. 1993 at the chain of stations plotted on a grid of local time and dip angle

observations cover the region right from the magnetic equator to dip of 40°. The local time correction has been made in the figure. The onset is earliest at Waltair (dip 19.3°N) and Nuzvid (dip 18°N), which is about an hour before the onset at Tiruchendur located at the dip equator. The duration of scintillations is also longest at these two stations. There is a systematic decrease in the duration of scintillations for the stations located in the anomaly crest region and beyond. Progressive delay in the onset time is seen, but more striking is the earlier decay of scintillations at these stations.

The variation of the onset time of scintillations with latitude is studied from the average nocturnal variations of the percentage occurrence of scintillations during the campaign period of February-March 1993 based on quarter-hourly values and shown in Fig. 5. The onset time is corrected for the local time differences. It is clearly seen that the scintillations first appear near the magnetic equator (at 1840 hrs IST at Tiruchendur, at 1900 hrs IST at Madras with dip of 10°N) and the onset time increases with the dip angle. There is a delay of about an hour for stations close to the ionization anomaly crest and about two hours for Delhi, the northernmost station. Assuming that scintillations first appear at a magnetic equator and that the onset at latitudes away from the dip equator is related to the vertical rise of the depleted regions of plasma density through the geomagnetic field lines, the vertical rise velocities of the plasma depletions have been estimated by some

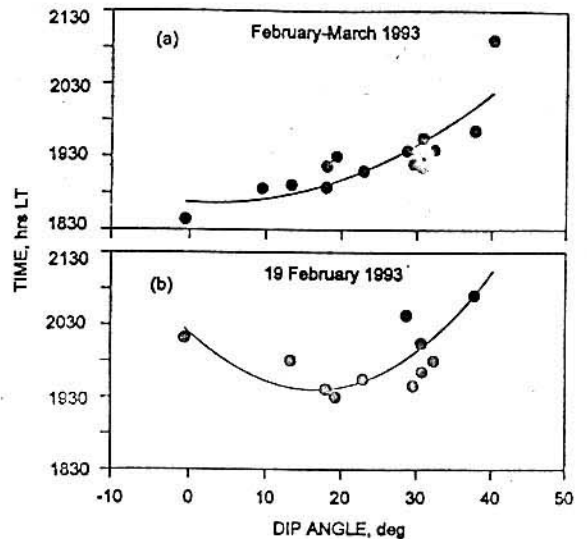


Fig. 5—Variations of the onset times of scintillations with dip angle: [(a) average for February-March 1993 and (b) for the night of 19-20 Feb. 1993]

workers^{10,11}. If we assume that F-region altitudes associated with irregularities causing scintillations are around 300 km, the altitudes of the depleted plasma over the dip equator, connected to the 300 km at other latitudes through magnetic field lines, can be obtained. The vertical velocity of the plasma depletions has been estimated from time delays between the onset of scintillations at locations centred at 0, 10, 20, 30 and 40° dip angles. The altitudes at dip equator corresponding to the field lines at 300 km at the locations of 10, 20, 30 and 40° dip are about 365, 550, 850, and 1350 km, respectively. Thus, one can compute vertical rise velocity at different altitudes of F-region. For the time delays observed from the monthly mean onset times, the velocities come out to be 40, 420, 330 and 140 m/s for the altitude regions 300-365, 365-550, 550-850 and 850-1350 km, respectively. Thus, the high vertical velocity is noticed between the altitude regions of 365-550 and 550-850 km.

The variation with latitude of the onset time of scintillations on the night of 19-20 February is also shown in Fig. 5. During this night the onset is earliest at dip angles 18-20°. Chandra *et al.*¹² have reported a case of nighttime F-region scintillations extending into daytime during 11 Nov. 1991. The event was characterized by onset earlier at Bombay than at Trivandrum. Also the scintillations disappeared first at Trivandrum rather than at Bombay. The event, however, followed a magnetic storm with sudden commencement on 10 Nov. 1991. The period of 19 February is not classified as a geomagnetic disturbed day; however, there was a sudden commencement on 17 February and the period after 20 February had high K_p values. The time delays in the onset of scintillations from region of 20° dip angle and beyond during the night of 19 Feb. 1993 give vertical velocity of 400 m/s between 550 and 850 km and 100 m/s between 850 and 1350 km. These are close to the values estimated from the mean time delays for February-March 1993.

The locations of the stations Bhopal and Ujjain in the anomaly crest zone with same latitude but different longitudes have been utilized to determine east-west velocity of the scintillation patches derived from the time delay in the onset of scintillation patches at the two stations. Figure 6 shows a plot of the eastward velocity during the night of 19-20 Feb. 1993. The velocity decreases from more than 200 m/s at around 2000 hrs IST to about 100 m/s at around

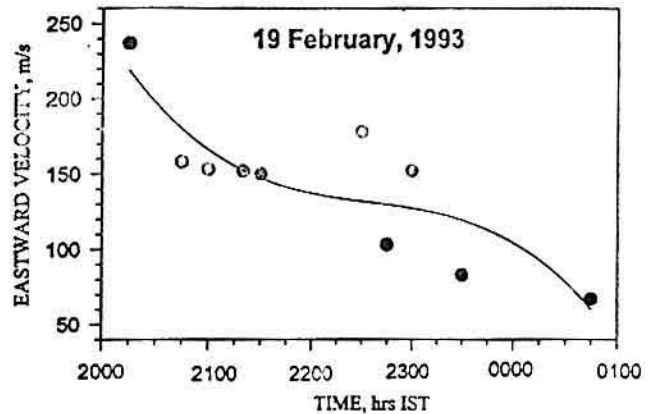


Fig. 6—Time variation of the eastward velocity of the patches of scintillations during the night of 19-20 Feb. 1993 derived from the time delay in the onset time of scintillations at Bhopal and Ujjain located at the same latitude but at different longitudes

midnight. This is consistent with the velocity obtained from the recording of scintillations of SIRIO and FLEETSAT signals simultaneously over Bombay¹³.

4 Discussion

The irregularities associated with equatorial spread-F (ESF) cover a wide range of scale sizes from several hundreds of kilometres to few centimetres. It is well accepted that the onset of ESF is due to the generation of intermediate scale size irregularities in the bottom side of F-region by the generalized Rayleigh-Taylor instability that includes the electric field and neutral winds^{14,15}. The depleted regions of plasma rise rapidly and align along the geomagnetic field lines. The sharp gradients at the walls of plasma depletions result in smaller scale irregularities that give rise to scintillation of radio waves, plumes on backscatter radar maps, and spread-F on ionograms¹⁶⁻²¹. The plasma depletions have large spatial extent along N-S and the rapid rise of these results in the onset of scintillations at latitudes away from the dip equator. The plasma depletions (bubbles) are known to have large vertical velocities. At collision-dominated low-altitude region (~below 350 km) the rise velocity is related to the degree of depletion. Measured bubble velocities show a saturation value of around 200 m/s for the collision-dominated region²¹. At higher altitudes the rise velocity is related to the size of the bubble and should reach a maximum value between 200 and 700 m/s above 550 km for bubble radii between 16 and 200 km (Ref. 22). Tsunoda *et al.*²³ have reported bubble

rise velocity ranging between 50 and 350 m/s. Dabas and Reddy¹¹ made scintillation observations at four stations in India during high solar activity period (covering geographic locations from dip equator to up to 30°N). The time delays in the onset of scintillations were found to be consistent with the bubble rise velocity of 50-350 m/s. Aggson *et al.*²⁴ reported two events of plasma bubbles up-drifting with velocities of about 2 km/s from satellite measurements of eastward electric field within the bubble. The location of the two events mapped to altitudes of about 600 and 800 km at dip equator. Rocket-borne *in situ* DC electric field measurements have been made up to 950 km during equatorial spread-F (Ref. 25). Outside the regions of plasma depletions, electric field was found to be primarily vertical. However, inside the depletions vertical electric fields were found to be comparable to zonal electric fields. The zonal electric field was found to be enhanced in the depleted regions with maximum around 550 km. The plasma depletions were found to rise with speeds of up to 100 m/s. Recently, Sekar *et al.*²⁶ have reported upward velocity up to 200 m/s in the central regions of the plume structures from the observations made by using Indian MST radar.

The bubble rise velocity of about 300-400 m/s in the altitude region 365-850 km and a less velocity at lower and higher altitudes estimated from the time delays in the onset of scintillations at a chain of stations in India are consistent with the satellite-borne *in situ* measurements of electric field. The values are in agreement with those determined from the chain of scintillations receivers and radar. Sekar *et al.*¹⁵ had shown earlier, from non-linear simulation studies, the upward velocities of few hundreds of metres per second under favourable vertical winds. The scintillation data at the closely spaced meridional chain of stations offer a simple method to detect the bubble rise velocity on a day-to-day basis.

5 Summary

The scintillation data at the chain of stations that operated during the third campaign of February-March 1993 reveal that

- (i) The maximum occurrence of scintillations in the equatorial, intermediate, anomaly crest region and beyond the anomaly crest region has decreased by about 10 % from the maximum values observed during the campaign of March-

April 1991. This is due to the decrease in solar activity.

- (ii) The latitudinal variations of the occurrence of scintillations during different hours show that there is an increase in the occurrence rates around latitude of 17-18°. This was also seen in the plots from the earlier campaign.
- (iii) The data during the night of 19-20 Feb. 1993, when an extensive 'Ionisation Hole Campaign' was conducted, show earlier onset of scintillations and longer duration at Waltair and Nuzvid compared to the magnetic equator. However, based on the monthly mean variations during February 1993, the onset appeared first in the equatorial region.
- (iv) Eastward velocity of the patches of scintillations has been determined from the time delay in the onset time of scintillations at Ujjain and Bhopal (same latitude but different longitudes) during the night of 19-20 Feb. 1993. The eastward velocity decreases from about 200 m/s at the time of onset to less than 100 m/s around midnight.
- (v) The delays in the mean onset time with latitude for the period February-March 1993, after local time correction, are used to determine the vertical velocity of plasma depletions for different altitude regions. The velocity ranges from less than 100 m/s at altitudes below 365 km to more than 400 m/s at altitudes of 365-850 km. These are consistent with the electric field measurements within the depletions by satellite measurements and with the velocities reported from radar observations.

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