Indian Journal of Radio & Space Physics
Vol. 32, April 2003, pp. 83-92

Association between equatorial and tropical spread-F

S Alex
Indian Institute of Geomagnetism, Colaba, Mumbai 400 005
and
H Chandra & R G Rastogi
Physical Research Laboratory, Navarangpura, Ahmedabad 380 009

Received 27 February 2002; revised 6 June 2002; accepted 21 November 2002

Comparative study of spread-F is made from the quarter-hourly ionograms at Huancayo, near the magnetic equator and Bogota, close to the anomaly crest region in the same longitude sector. The occurrence of equatorial spread-F is seen only during nights, preceded by very rapid rise of the F-layer close to the magnetic equator. Based on quarter- hourly ionospheric data at a closely spaced chain of 8 stations in the American sector that operated during IGY, the occurrence of spread-F at low latitudes is shown to be associated with the post-sunset intensification of the ionization anomaly. The ratio of f_oF2 at Bogota (anomaly crest) to that at Huancayo (dip equator) shows sudden intensification on spread-F days around 1900 hrs LT, peaking between 2000 and 2100 hrs LT and can be used as a precursor to predict spread-F near the magnetic equator. The onset of spread-F at Bogota, however, requires additional condition of strong spread-F at Huancayo covering a wide range of altitudes and stronger uplift of the F-layer. There are indications that the vertical uplift velocity of F-layer between 1800 and 1900 hrs LT could be used to predict the onset of equatorial spread-F even at crest.

1 Introduction

The occurrence of equatorial spread-F (ESF) is preceded by the rapid rise of F-layer[1-6]. From the electron density profiles obtained from the true height analysis at Thumba[7] and Huancayo[8] it has been shown that the whole of the F-layer is uplifted in the post-sunset period with simultaneous increase in both the base and the peak of the F-layer. The semi-thickness of the F-layer remains constant in this period. Electron density contours on altitude versus local time grid obtained by the backscatter radar at Jicamarca also indicate the rise of the whole of F-layer before the initiation of spread-F irregularities.

During IGY the tabulation of f_oF2 incorporated the symbol 'F' to indicate the uncertainties in the determination of f_oF2 due to spread-F. Based on the published f_oF2 data, occurrence of spread-F was studied and a belt of high incidence of spread-F centered on the magnetic equator and extending to $\pm$ 30°dip latitude was discovered[9,10]. Abdu *et al.*[11] made a comparative study of the ionograms at the equatorial station Fortaleza (dip 3.5° S) and tropical latitude station Cachoeira Paulista (dip 26° S) in the Brazilian sector. It was found that all the spread-F events at Cachoeira Paulista were accompanied by the occurrence of spread-F at Fortaleza, but the converse was not true. Also the onset times of spread-F at the tropical latitude station were systematically later from that at the equatorial station.

Cohen and Bowles[12] interpreted the spread-F echoes on ionograms at stations near the magnetic equator arising due to the scattering from thin sheets of irregularities aligned along the geomagnetic field lines. Calvert and Cohen[13] explained the configuration of equatorial spread-F echoes on ionograms from the appropriate distribution of the scattering centers. King[14] suggested spread-F echoes due to the total reflections from large tilted surfaces of ionization. Satellite traces are associated with the off-vertical reflections from such tilts[15]. The spread-F at tropical latitudes was suggested due to the superimposition of additional off-vertical h'-f traces from the patches of irregularities drifting from equatorial regions guided by the geomagnetic field lines.

The characteristics of spread-F on ionograms at tropical latitude differ very much from those at an equatorial station[16]. Spread-F echoes at a temperate latitude station, Grand Bahama, start with additional traces near the penetration frequencies due to off-vertical echoes. With time these additional traces increase in intensity and in number and extend to lower frequencies giving rise to range spread[17]. The temperate type of spread-F was suggested to arise from the reflection of radio waves from the ripples in the iso-ionic surfaces rather than from the scattering of radio waves from plasma density irregularities.

Multi-technique investigations of ESF using *in situ* rocket/satellite measurements, VHF/UHF radar measurements, radio scintillation and optical observations and numerical simulation studies have greatly advanced our understanding of the phenomenon of ESF (Recent reviews[18-21]). 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 thus generated rise fast to cover entire F-region including the topside. Steep plasma density gradients thus generated are responsible for the generation of smaller scale irregularities. Higher the altitude to which plasma depletions rise near the magnetic equator, farther is the latitudinal extent of ESF. The VHF scintillations recorded at a chain of 20 stations in India under AICPITS showed systematic time delay in the onset time of scintillations at latitudes away from the dip equator with maximum delay of 2 h for Delhi[22].

Recent studies of the electron density profiles at a number of low latitude stations in the Indian and American longitudes have revealed an intensification of the equatorial ionization anomaly in the post-sunset hours preceding the equatorial spread-F (Refs 23-25). Association of the ionization anomaly and spread-F is further provided by the ionospheric total electron content (N_T) data collected at a network of stations in India during the ATS-6 phase II. On nights with strong spread-F, N_T was reduced at Ootacamund and increased at stations close to anomaly crest[26]. However, the studies were based on measurements at just one station close to dip equator and one or more stations in the anomaly crest region.

In the present paper, we have compared the structure of spread-F irregularities from quarter-hourly ionograms at the equatorial station Huancayo and at Bogota situated near the crest of ionization anomaly. Ionospheric data at a close chain of 8 stations are used to examine the anomaly during spread-F and non-spread-F days.

2 Results

The F-layer parameters, h'F and f_0F2 for the network of eight stations in the American longitudes that operated during IGY are examined first. The locations of the stations are shown in the map in Fig. 1. The map also shows the iso-dip angle lines. In Fig. 2 are shown the contour plots of h'F and f_0F2 drawn on the dip latitude versus local time grid for 21-22 Apr. 1958 when no spread-F was seen at equatorial stations and 25-26 Apr. 1958 when strong equatorial spread-F was observed. On the non-spread-F day (21-22 April), F-layer rose after sunset with h'F more than 350 km at equator and 300 km at other latitudes. On spread-F night (25-26 April), h'F was more than 500 km near the dip equator and was around 300 km at latitudes from 15° to 30°N. Another notable difference is in the time of maximum of h'F. On spread-F days the maximum in h'F occurs around 2000 hrs LT at all the stations of the chain. On non-spread-F days, however, the maximum in h'F occurs around 1900 hrs LT close to dip equator, but with slight delay at stations away from dip equator. Looking at the contours of f_0F2 on non-spread F days, the maximum (15 MHz) is seen near the dip equator around 1500 hrs LT. On spread-F night the maximum in f_0F2 (19 MHz) was seen near

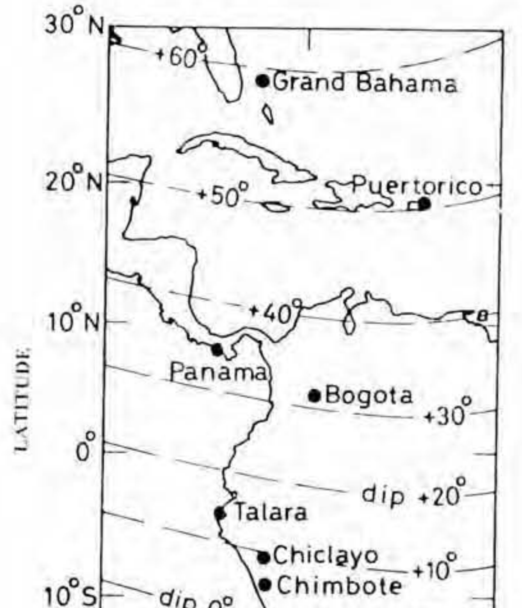

Fig. 1—Map showing the geographic locations of the eight stations that operated during IGY period in the American longitude sector [The dip angle is also marked]

the dip latitude of 15° around 2100 hrs LT. Thus, the large rise of the F-layer in the post-sunset period at Huancayo was followed by a large concentration of ionization near the latitude of Bogota. The post-sunset peak near the anomaly crest latitude was different from the peak around 1500 hrs LT (15 MHz).

The temporal variations of $h'F$ at Huancayo and of f_oF2 at Huancayo and Bogota on two consecutive days of 14 and 15 Apr. 1958 are shown in Fig. 3. A rapid increase of $h'F$ is seen in the evening of 14 Apr. 1958 with a value of 500 km around 2015 hrs LT. The large uplift of the F-layer at Huncayo is followed by the generation of spread-F at Huancayo around 2100 hrs LT and at Bogota around 2300 hrs LT. On 15 Apr. 1958 the F-layer rise was small ($h'F$ reaching 350 km at 1900 hrs LT) and spread-F was not observed at either of the stations. It must be noted that on 14 Apr. 1958 the f_oF2 values at Huancayo decreased rapidly from 1800 hrs LT to midnight, while increased at Bogota in the same period. The f_oF2 values at Bogota were higher than at Huancayo for the entire day. However, the difference is very large from 1800 hrs LT to midnight. On 15 Apr. 1958, the f_oF2 values at Huancayo were larger from about 0800 hrs LT to 1500 hrs LT, but from 1700 hrs to 2300 hrs LT the values were higher for Bogota though the difference is not more than 3 MHz compared to about 10 MHz on 14 Apr. 1958. This is because of the smaller rise of F-layer in the post-sunset period on 15 Apr. 1958 and, hence smaller uplift of the plasma from equatorial region towards the anomaly crest region. Thus, the difference in the ionization anomaly (or in the variation of f_oF2 at the two locations) is noted much before the onset of spread-F at Huancayo. The ratio of f_oF2 at Bogota to that at Huancayo at 2100 hrs LT is about 2.5 on 14 April, but only 1.5 on 15 April.

Similar plots for another set of days for 27, 28 and 29 Jan. 1958 are shown in Fig. 4. An abnormal increase of $h'F$ was seen at Huancayo in the post-sunset period of 28 Jan. 1958 with $h'F$ reaching a peak value of 600 km at around 2100 hrs LT. The post-sunset increase of $h'F$ on other two days was much smaller

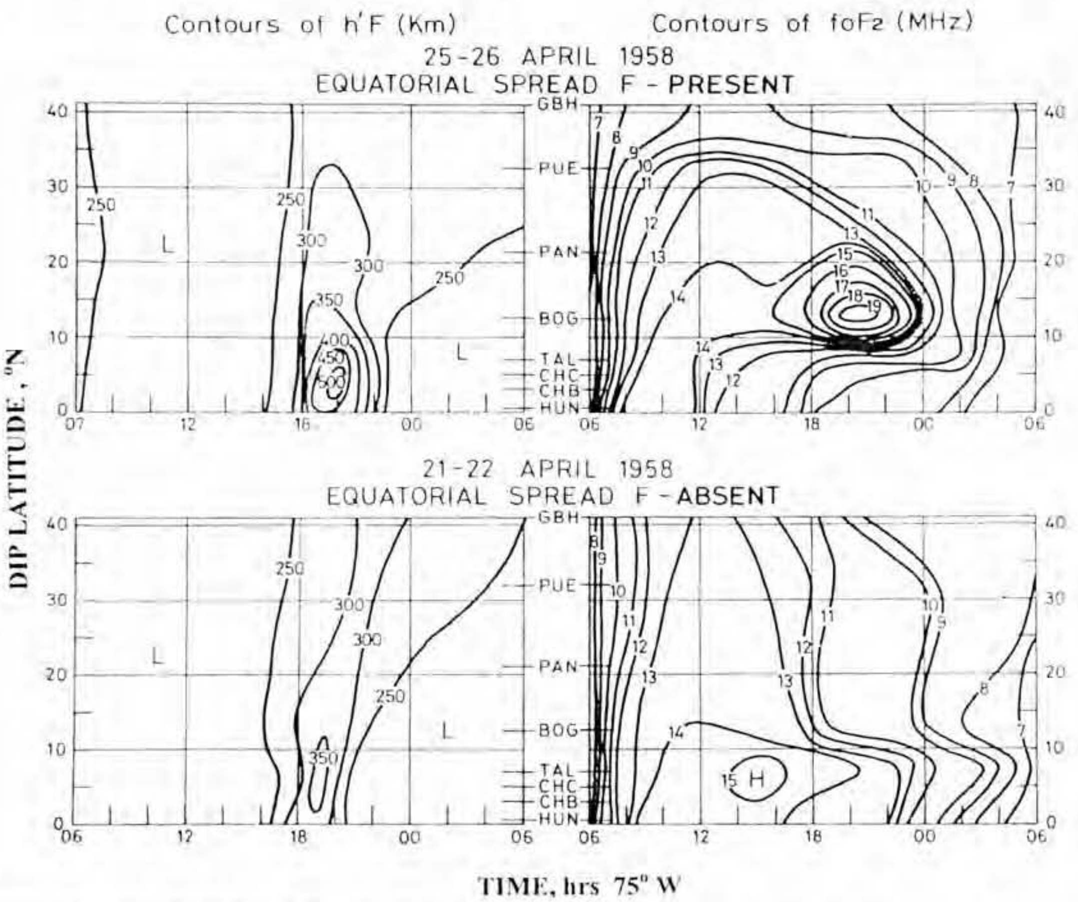

Fig. 2—Contours of $h'F$ and f_oF2 plotted in the grid of latitude versus local time for a day with spread-F present (25-26 Apr. 1958) and for a day with spread-F absent (21-22 Apr. 1958)

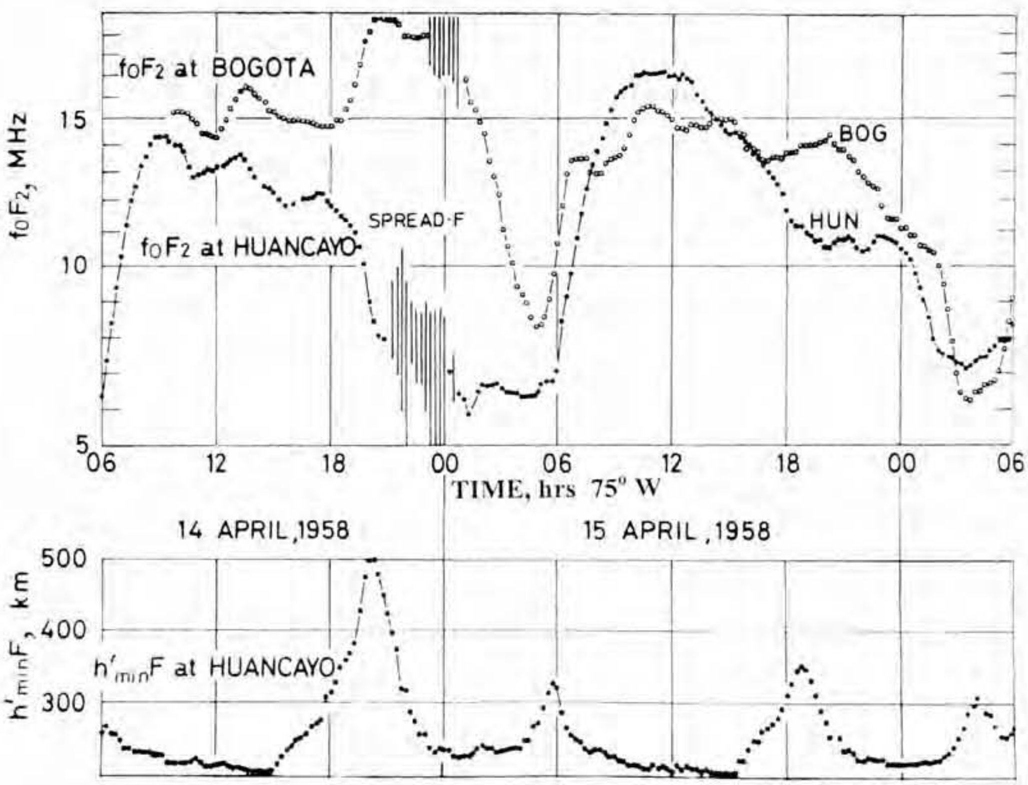

Fig. 3—Temporal variations of the minimum virtual height of the F-layer ($h'F$) at Huancayo and of the critical frequency of F-layer (f_0F2) at Huancayo and Bogota on 14 and 15 Apr. 1958

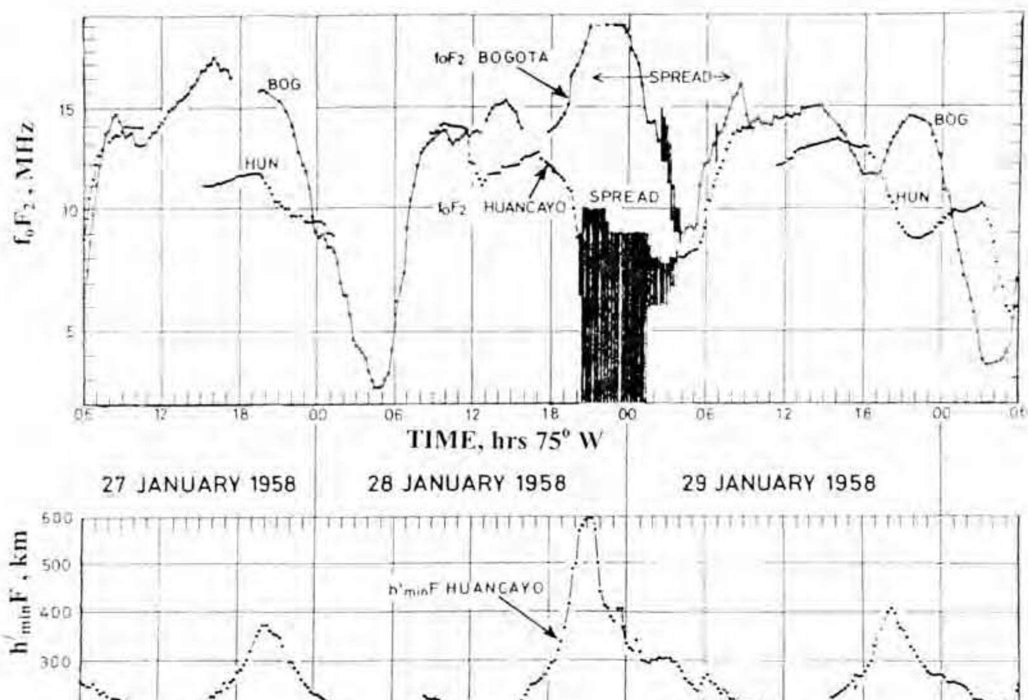

Fig. 4—Temporal variations of $h'F$ at Huancayo and f_0F2 at Huancayo and Bogota for the three consecutive days 27, 28 and 29 Jan. 1958

(375 km on 27 January and 400 km on 29 January both peaking at around 2000 hrs LT). The large rise of F-layer on 28 Jan. 1958 resulted in strong spread-F at Huancayo starting at around 2000 hrs LT and at Bogota from 2100 hrs LT. As seen in the earlier example, f_oF2 shows a large decrease at Huancayo and increase at Bogota from about 1800 hrs LT to midnight with the difference more than 10 MHz on spread-F day in contrast to about 5 MHz on other two days. The ratio of f_oF2 at Bogota to that at Huancayo at 2100 hrs LT is about 2.6 on 14 and 28 January but only about 1.5-1.6 on 27 and 29 January.

Few examples of ionograms at Huancayo during the nights of 27, 28 and 29 Jan. 1958 are shown in Fig. 5. On 27 and 29 January when the F-layer rise in the post-sunset period was small, only weak spread-F echoes were observed at the base of the F-layer and the irregularities did not extend to higher altitudes and no spread-F could be observed at Bogota. On 28 Jan. 1958, the spread-F at the base of the F-layer over Huancayo extended well throughout the layer and a number of strong scattering layers were observed. The base of the F-layer is almost at 600 km on 28 January, about 200 km higher than on 27 and 29 January.

Some ionograms at Bogota during the night of 28-29 Jan. 1958 are shown in Fig. 6. At 2300 hrs LT some additional off-vertical traces, the characteristics of the tropical spread-F were recorded, but the critical frequency is clearly identified. These features are not indicated as occurrence of spread-F in the routine scaling of ionograms. These additional traces later increased in number and intensity, leading to strong tropical range type spread-F. The group retardation effects are clearly seen in the additional traces and, therefore, are due to regular off-vertical reflections from irregularities in the iso-ionic surfaces and not due to the scattering. The characteristics of tropical spread-F are very different from those of equatorial spread-F shown in Fig. 5.

The ionograms at Huancayo and Bogota for the month of April 1958 were examined for the occurrence of spread-F and three sets of days were selected: (i) no spread-F at Huancayo or Bogota, (ii) spread-F seen at Huancayo only and (iii) spread-F seen both at Huancayo and Bogota. Number of days in the three groups were 19, 5 and 6, respectively. The mean variations of $h'F$ at Huancayo and of f_oF2 at Huancayo and Bogota for the three sets of days are shown in Fig. 7. Spread-F at Bogota was seen only on nights when strong spread-F was present at Huancayo. The increase of $h'F$ in the evening was small (peak value about 375 km at 1900 hrs LT) on nights with absence

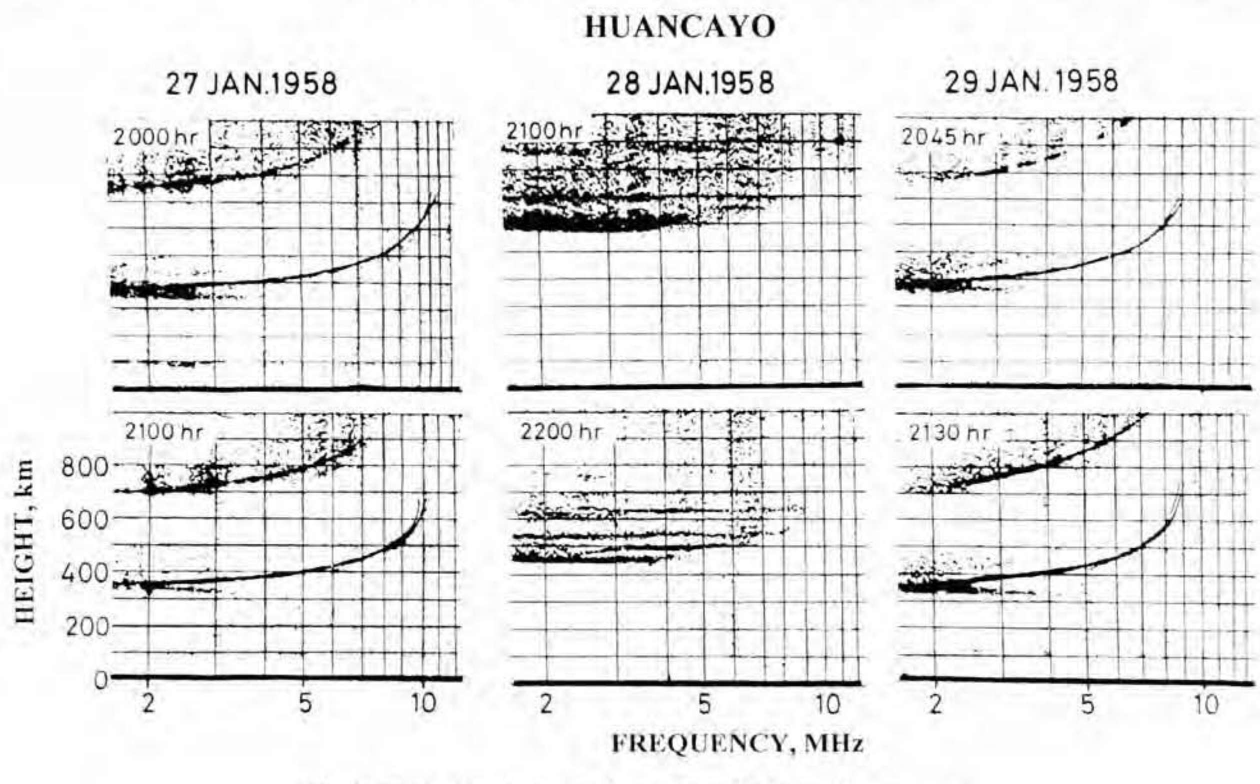

Fig. 5—Typical ionograms at Huancayo on 27, 28 and 29 Jan. 1958

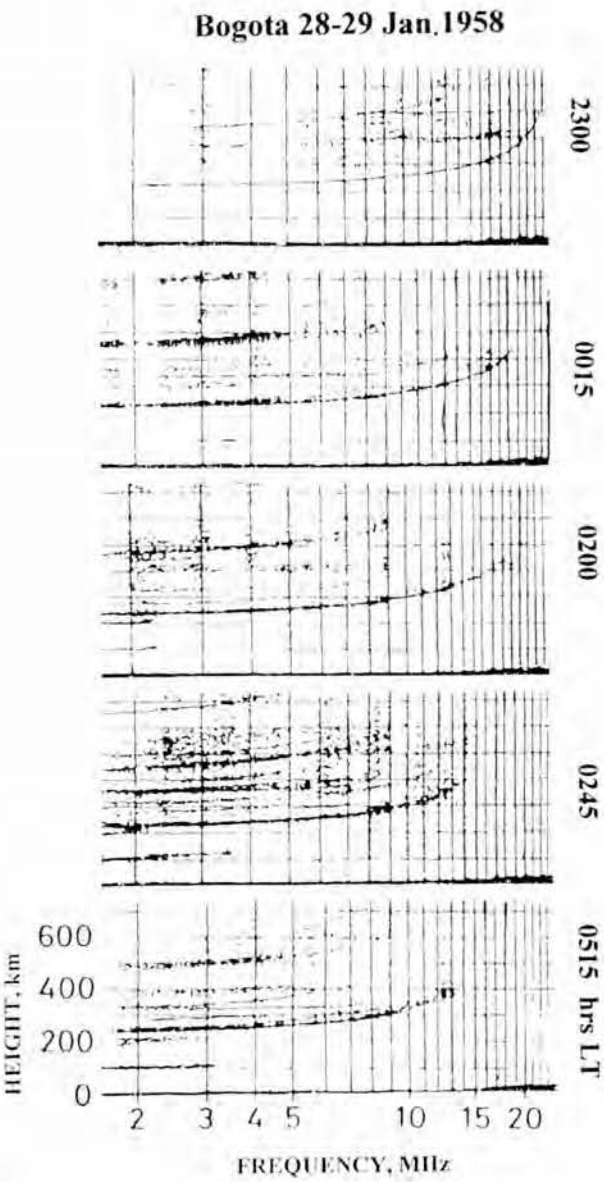

Fig. 6—Ionograms at Bogota showing the characteristics of tropical spread-F

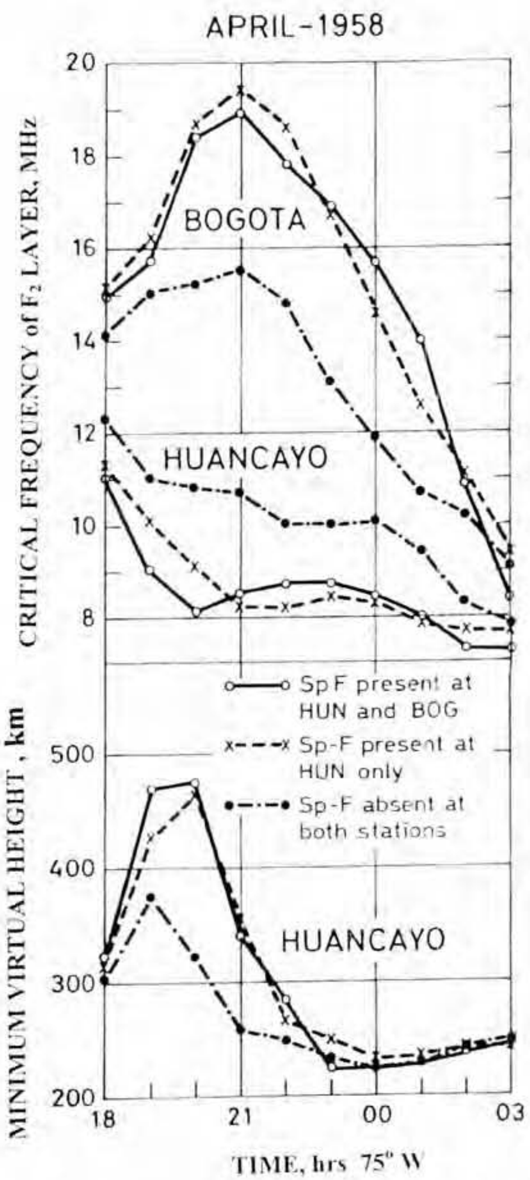

Fig. 7—Temporal variations of h'F at Huancayo and f_0F2 at Huancayo and Bogota averaged for three set of days of April 1958, namely (i) spread-F absent at both stations, (ii) spread-F present only at Huancayo and (iii) spread-F present at both stations (The number of days in each group are also indicated.)

of spread-F at both Huancayo and Bogota. On nights when spread-F was present at Huancayo or both at Huancayo and Bogota, there was rapid rise of F-layer with peak h'F value reaching about 475 km at 2000 hrs LT. The rate of increase in h'F between 1800 and 1900 hrs LT is, however, different for the three sets of days. The vertical uplifts of the F-layer in this period are 42 m/s on days with spread-F at both Huncayo and Bogota, 30 m/s on days with spread-F at Huancayo only and 21 m/s on days with no spread-F at the two stations.

The variations of f_0F2 show that on nights with spread-F absent at both the stations, values at Huancayo were unusually high and at Bogota unusually low, suggesting a weak ionization anomaly on those evenings. The values of f_0F2 were lower on nights with spread-F at Huancayo and still lower on nights with spread-F at both stations. There were abnormally large values of f_0F2 at Bogota when spread-F was observed at Huancayo or at both Huancayo and Bogota. The f_0F2 at Huancayo shows a faster decrease from 1800 to 2000 hrs LT on days of spread-F at both the locations than on days with spread-F at Huancayo only. Nelson *et al.*[27] showed that changes of $h'F$ at Fortaleza and Cachoeira Paulista for the equinoctial months did not show significant differences in the variations on nights when spread-F was seen only at equatorial station or at both the equatorial and tropical latitude station. This suggests that the feeble rise of $h'F$ does not promote the growth of spread-F at low latitudes. Further, the large rise of $h'F$ with decrease of f_oF2 at Huancayo and increase at Bogota is associated with spread-F at equatorial or at both equatorial and tropical latitudes.

The ratio of f_oF2 at Bogota to that at Huancayo for the three set of days during April 1958 is shown in Fig. 8. For days with spread-F absent at both Huancayo and Bogota the ratio increases from a value of 1.15 at 1800 hrs LT to 1.48 at 2200 hrs LT and decreases to about 1.15 at 0300 hrs LT. However, for days with spread-F present both at Huancayo and Bogota the value increases from 1.36 at 1800 hrs LT to more than 2.20 at 2000 and 2100 hrs LT and then decreases steadily to 1.15 at 0300 hrs LT. The values for the days with spread-F only at Huancayo show almost similar pattern, but the peak value of 2.35 appears at 2100 hrs LT. Thus, while the ratio of f_oF2 does not show much variation from 1900 to 2300 hrs LT on days with no spread-F, it increases rapidly between 1900 and 2100 hrs LT on days with spread-F at both the stations or at Huancayo only. Thus, the rate of change of this ratio can be used to predict the onset of spread-F at Huancayo.

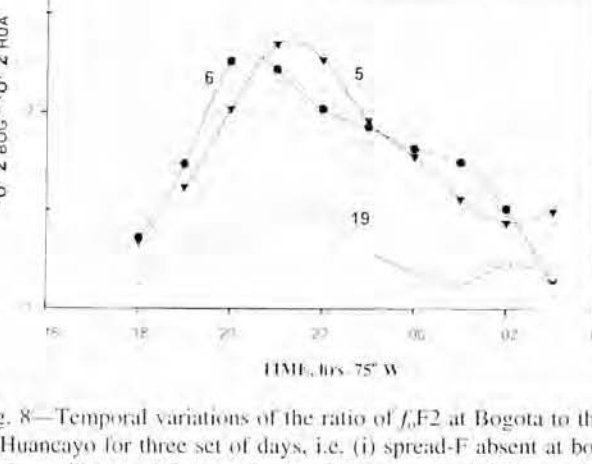

Fig. 8—Temporal variations of the ratio of f_oF2 at Bogota to that at Huancayo for three set of days, i.e. (i) spread-F absent at both stations, (ii) spread-F present only at Huancayo and (iii) spread-F present at both stations (Number of days in each group are also indicated.)

The ionograms recorded at both the stations were examined on nights with spread-F at Huancayo only or at both the stations. In Fig. 9 are shown few ionograms at Huancayo and Bogota on the nights when spread-F is seen only at Huancayo or at both Huancayo and Bogota. On the nights when spread-F echoes are absent at Bogota (8 and 16 Apr. 1958) weak scatter echoes are seen at lower frequency end of the ionograms. The $h'F$ traces at higher frequencies were limited to the lower portion of the F-region and the bubble had not risen to the top of the F-region even though there was an increase of $h'F$. On 12 and 13 Apr. 1958 spread echoes at Bogota were recorded as additional traces above first order $h'F$ trace and the critical frequencies were identifiable with reasonable accuracy. The corresponding ionograms at Huancayo showed intense range spreading with number of scattering layers at different altitudes and the normal $h'F$ trace was completely obliterated. The irregularities covered the whole of the F-region at these times.

3 Discussion

The day-to-day variability of equatorial spread-F is still not understood completely. Comparative studies of several ionospheric parameters have been made in the past to differentiate the patterns on spread-F and non-spread-F days. Chandra and Rastogi[28] showed from measurements at Thumba that the spread-F days were marked by later reversal of the F-region drifts in the post-sunset period and higher rise of F-layer. Similar results were later reported from drift measurements at Tiruchirapalli[29]. Rapid soundings from SHAR during the equatorial spread-F campaign of October 1988 also revealed that the later reversal of the electric field as determined from and higher rise of F-layer were associated with spread-F days. The F-layer rose to over 400 km on spread-F days and to 300-320 km on non-spread-F days.

From the true height analysis of ionograms at Ahmedabad, Waltair and Kodaikanal[20] it was shown that the ratio of electron density over Ahmedabad to that over Waltair for altitudes 270 km and 300 km show sudden enhancement (factor of 8-32) from 1800 hrs LT on days with spread-F present. The enhancements in the ratio of f_oF2 shown in the present work come out to be between 5 and 6 when translated into the ratio of the maximum electron density.

Sridharan *et al.*[30] have shown from the bi-directional 630 nm day glow measurements made from Waltair that the ratio of the intensity along the

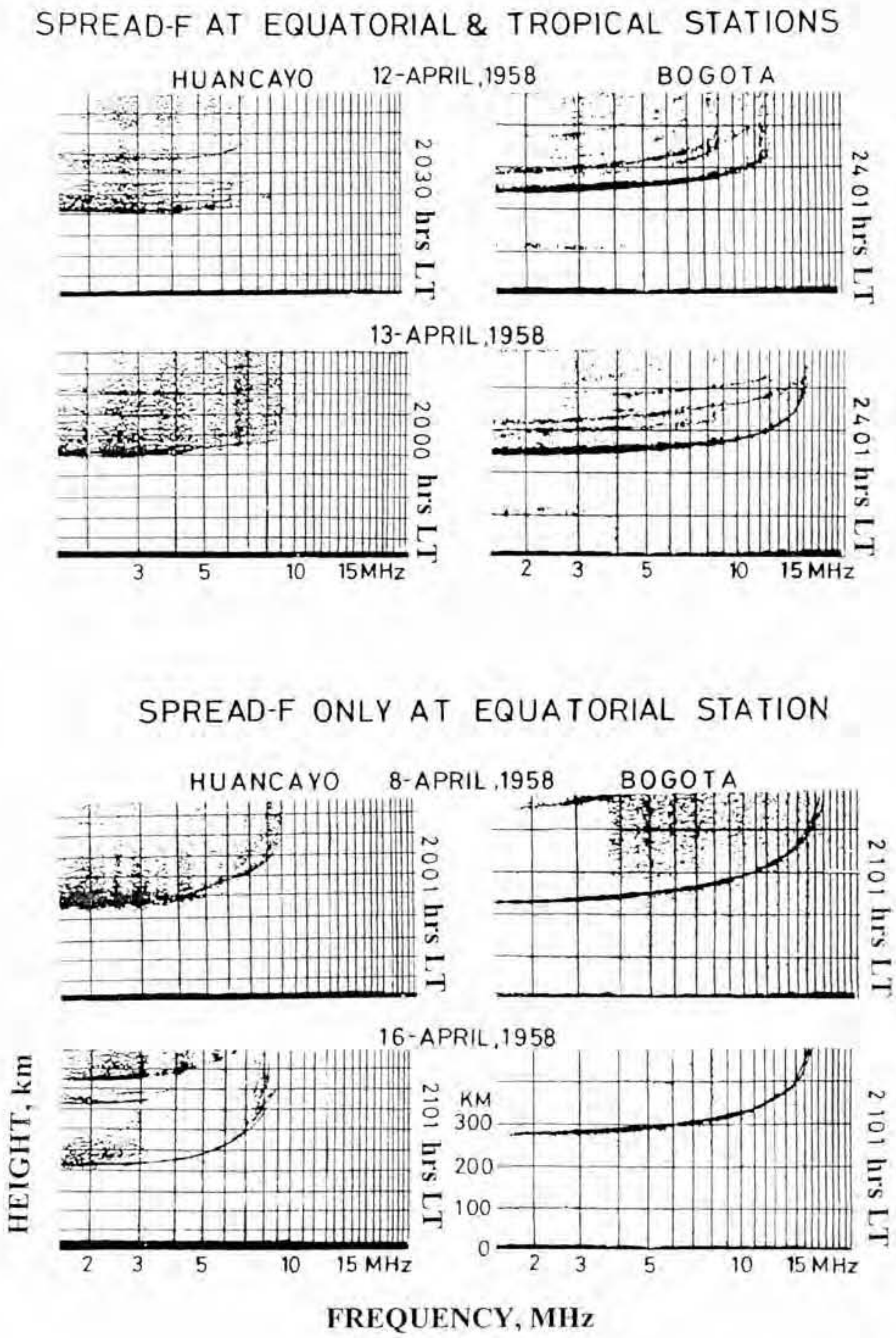

Fig. 9—Typical ionograms at Huancayo and Bogota on the nights when spread-F is seen only at Huancayo or at both Huancayo and Bogota.

direction pointing to north to that along the direction pointing to south is a good precursor to predict spread-F. Predictions were successfully made 3 h prior to its onset as seen in the ionograms for rocket flight[31] during spread-F. Recently there have been some detailed studies on the day-to-day variability in equatorial spread-F in the American sector. Mendillo *et al.*[32] have reported results from Multi-Instrumented Studies of Equatorial Thermospheric Aeronomy (MISETA) campaign of September 1998. The campaign involved neutral wind measurements from high-resolution Fabry-Perot interferometer (630 nm), all sky optical images at 630 nm and GPS observations of phase fluctuations (ESF activity) and total electron content (Appleton anomaly). From the 8 nights of data the best available precursor for pre-midnight ESF appeared to be the strength of the Appleton anomaly in TEC at sunset. On seven out of the 8 nights ESF could be predicted from the anomaly strength. Valladares *et al.*[33] have compared the latitudinal profiles of TEC from 6 GPS receivers in south America on days of ESF and no-ESF (based on Jicamarca radar and scintillation data) during the year 1998. Drastic increases of crest values and sharp decreases near the trough were seen on ESF days. On no-ESF days, there exists almost uniform decreases in TEC at all latitudes. The ESF events were characterized by high crest to trough ratio and small trough values. Whalen[34] has studied the interrelation between equatorial bubbles and anomaly. An array of 11 ionospheric sounders located near 75° W longitude measured latitudinal profiles of N_mF2 for a period of 30 days during equinox of solar maximum. Out of the 30 continuous days of observations 7 days were with macroscopic bubbles at anomaly with bottomside spread-F (BSSF) at equator. On 10 days, strong BSSF was seen at equator, but macroscopic bubbles were not seen (lesser bubbles could have occurred). On 6 days, weak BSSF was seen with no bubbles, while on 7 days no BSSF or bubbles could be detected. Crest latitude, crest electron density and poleward extent (therefore, the integrated electron density of profiles) all decrease in the order of decreasing spread-F. At 2100 hrs LT, the time of highest latitude of anomaly, crest latitude and magnitude show a linear relation above a threshold of 38×10^5 el./cm^3 and 15.4° dip latitude. This corresponds to a maximum drift velocity of 50 m/s. For all cases of strong BSSF and macroscopic bubbles the threshold limit of the vertical drift of 50 m/s was noted. These results are consistent with the observations reported here and further strengthen the role of the electrodynamics and ionization anomaly in the onset of ESF.

Thus, there are several parameters which can be used to predict onset of spread-F in the equatorial region. True height analysis of ionograms is rather involved and not easily accomplished. However, f_oF2 and h'F are scaled automatically from modern ionosondes and data from 2-3 locations can easily be analysed for prediction purpose. Currently a chain of six digital ionosondes is available in India and a study to examine the feasibility of F-layer parameters to predict spread-F both in the equatorial and anomaly crest region is desirable.

4 Conclusions

It is concluded that the rapid lifting of the F-layer at the equator and strong anomaly are necessary conditions for the generation of spread-F at equatorial latitudes. For the high solar activity period the threshold for the h'F value during April is shown to be more than 400 km for American longitude sector. Vertical drift velocities (during1800-1900 hrs LT) on days with spread-F both at Huncayo and Bogota (crest), on days with spread-F at Huancayo only and on days with no-spread-F were 42 m/s, 30 m/s and 21 m/s, respectively. The ratio of f_oF2 at Bogota to that at Huancayo also shows sudden intensification around 1900 hrs LT on ESF days (reaching a peak value of about 2.5 around 2000-2100 hrs LT as compared to 1.5 on non-ESF days).

Acknowledgement

Thanks are due to World Data Center-A for STP Boulder, Colorado, USA for supplying the required data.

References

1 Booker H G & Wells H W, *Terr Magn Electr (USA)*, 43 (1938) 249.
2 Osborne B W, *J Atmos & Terr Phys (UK)*, 2 (1952) 66.
3 Wright R W, Koster J R & Skinner N J, *J Atmos & Terr Phys (UK)*, 8 (1956) 240.
4 Chandra H & Rastogi R G, *Ann Geophys (France)*, 28 (1972) 37.
5 Abdu, M A, Batista I S & Bittencourt J A, *J Geophys Res (USA)*, 86 (1981) 6836.
6 Chandra H, Vyas G D, Sinha H S S, Prakash S & Misra R N, *J Atmos & Terr Phys (UK)*, 59 (1997) 191.
7 Chandra H, Girija Rajaram & Rastogi R G, *Indian J Radio & Space Phys*, 2 (1973) 243.
8 Rastogi R G, *Proc Indian Acad Sci*, 87A (1978) 115.
9 Shimazaki T, *J Radio Res Lab (Japan)*, 6 (1959) 669.
10 Singleton D G, *J Geophys Res (USA)*, 65 (1960) 3615.
11 Abdu, M A, de Medeiros R T & Nakamura Y, *J Geophys Res (USA)*, 88 (1983) 4861.
12 Cohen R & Bowles K L, *J Geophys Res (USA)*, 66 (1961) 1081.
13 Calvert W & Cohen R, *J Geophys Res (USA)*, 66 (1961) 3125.
14 King G A M, *J Atmos & Terr Phys (UK)*, 32 (1970) 209.
15 Bowman G G & Dune G S, *J Atmos & Terr Phys (UK)*, 43 (1981) 1295.
16 Rastogi R G, *Indian J Radio & Space Phys*, 12 (1983) 104.
17 Rastogi R G, *Ann Geophys (France)*, 7 (1989) 177.

18 Fejer B G & Kelley M C, *Rev Geophys Space Phys (USA)* 18 (1980) 401.

19 Ossakow S L, *J Atmos & Terr Phys (UK)*, 43 (1981) 437.

20 Basu S & Basu S, *J Atmos & Terr Phys (UK)*, 47 (1981) 753.

21 Chandra H, *Indian J Radio & Space Phys*., 19 (1990) 215.

22 Sushil Kumar, Gwal A K, Ramarao P V S, Jayachandran P T, Prasad D S V V D, Singh R P, Singh U P, Dasgupta A, Basu K, Sethuraman R, Pathan B M, Rao D R K, Banola S, Kesavarao P S, Naidu A, Tyagi T R, Vijaykumar P N, Chandra H, Vyas G D, Singh Birbal, Chauhan Pawan, Iyer K N, Pathak K N, Shalgaonkar C S, Vyas B M & Rastogi R G, *Indian J Radio & Space Phys*., 29 (2000) 22.

23 Rastogi R G, *Indian J Radio & Space Phys*., 18 (1989) 95.

24 Raghavarao R, Nageswarrao M, Sasti J H, Vyas G D & Sriramarao M, *J Geophys Res (USA)*, 93 (1988) 5959.

25 Alex S, Koparkar P V & Rastogi R G, *J Atmos & Terr Phys (UK)*, 51 (1989) 371.

26 Rastogi R G, Alex S & Koparkar P V, *J Geomagn & Geoelectr (Japan)*, 41 (1989) 753.

27 Nelson O R, Abdu M A & Batista I S, *J Atmos & Terr Phys (UK)*, 48 (1986) 181.

28 Chandra H & Rastogi R G, *Indian J Radio & Space Phys*, 7 (1978) 265.

29 Vyas G D & Chandra H, *Ann Geophys (France)*, 9 (1991) 299.

30 Sridharan R, Pallam Raju D, Raghava Rao R & Ramarao P V S, *Geophys Res Lett (USA)*, 21 (1994) 2797.

31 Sridharan R, Chandra H, Das S R, Sekar R, Sinha H S S, Pallam Raju D, Narayanan R, Raizada Shikha, Raghavarao R, Vyas G D, Rao P B, Ramarao P V S, Somayajulu V V, Babu V V & Danilov A D, *J Atmos & Sol Terr Phys (UK)*, 59 (1997) 2051.

32 Mendillo M, Meriwether J & Biondi M, *J Geophys Res (USA)*, 106 (2001) 3655.

33 Valladares C E, Basu S, Groves K, Hagan M P, Hysell D, Mazzella (Jr.) A J & Sheehan R E, *J Geophys Res (USA)*, 106 (2001) 29133.

34 Whalen J A, *J Geophys Res (USA)*, 106 (2001) 29125.