Ann. Geophysicae 13, 724–729 (1995) © EGS – Springer-Verlag 1995

500

Annales Geophysicae

# Zonal drifts of ionospheric irregularities at temperate latitude in the Indian region

Sushil Kumar[1], A. K. Gwal[1], B. M. Pathan[2], D. R. K. Rao[2]

[1] Space Plasma Laboratory, Department of Physics, University of Bhopal 462 026, India
[2] Indian Institute of Geomagnetism, Colaba, Bombay 400 005, India

Received: 4 May 1994/Revised: 14 December 1994/Accepted: 13 January 1995

**Abstract.** The systematic time differences observed in the onset of postsunset VHF scintillations recorded simultaneously at Ujjain (Geogr. lat. 23.2°N, Geogr. long. 75.6°E) and Bhopal (Geogr. lat. 23.2°N, Geogr. long. 77.6°E), situated at the peak of the anomaly crest in the Indian region, have been analysed to determine the zonal drifts of scintillation-producing irregularities. The method is based on the assumption that the horizontal movement of irregularities does not change while crossing the F-region cross-over points of these stations. The calculated velocities of irregularities indicate an eastward drift decreasing from about 180 m $s^{-1}$ to 55 m $s^{-1}$ during the course of night. In the premidnight period, the drifts are reduced under the magnetically disturbed conditions. The average east-west extension of irregularites is found to be in the range of 200–500 km.

## 1 Introduction

Scintillations monitored on the radio beacon travelling through the ionosphere have been used quite successfully to obtain information on the structure and dynamics of irregularities in the electron density of the ionosphere (Basu *et al.*, 1978; Woodman and LaHoz, 1976; Krishna Moorthy *et al.*, 1979; Aarons *et al.*, 1980; Tsunoda, 1981; Rastogi, 1982; Somayajulu *et al.*, 1984). The irregularities which give rise to scintillations on the VHF signals are believed to be generated on the bottom side of the F-layer by a generalised Rayleigh-Taylor (GRT) instability (Haerendel, 1974; Zargham and Seyler, 1987). Subsequently, they rise to the top side of ionosphere through the non-linear evolution of the $\boldsymbol{E} \times \boldsymbol{B}$ drift (Balsley *et al.*, 1972; Ossakow *et al.*, 1979; Tsunoda *et al.*, 1982) and also drift westward with respect to the background ionosphere. They are frequently observed at the equatorial and low latitudes at night, occurring in patches with horizontal dimensions of up to 500 km or more (Tetheridge, 1963; Koparkar, 1988).

Using the radio wave scintillation recordings at Bombay from two closely spaced satellites, SIRIO (65°E) and FLEETSAT (73°E), Koparkar (1988) estimated east-west drift speeds to vary from about 170 m $s^{-1}$ to 60 m $s^{-1}$ during the course of night. Chandra *et al.* (1989) deduced the zonal drifts to vary in the range of 300–100 m $s^{-1}$ in nighttime. Based on the time shifts in the onset of scintillations at two Indian equatorial stations, Trivandrum (TRV) and Tiruchendur (TRC), seperated by 105 km at F-region heights, using FLEETSAT signals, Koparkar *et al.* (1991) measured the eastward velocity ranging from 110 to 60 m $s^{-1}$. Occasionally they also observed a westward velocity. Pathan *et al.* (1991) compared the eastward velocity at the TRV-TRC pair of stations with the Karur (KAR) and Annamalainagar (ANM) pair situated a few degrees north. They found a slight difference in the velocities which could either be due to the seperation in latitude or to a difference in solar activity levels for both the sets of data.

This paper presents a study on the zonal drifts of the ionospheric irregularities computed from the time delays in the onset of similar scintillation patches at Ujjain and Bhopal, situated at the peak of the anomaly crest. These stations provide a unique configuration for such a study in the Indian region since they are at exactly the same latitude. The magnetic declination (*D*) at 400 km is about 0.89°W at Ujjain and 0.94°W at Bhopal. The experiments were conducted under the All India Coordinated Programme on Ionospheric Thermospheric Studies (AICPITS).

## 2 Experimental data and analysis

The amplitude of the 244 Mc $s^{-1}$ radio signal transmitted from the geostationay satellite FLEETSAT (73°E) was recorded at Ujjain (sub-ionospheric points at 400 km 21.6°N, 75.6°E and dip lat. 16.6°N) and Bhopal

*Correspondence to:* A. K. Gwal

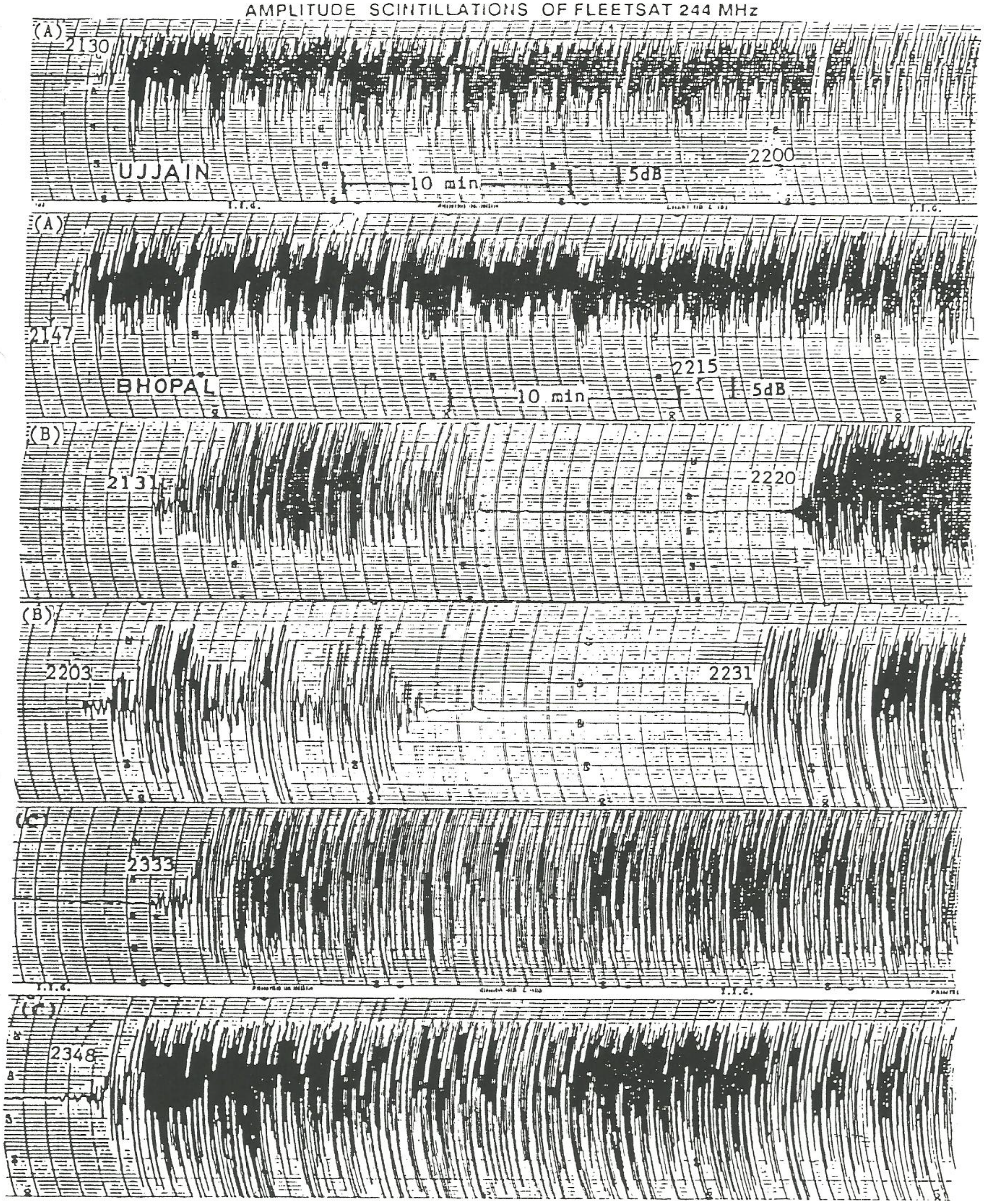


**Fig. 1a–c.** Scintillation records observed at Ujjain and Bhopal **a** 15–16 October 1991, **b** 22–23 February 1993, **c** 27–28 February 1991 indicating east-west movement of scintillation producing irregularity patches

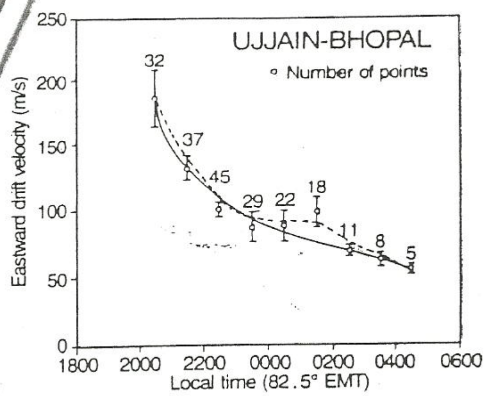


Fig. 2. Nocturnal variation of eastward drift velocity of irregularity patches. The *dashed curve* shows the variation of median velocity as a function of 82.5 E meridian time. The *vertical bars* indicate the standard error.

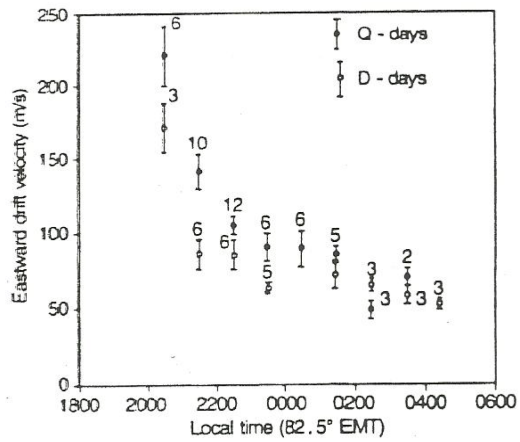


Fig. 3. Nocturnal variation of eastward drift speed on the geomagnetically quiet and disturbed days as a function of 82.5' E meridian time

(sub-ionospheric points at 400 km 21.6°N, 77.2 E and dip lat. 16.5 N), using identical receiving systems. The receiving system consists of a simple eleven element Yagi-Uda antenna, an indigenously made VHF receiver and a strip chart recorder. The period of observations was from January 1991 to March 1993, indicating a relatively higher solar activity period to the decaying phase of the current solar cycle. Attributing the time delays observed in the onset of identical scintillation patches to the east-west motion of the same irregularity patches, the zonal drifts have been computed simply by dividing the distance between F-region cross-over points (180 km) of these stations with the measured time delays in the onsets. From the durations of the scintillation patches and corresponding velocities the size of the irregularities are computed.

## 3 Results

### *3.1 General features of scintillation*

In Fig. 1 we present the examples of scintillations at Ujjain and Bhopal. The onset of scintillation at both the stations is in general abrupt reaching peak-to-peak fluctuations of 10–20 dB within a few minutes. In premidnight saturated scintillations (exceeding 15 dB peak-to-peak) with a fading rate of 15 fades $min^{-1}$ or higher, while during post-midnight rather weak and slow scintillations are observed. The scintillation records at these two stations are generally found to be consistantly similar but shifted in onset times, suggesting this effect to be equivalent to the passage/movement of the same irregularity patch over the F-region cross-over points of these stations with a certain drift velocity.

### *3.2 Zonal drifts of plasma irregularities*

The nocturnal variation of zonal drifts computed from similar onset of scintillations together with their standared error is presented in Fig. 2 wherein the variation of median velocities which are well within the error limits of mean drift velocities is shown by a smooth dashed curve, as a function of 82.5 E meridian time. It is clearly seen from this figure that the eastward drift velocity of irregularity patches decreased from about 180 $m s^{-1}$ to about 55 $m s^{-1}$ during the course of night. The range of velocities calculated here is found to fall in the range of velocities of 100–150 $m s^{-1}$ reported by Basu *et al.* (1977), 140–80 $m s^{-1}$ by Koster *et al.* (1978), 100–200 $m s^{-1}$ by Aarons *et al.* (1980) and 200–100 $m s^{-1}$ by Pathan *et al.* (1991). The deviation of zonal drifts from the mean level shown by the standared error is an indication of the day-to-day variability of zonal drifts, which can be attributed to the fluctuations in the F-region electric field caused by GRT instability since they play important role in determining the generalised gradient drift instability. The onsets of scintillations at these stations can be determined within an accurracy of $\pm 1$ min, and hence overall inaccurracy in determining the relative time delay at these stations was $\pm 2$ min. The error in measuring the time delays for lesser time delays causes larger deviation of drift speed from the mean level, and as the time delays increase, the deviation will also decrease proportionally.

### *3.3 Magnetic activity effect on zonal drifts*

To examine the effect of geomagnetic activity on the drift velocities of the irregularities, the scintillation data from this pair of stations were divided into two groups of five international quiet (Q) and five international disturbed (D) days from the data of each month to obtain the average for each group of data. The drift velocities computed for both the groups of data have been plotted in Fig. 3. It should be noted that the magnetic disturbance reduces the drift velocities significantly in the premidnight period.

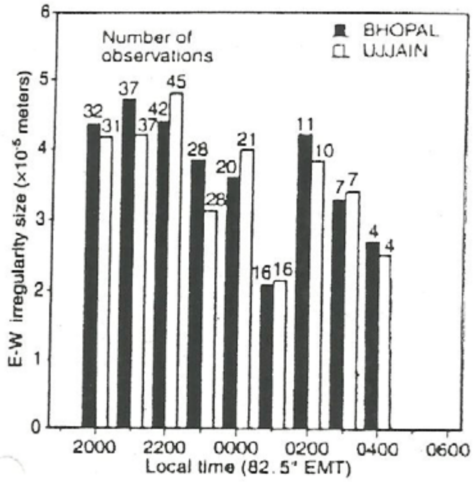


Fig. 4. Histogram showing the variation in east-west size of irregularity patches at both the stations

### 3.4 *Irregularity patch sizes*

Much of our knowledge of the dynamical characteristics of ionospheric irregularities has emerged from VHF radar observations. These observations indicate that at the altitudes of above about 500 km over the equator, rather distinct patches of irregularities of modest east-west dimension are present along the magnetic field lines which cause scintillations at temperate latitudes (Basu *et al.*, 1977). The duration of the scintillation patch represents the east-west dimension of the irregularity patch. Assuming that plasma bubbles travel with the same velocity while crossing the F-region cross-over points of Ujjain and Bhopal, the patch sizes of the irregularities have been computed and are presented as a histogram in Fig. 4. The ·an east-west size of the irregularity patches at these longitudes is of the order of 200–500 km. Also, comparatively longer irregularity patches are found in the premidnight period compared to those in the postmidnight period.

## 4 Discussion

The nighttime ionospheric irregularities are first generated in the equatorial F-region. Subsequently distinct patches of irregularities are mapped down along the magnetic field lines to the temperate latitudes. Although the exact mechanism that triggers the irregularities and subsequent development is yet to be probed for complete understanding, it is believed that these irregualrities are constantly in motion, due to neutral wind and electric fields in the presence of geomagnetic field.

The east-west movement of ionospheric irregularities has been studied extensively using different techniques. Fejer *et al.* (1985) used incoherent radar observations at Jicamarca, and estimated the eastward drift to be 150 m s$^{-1}$ at about 2100 LT, reversing its direction westward during daytime. From a spaced polarimeter experiment in Brazil, Abdu *et al.* (1985) reported the eastward drift to decrease from 230 m s$^{-1}$ at 2100 LT to 80 m s$^{-1}$ at 0300 LT during the course of night. The airglow measurements at 630 nm at Cachoeira Paulista (14.9 S dip lat.) by Sobral *et al.* (1985) gave an eastward drift ranging from 200 to 80 m s$^{-1}$ with the peak at 2130 LT.

A radio-wave scintillation technique has also been effectively used by many researchers to study the dyanmics of plasma irregularities. Aarons *et al.* (1980) have shown that scintillation producing irregularities, soon after the sunset, have a westward expansion and later drift eastward, with velocities of the order of 100 m s$^{-1}$. Weber *et al.* (1983), using scintillation data from geostationary satellites FLTSAT and Marisat at Ascension Island, have shown an eastward drift of the irregularities to be, on average, 160 m s$^{-1}$. Similar results worked out in the Indian longitudes at Bombay (Koparkar and Rastogi, 1985) and Waltair (Rama Rao *et al.*, 1988) have yielded the drift velocities varying in the range of 200–60 m s$^{-1}$. Spaced scintillation experiments were conducted to study the plasma zonal drifts in the equatorial and low-latitude regions (Yeh *et al.*, 1981; Spatz *et al.*, 1988). A similar experiment conducted in India by Chandra *et al.* (1989) at Tiruchirapalli (4.2°N dip) indicated the drift velocities varying in the range of 300–100 m s$^{-1}$. Pathan *et al.* (1991) recorded the radio beacons simulataneously at pairs of stations at 0° and 3°N dip latitude in the Indian region and found the drifts to be predominantly eastward. They also reported that drifts were significantly higher at 3°N compared to those observed near the dip equator. Dabas *et al.* (1992) simultaneously recorded the radio beacons from INSAT-1B (74°E) and INSAT-1C (94°E) at Sikandrabad (24.2°N dip lat.) and Chingelpet (5.3°N dip lat.). They found that the drifts at Sikandrabad, varying between 92 and 55 m s$^{-1}$ were significantly lower compared to those estimated at Chingelpet which varied in the range of 174–118 m s$^{-1}$. Using in situ measurements on board the DE-2 satellite, Wharton *et al.* (1984) found that neutral wind speed decreases gradually with an increase in the dip latitude while Aggson *et al.* (1987) reported maximum plasma zonal drifts at about 8° dip latitude.

The drifts estimated at 16°N dip latitude reported here varied between 180 and 55 m s$^{-1}$ which is lower than that reported for stations situated south of this latitude but higher than that reported for stations situated north of it. This latitudinal dependence of plasma zonal drifts may be understood in terms of the altitude dependence of zonal drifts over the dip equator. Kudeki *et al.* (1981), using the Jicamarca radar in interferometer mode had detected positive shears, the velocity increasing with the altitude up to a height of 500–600 km. Using a 630-nm airglow angular scanning photometer at Cachoeira, Sobral and Abdu (1991) found that zonal drifts were higher at 540 km over the magnetic equator when compared with those at 660 km. Thus there are enough indications that the zonal drifts have negative shears above 600 km over the magnetic equator. Also, Rishbeth (1971) has suggested that the shears in zonal velocities may be due to the fact that the magentic field line integrated Pedersen conductivity has a finite contribution from plasma at higher latitude E-region. The vertical polarization electric field driven by neutral wind at the equator is partially shorted out by E-region conductivity, causing relative motion between plasma and neutral wind. Using model calculations, Zalesak *et al.* (1982) explained this shear on the basis of F-region Pedersen conductivity maximizing at the F-region peak. The shorting effect of the magnetic field-line linked E-region on the F-region dynamo polarization field would be small at the F-region peak over the dip equator.

The mean zonal drifts reported here correspond to a height of about 1000 km over the equator which is in the negative shear region. Thus, the drifts are lower than those reported for the latitudes south of this pair of stations and higher than those reported by Dabas *et al.* (1992) which corresponds to 1200 km over the dip equator.

Drifts are found to be high on the magnetically quiet days when compared to those on magnetically disturbed days. Fejer *et al.* (1981) found very little effect of magnetic activity on Jicamarca drifts while Ganguly *et al.* (1987) reported that the increase in the magnetic activity seems to decrease plasma zonal drifts measured by incoherent scatter radar at Arecibo (31°N dip latitude). This effect may be due to the fact that a sudden perturbation in the magnetospheric potential during the magnetically disturbed conditions across the polar cap, often results in short-lived electric potential, propagating almost simultaneously from high to middle and equatorial latitudes and effecting the electrodynamic drifts in the region.

The east-west irregularity patch dimension of the order of a few hundered kilometers has been reported by many researchers. Somayajulu *et al.* (1984) have shown that scintillations at stations situated off the dip equator are controlled by the equatorial spread-F. Sastri (1985) has reported that the patch duration of the equatorial spread-F is seasonally controlled. Scintillations at the equator, caused by the vertically integrated effects from both strong and weak irregularity layers, appear to be moderately strong and continuous in time while discrete patches are observed away from the equator (Mathew *et al.*, 1992; Pathan *et al.*, 1992). Scintillations at the latitudes of Ujjain and Bhopal occur in patches due to F-region irregularities of the dimensions of 200–500 km in the east-west direction and drifting predominantly in the easterly direction.

*Acknowledgements.* This work was supported by the Department of Science and Technology, Govt. of India, New Delhi, India under the All India Coordinated Programme on Ionospheric Thermospheric Studies (AICPITS). One of the authors (SK) thanks the Council of Scientific and Industrial Research (CSIR) New Delhi, for awarding a Research Associateship.

Topical Editor P. J. S. Williams thanks E. Kudeki and R. S. Dabas for their help in evaluating this paper.

## References

**Aarons, A., J. P. Mullen, H. E. Whitney, and E. M. Mackenzie,** The dynamics of equatorial patch formation, motion and decay, *J. Geophys. Res.*, **85**, 139–149, 1980.

**Abdu, M. A., I. J. Kantor, I. S. Batisa, and E. R. Depaula,** East-west plasma bubble irregularity motion determined from spaced VHF polarimeters: implications on velocity shear in the zonal F-region bulk plasma motion, *Radio Sci.*, **20**, 111–122, 1985.

**Aggson, T. L., N. C. Maynard, F. A. Herrero, H. G. Mayr, L. H. Brace, and M. C. Librechet,** Geomagnetic equatorial anomaly in zonal plasma flow, *J. Geophys. Res.*, **92**, 311–315, 1987.

**Basu, Su., J. Aarons, J. P. McClure, C. LaHoz, A. Bushby, and R. F. Woodman,** Preliminary comparision of VHF radar maps of F-region irregularities with scintillation in the equatorial region, *J. Atmos. Terr. Phys.*, **39**, 1251–1261, 1977.

**Basu, S., Su. Basu, J. Aarons, J. P. McClure, and M. D. Cousins,** On the coexistance of kilometer and meter scale irregularities in the nighttime equatorial F-region, *J. Geophys. Res.*, **83**, 4219–4226, 1978.

**Balsley, B., G. Haerendel, and R. A. Greenwald,** Equatorial spread-F, Recent observations and new interpretation, *J. Geophys. Res.*, **77**, 5625–5630, 1972.

**Chandra, H., V. P. Patel, M. R. Deshpande, and G. D. Vyas,** Spaced receiver scintillation measurements near magnetic equator, *Ind. J. Radio Space Phys.*, **18**, 125–132, 1989.

**Dabas, R. S., P. K. Banerjee, S. Bhattacharya, B. M. Reddy, and J. Singh,** Study of equatorial plasma bubble dynamics using GHz scintillations in the Indian Sector, *J. Atmos. Terr. Phys.*, **54**, 893–901, 1992.

**Fejer, B. G., D. T. Farley, C. A. Gonzales, R. F. Woodman, and C. Calderon,** F-region east-west drifts at Jicamarca, *J. Geophys. Res.*, **86**, 215–218, 1981.

**Fejer, B. G., E. Kudeki, and D. T. Farley,** Equatorial F-region zonal plasma drifts, *J. Geophys. Res.*, **90**, 12249–12255, 1985.

**Ganguly, S., R. A. Behnke, and B. A. Emery,** Average electric field behavior over Arecibo, *J. Geophys. Res.*, **92**, 1199–1210, 1987.

**Haerendel, G.,** Theory of equatorial spread-F, *Tech. Rep.*, Max-Planck-Inst. für Phys., Astrophys., Garching, Germany, 1974.

**Koparkar, P. V., and R. G. Rastogi,** VHF radio scintillations at Bombay, *J. Atmos. Terr. Phys.*, **47**, 907–910, 1985.

**Koparkar, P. V.,** Drift of ionospheric scintillation irregularities at subtropical latitudes, *Ann. Geophys.*, **6**, 201–204, 1988.

**Koparkar, P. V., B. M. Pathan, and R. G. Rastogi,** East-west movement of irregularities causing scintillations, *Ind. J. Radio Space Phys.*, **20**, 333–337, 1991.

**Koster, J. R., W. L. Korfeber, and D. Yeboaach-Amahkwah,** Studies of equatorial ionospheric phenomenon using transmissions from active satellites, Dep. Physics, University of Ghana, 1978.

**Krishna Moorthy, K., C. R. Reddi, and B. V. Krishna Murthy,** Nighttime ionospheric scintillations at the magnetic equator, *J. Atmos. Terr. Phys.*, **41**, 123–134, 1979.

**Kudeki, E., B. G. Fejer, D. T. Farley, and H. M. Ierkic,** Interferometer studies of equatorial F-region irregularities and drifts, *Geophys. Res. Lett.*, **8**, 377–380, 1981.

**Mathew, B., K. N. Iyer, and B. M. Pathan,** Patchy occurrence of VHF scintillations at tropical latitudes, *J. Atmos. Terr. Phys.*, **54**, 963–968, 1992.

**Ossakow, S. L., S. T. Zalesak, B. E. MacDonald, and P. K. Chaturvedi,** Non-linear equatorial spread-F: Dependence on altitude of the F-peak and bottomside background electron density gradient scale length, *J. Geophys. Res.*, **84**, 17–29, 1979.

**Pathan, B. M., P. V. Koparkar, R. G. Rastogi, and D. R. K. Rao,** Dynamics of ionospheric irregularities producing VHF radio wave scintillations at low latitudes, *Ann. Geophys.*, **9**, 126–132, 1991.

**Pathan, B. M., R. G. Rastogi, and D. R. K. Rao,** On the width and complexities of the equatorial night time radio-wave scintillation belt in the Indian region, *J. Geomagn. Geoelectr.*, **44**, 129–142, 1992.

**Rama Rao, P. V. S., B. V. Ramana Rao, and K. K. Bose,** On the occurrence of VHF and UHF scintillations and the zonal movement of irregularities during the low solar activity period of 1983–1984, in *Proc. Int. Beacon Satellite Symp.*, Beijing, China, 18–21 April 1988, 225–232, 1988.

**Rastogi, R. G.,** Solar cycle effects on radio scintilations at Huancayo, *Indian J. Radio Space Phys.*, **13**, 215–221, 1982.

**Rishbeth, H.,** Polarization fields produced by winds in the equatorial F-region, *Planet. Space Sci.*, **19**, 357–369, 1971.

**Sastri, J. H.,** Patchy occurrence of equatorial spread-F, *Ann. Geophys.*, **3**, 589–592, 1985.

**Sobral, J. H. A., M. A. Abdu, and Y. Sahai,** Equatorial plasma bubble eastward velocity characteristics from scanning airglow photometer measurements over Cachoeria Paulista, *J. Atmos. Terr. Phys.*, **47**, 895-900, 1985.

**Sobral, J. H. A., and M. A. Abdu,** Solar activity effects on equatorial plasma bubble zonal velocity and its latitude gradient as measured by airglow scanning photometers, *J. Atmos. Terr. Phys.*, **53**, 729-742, 1991.

**Somayajulu, Y. V., S. C. Garg, R. S. Dabas, Lakha Singh, T. R. Tyagi, B. Lokanadham, S. Ramakrishna, and G. Navneeth,** Multistation study of nighttime scintillations in low latitudes, Evidence of control by equatorial F-region irregularities, *Radio Sci.*, **19**, 707-718, 1984.

**Spatz, D. E., S. J. Franke, and K. C. Yeh,** Analysis and interpretation of spaced receiver scintillation data recorded at an equatorial station, *Radio Sci.*, **23**, 347-361, 1988.

**Tetheridge, J. E.,** Large-scale irregularities in the ionosphere, *J. Geophys. Res.*, **68**, 3399-3417, 1963.

**Tsunoda, R. T.,** Time evolution and dynamics of equatorial backscatter plumes, I: Growth Phase, *J. Geophys. Res.*, **86**, 139-149, 1981.

**Tsunoda, R. T., R. C. Livingston, J. P. McClure, and W. B. Hanson,** Equatorial plasma bubbles; Vertically elongated wedges from the bottomside F-layer, *J. Geophys. Res.*, **87**, 9171-9180, 1982.

**Weber, E. J., J. Aarons, and A. L. Johnson,** Conjugate studies of an isolated equatorial irregularity region, *J. Geophys. Res.*, **88**, 3175-3180, 1983.

**Wharton, L. E., N. W. Spencer, and H. G. Mayr,** The Earth's thermospheric superrotation from Dynamics Explorer-2, *Geophys. Res. Lett.*, **11**, 531-533, 1984.

**Woodman, R. F., and C. LaHoz,** Radar Observations of F-region equatorial irregularities, *J. Geophys. Res.*, **81**, 5447-5466, 1976.

**Yeh, K. C., J. P. Mullen, J. R. Medeiros, R. F. Da Silva, and R. T. Medeiros,** Ionospheric scintillation observations at Natal, *J. Geophys. Res.*, **86**, 7527-7232, 1981.

**Zargham, S., and C. E. Seyler,** Collisional interchange instability; Numerical simulations of intermediate scale irregularities, *J. Geophys. Res.*, **92**, 1073-1088, 1987.

**Zalesak, S. T., S. L. Ossakow, and P. K. Chaturvedi,** Non-linear equatorial spread-F: The effect of neutral winds and Pedersen conductivity, *J. Geophys. Res.*, **87**, 151-166, 1982.