PLASMA REDISTRIBUTION IN LOW LATITUDE IONOSPHERE DURING INTENSE SPREAD F CONDITIONS

S. ALEX, P. V. KOPARKAR and R. G. RASTOGI
Indian Institute of Geomagnetism, Bombay 400 005, India

IT has been shown that during periods of intense night-time equatorial spread F the columnar electron content is reduced at the equatorial regions and increased at tropical latitudes. The generation of equatorial F region irregularities on certain nights is associated with intensification of equatorial plasma fountain in the evening hours due to the continuation of horizontal electric field in the eastward direction even during the post-sunset period.

Scintillations of radio waves from stars or from artificial satellites received at equatorial latitudes have been known to be associated with spread F irregularities[1–4]. The discovery of scintillations even at GHz range of radio waves[5–7] at equatorial latitudes has generated keen interest in studies concerning radio wave scintillations and cause and effects of F region plasma irregularities. Unfortunately, during periods of intense equatorial spread F, most of the techniques to monitor the ionospheric plasma density distribution fail due to strong reflected or scattered echoes from these irregularities or due to violent fluctuations of the amplitude of trans-ionospheric radio waves from geostationary satellite. *In situ* measurements of plasma density by satellite-borne probes have shown large bite-outs up to three orders of magnitude in plasma density because of the plasma bubbles associated with spread F over the size scales of 10 to 200 km[8]. Therefore, no measurements have been reported of the temporal variation of background plasma density or of electron content at equatorial regions during intense spread F.

With the cooperation of the Environment Research Laboratory, Boulder, USA and the Physical Research Laboratory, Ahmedabad, India, a sophisticated receiving station was set up at Ootacamund, India, to record the amplitudes of various carrier and side bands of the radio beacons from geostationary satellite ATS-6 then situated at 35°E longitude. The system and measurement techniques have been described by Davies *et al.*[9] The amplitudes of all the signals were recorded separately on two orthogonal aerials into digital tapes at intervals of 0.1 s during October 1975–January 1976. To this day these data remain unique for equatorial latitudes and have not been repeated at any other low latitude station.

During intense spread F conditions, the analogue records of Faraday fadings of the received beacons are obliterated due to rapid and violent fluctuations of the signal amplitude, rendering the measurement of ionospheric electron content impossible during these conditions. Using the 0.1 s digital data of beacon received at Ootacamund, Bhattacharyya and Rastogi[10] have shown that during periods of intense amplitude scintillations, the Faraday phase fluctuation for 140 MHz is negligible although the quadrature components from which the Faraday rotation angle is derived show large fluctuations. Thus, using digital data, it has been possible to compute the true Faraday rotation of the 140 MHz signal and thereby compute the ionospheric electron content (N_F) over the equator even during intense scintillation events. Using the amplitude data at interval of 0.1 s the scintillation index S_4 for every 15 min is defined as the root mean square deviation of the power of the received signal divided by the mean power. The Physical Research Laboratory had also organized the measurement of N_F at a number of low and tropical latitude stations during the same period using Titheridge-type polarimeters. The data were recorded on analogue strip charts. During the study, scintillations on Faraday phase fluctuations were not recorded at Ahmedabad or Patiala. The N_F values were available at these stations during the periods when strong amplitude scintillations were observed at Ootacamund. These data were supported

Table 1 *Geographical locations at various stations studied*

	Station coordinates			Sub-ionospheric coordinates		
Station	Lat. °N	Long. °E	Magnetic dip °N	Lat. °N	Long. °E	Magnetic dip °N
Kodaikanal	10.2	77.5	3.5	—	—	—
Ootacamund	11.4	76.7	6.0	10.6	72.9	4.4
Ahmedabad	23.0	72.6	34.0	21.5	69.4	31.6
Patiala	30.4	76.4	45.0	28.2	72.1	42.3

by vertical incident ionosonde observations at Kodaikanal and Ahmedabad. The geographical locations of the stations whose data are used in the present paper are listed in table 1. With respect to the equatorial F layer anomaly belt, Kodaikanal/Ootacamund were close to the trough, Ahmedabad was close to the crest and Patiala was well outside the belt. The N_F or S_4 data were computed for every 15 min intervals for the period October 1975 to January 1976. Based on S_4 (140 MHz) data at Ootacamund two groups of days were selected (i) when strong scintillations were recorded, and (*ii*) when practically no scintillations were observed. The lowest limit of no scintillation on chart corresponded to digitally derived $S_4=0.04$. The average temporal variation of S_4 was computed separately for these two groups of days for the hours 1600–2400 h for the entire period October 1975–January 1976. Similarly the mean temporal variations of N_F at Ootacamund, Ahmedabad and Patiala as well as the minimum virtual height of the F layer and the per cent occurrence of spread F at Kodaikanal were computed for the two groups of days. The resultant curves are shown in figure 1.

First, the mean value of S_4 on no scintillation days varied between 0.03 and 0.04 corresponding to peak fluctuations of 1/3 dB, for any of the hours between 1600 and 2400 h. On the other hand, the mean S_4 on scintillation present days was around 0.03–0.04 up to 1815 h after which it started to increase reaching a value of 0.40 by 2015 h and remained at the same level up to midnight. The individual values of S_4 ranged from 0.02 to 0.90.

It was found that no spread F was observed on no-scintillation nights. The mean per cent occurrence of spread F on the scintillation nights was zero up to 1800 h after which it started increasing to 100% at 2130 h and decreased to a value of 60% by midnight. Good correlation was seen in the mean curves of spread F and scintillations.

The temporal variation of $h'F$ at Kodaikanal started increasing from 220 km at 1600 h to 260 km between 1800 and 1900 h after which it started decreasing towards midnight. This increase of $h'F$ during the evening hours was due to the increasing zenith distance of the sun causing relatively faster decay of ionization in the lower levels of the F region, giving an impression of uplifting of the layer. On the scintillation-present nights also $h'F$ was 220 km at 1600 h, continued to increase faster reaching a value of 300 km at 2000 h. It is to be noted that $h'F$ on these days was not only higher but the peak value was delayed with respect to the same on scintillation-absent days. These effects are to be interpreted as due to genuine uplifting of the F

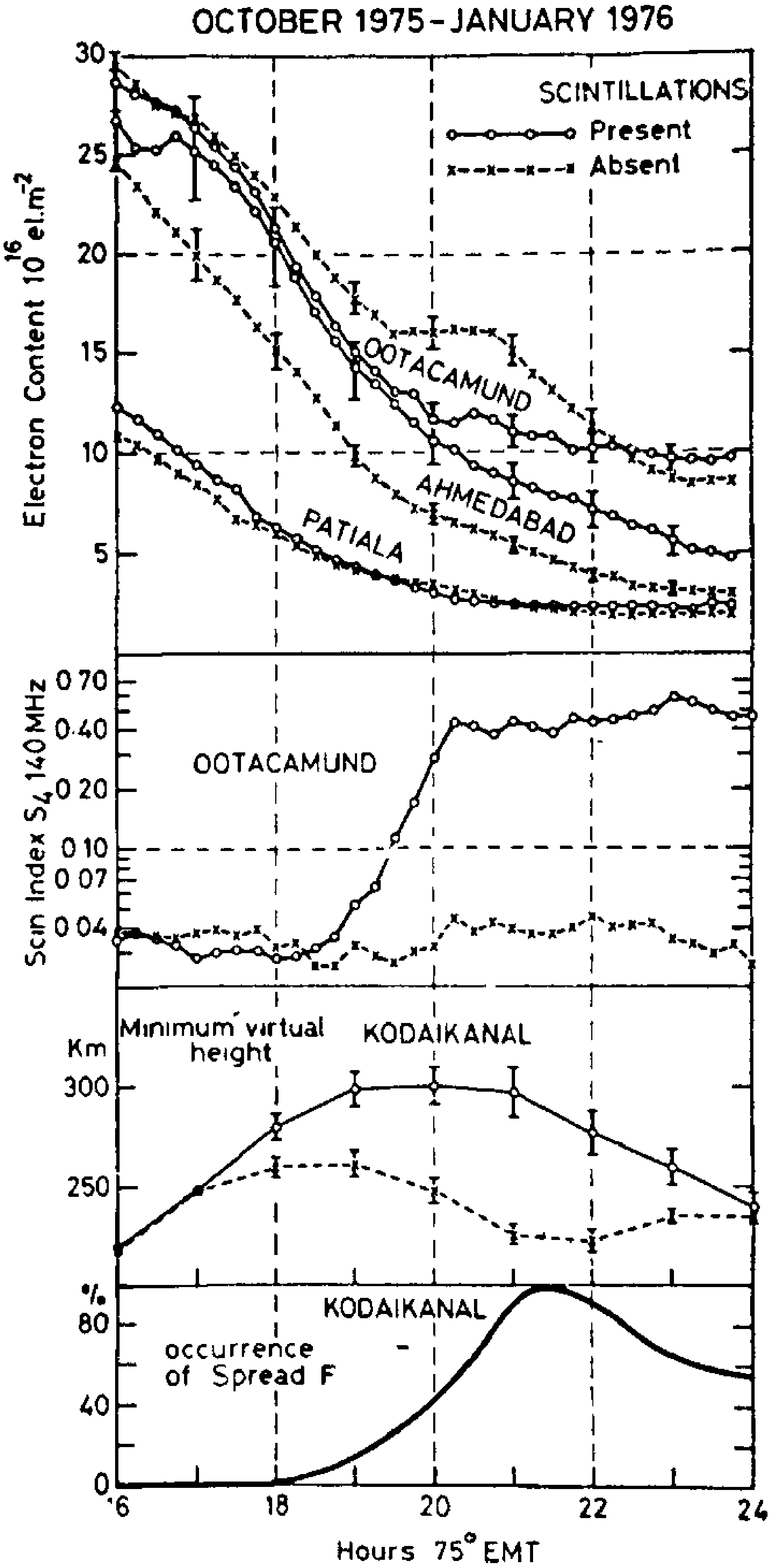

Figure 1. Temporal variations of minimum virtual height of F layer ($h'F$) at Kodaikanal, scintillation index S_4 at Ootacamund, ionospheric Faraday electron content at Ootacamund, Ahmedabad and Patiala averaged for two groups of days when scintillations were present and another when scintillations were absent at Ootacamund for the period October 1975 to January 1976.

layer besides the effects due to the decay of ionization at low levels.

Referring to the curves showing temporal variations of N_F at Ootacamund it is seen that N_F was lower on scintillation-present nights even since 1700 h when $h'F$ also indicated a faster rise. The value of N_F at 2000–2100 h, when S_4 reached the maximum value, was 11.5×10^{16} electrons m^{-2} on scintillation-present days compared to 16.3×10^{16} electrons m^{-2} on scintillation-absent days. The difference of N_F at Ootacamund on two groups of days was insignificant after 2200 h.

The values of N_F at Ahmedabad were significantly higher on days when scintillations were present at Ootacamund. This effect continued throughout the period 1600–2400 h. Thus the effects of scintillation source at the equatorial regions produced a decrease of N_F at equatorial and an increase of N_F at tropical latitudes. The difference in N_F between two groups of days became insignificant at Patiala, a station well outside the equatorial F region anomaly belt.

This phenomenon is very analogous to the development of F_2 region anomaly during the daylight hours as the consequence of equatorial plasma fountain resulting from the action of eastward electric field on the northward magnetic field causing upward lift of plasma over the equator followed by transfer of plasma to tropical latitudes guided by the lines of earth's magnetic field. Rastogi[11] has shown that spread F and scintillations at Huancayo are observed only on the nights when the horizontal/vertical electron drifts measured at Jicamarca showed the continuation of eastward electric fields even well after sunset. This electric field causes uplifting of the whole F region during sunset hours.

Numerically solving the time-dependant plasma continuity equation including the effect of ionization production by solar ultraviolet radiation, loss through charge exchange and transport by diffusion, $\bar{E} \times \bar{B}$ drift and neutral winds, Anderson and Klobuchar[12] showed that the post-sunset enhancement of $\bar{E} \times \bar{B}$ drift is primarily responsible for the post-sunset increase in ionospheric electron content at a station close to the crest of equatorial F region anomaly belt.

The present results conclusively show that the generation of equatorial spread F irregularities is associated with intensification of latitudinal plasma density anomaly which requires a strong electric field. The hierarchy of the phenomena is the continuation of the eastward electric field in the evening beyond the sunset hour, causing the anomaly to develop. With the generation of sharp gradient at the base of the F region after sunset the eastward electric field generates $\bar{E} \times \bar{B}$ gradient drift instability, sometimes referred to as bubbles. The buoyancy effects associated with the Rayleigh–Taylor instability mechanism extend the irregularities to greater altitudes over the equator. Together with the plasma fountain, the irregularities are lifted up and later diffuse to higher latitudes creating an equatorial belt of high incidence of spread F occurrence at low latitudes, analogous to the daytime belt of the bite out of F_2 layer critical frequencies. This idea fits in very well with the latitudinal belt of high occurrence of spread F observed by ground ionosondes[13] or by satellite-borne ionosondes[14].

Research facilities at the Institute of Geomagnetism are financed by the Department of Science and Technology, New Delhi.

26 December 1988; Revised 10 March 1989

1. Koster, J. R., *J. Atmos. Terr. Phys.*, 1958, **12**, 100.
2. Bhargava, B. N., *J. Inst. Telecommn. Eng.*, 1964, **10**, 404.
3. Bandyopadhayay, P. and Aarons, J., *Radio Sci.*, 1970, **5**, 931.
4. Rastogi, R. G., *Indian J. Radio Space Phys.*, 1982, **11**, 1.
5. Skinner, M., Kelleher, R. F., Hacking, J. B. and Benson, R. W., *Nature (London)*, 1971, **232**, 19.
6. Craft, H. C. and Westlund, L. H., Paper No. 72/179, American Institute of Aeronautics and Astronautics, New York, 1972.
7. Taur, R. R., *COMSAT Tech. Rev.*, 1973, **3**, 145.
8. McClure, J. P., Hanson, W. B. and Hoffman, J. H., *J. Geophys. Res.*, 1977, **82**, 2650.
9. Davies, K., Donnelly, R. F., Grub, R. N., Rama Rao, P. V. S., Rastogi, R. G., Deshpande, M. R., Chandra, H., Vats, H. O. and Sethia, G., *Radio Sci.*, 1979, **14**, 85.
10. Bhattacharyya, A. and Rastogi, R. G., *J. Geophys. Res.*, 1987, **92**, 8821.
11. Rastogi, R. G., *J. Atmos. Terr. Phys.*, 1986, **68**, 687.
12. Anderson, D. N. and Klobuchar, J. A., *J. Geophys. Res.*, 1983, **88**, 8020.
13. Lyon, A. J., Skinner, N. J. and Wright, R. W., *J. Atmos. Terr. Phys.*, 1960, **21**, 100.
14. Calvert, W. and Schmid, C. W., *J. Geophys. Res.*, 1964, **69**, 1839.