Reseach Note

Patchy occurrence of equatorial spread-*F*

J. HANUMATH SASTRI

Indian Institute of Astrophysics, Bangalore 560034, *India*

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ABSTRACT. From a statistical analysis of ionogram data of Kodaikanal (Dip 3.5° N) it is shown that during years of high sunspot activity the discontinuous or patchy occurrence of equatorial spread-*F* (ESF) depends on season. While ESF occurrence is usually continuous on nights during the June solstice, it is frequently discontinuous on nights during the equinoctial months. This seasonal pattern which is similar to the one noticed in VHF scintillations by Dasgupta *et al.* (1983) is not evident during years of low sunspot activity.

Key words : equatorial spread-*F*, patchy occurrence.

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INTRODUCTION

The phenomenon of equatorial spread-*F* (ESF) refers to the presence of field-aligned irregularities with scale sizes from a fraction of a meter to ten to hundreds of kilometers in the plasma density of the night time equatorial *F*-region. That ESF irregularities manifest in cloud like patches rather than as a continuous distribution is well known. Calvert and Cohen (1961) showed that patches with east-west dimensions upto 300 km and thicknesses of 10 to 50 km that usually drift eastward with an average speed of about 100 ms^{-1} are responsible for ESF in ionograms. Transequatorial HF radio propagation experiments demonstrated the presence of large scale ESF irregularity patches with scale sizes in the range of ten to hundred kilometers in the evening equatorial *F*-region which move in wave-trains to the east with speeds in the range of 50-250 ms^{-1} (Rottger, 1973). The kilometer size irregularities that cause amplitude scintillations at VHF are found to occur in field-aligned clouds with east-west extent of about 400 km that form in the west to start with and, when fully developed, drift eastward with an average speed of 100 ms^{-1}, maintaining their integrity throughout their lifetime which is of the order of several hours (e.g. Aarons *et al.*, 1978). The patchy or discontinuous nature of ESF is also seen in VHF backscatter radar and ionosonde data (Farley *et al.*, 1970; Sastri and Murthy, 1975*a*). While on some nights ESF persists for a major portion of the night after it's onset in the post-sunset period; on some other nights it suddenly disappears after manifesting for a few hours after onset and reappears at a later time in the night. The disappearance and reappearance of ESF in ionograms occurs even more than once in a night though only occasionally.

Using the VHF amplitude scintillation data obtained during the recent sunspot maximum (1979-80) at Arequipa, Peru (dip 9.0° S), Dasgupta *et al.* (1983) reported that a remarkable difference exists in the duration and hence east-west extent (if the speed of the patches is constant) of scintillation patches observed in the December solstice and equinoctial months. While during the December solstice the average patch is found to last for about 6 hrs, in equinoctial months numerous patches of much shorter duration are seen. It is, therefore, of considerable interest to examine whether such a seasonal trend prevails in the patchy occurrence of ESF in ionograms which is due to irregularities with ten's of meters and larger in size (responsible for frequency and range types of spread-*F* respectively in ionograms). In this paper, we shall present and discuss the seasonal pattern in the discontinuous occurrence of spread-*F* activity in ionograms at the magnetic equatorial station, Kodaikanal (10° 14′ N, 77° 28′ E, dip 3.5° N).

OBSERVATIONS

Quarter-hourly ionograms for a 3-yr period of high sunspot activity (1957-59; mean $R_z = 178$) and a 3-yr period of low sunspot activity (1961-63; mean $R_z = 40$) are carefully scanned for the presence of spread-*F* on individual nights, and it's patchy occurrence is assessed as follows. A single patch of irregularities is taken to be present if, after onset, the spread-*F* condition was continuously seen on a night (the continuous manifestation of spread-*F* may also be due to overlapping patches). On the other hand, if after onset, the spread-*F* condition disappeared and reappeared at a later time in a night, two distinct patches or events

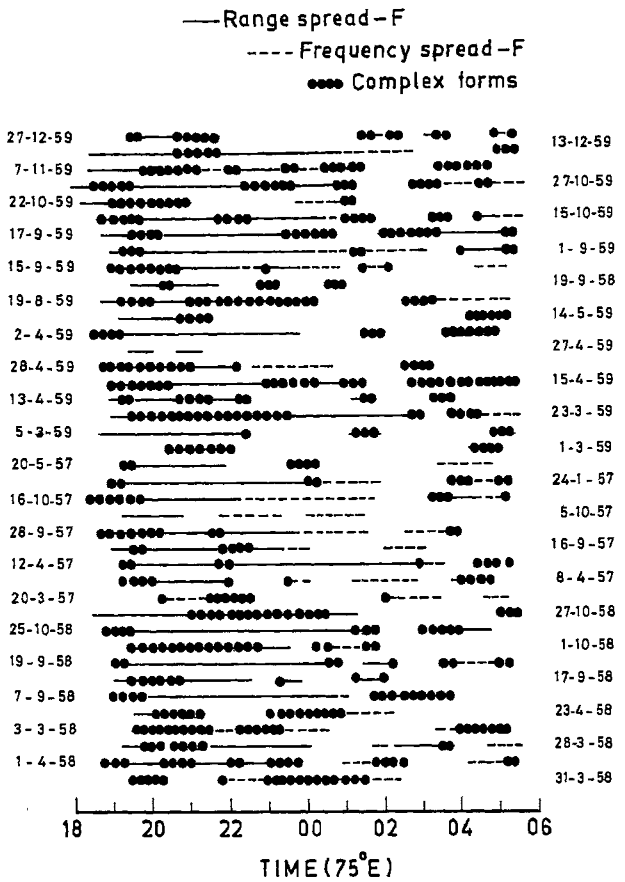

Figure 1.
Mass plot illustrating the discontinuous or patchy occurrence of spread-F at Kodaikanal. The dates are indicated on the right- and left-hand side of the plot. The change in the configuration of spread-F during the course of a night and the more or less random occurrence of spread-F patches may be noted.

of spread-*F* are inferred and so on. It is widely known that ESF manifests in two basic configurations in ionograms namely, range and frequency spread-*F* types. In the range type, spread is seen either over the entire frequency range of *F*-layer trace or only at the low frequency end of *F*-layer trace, and this type occurs predominantly in the pre-midnight period in the Indian equatorial region (Chandra and Rastogi, 1972; Sastri and Murthy, 1975*b*; Sastri *et al.*, 1979*a*). In the frequency type, spread is seen only at and around the critical frequencies of *F*-layer trace and this configuration mainly occurs in the post-midnight period (Chandra and Rastogi, 1972; Sastri and Murthy, 1975; Sastri *et al.*, 1979*a*). ESF is also known to manifest in rather unusual or complex forms in ionograms (Chandra and Rastogi, 1972; Sastri and Murthy, 1975*b*). We have not paid particular attention to the type of spread-*F* here in view of the following considerations. Firstly, the configuration of spread-*F* at Kodaikanal usually changes during the course of a night, and, as such, it is difficult to find patches exclusively of a particular type of spread-*F*. This feature may be seen from figure 1 where in the local time distribution of ESF patches is shown for a number of days during the years 1957 through 1959. The data presented in figure 1 also illustrate the more or less random occurrence of ESF patches in ionograms.

Secondly, although the occurrences of range and frequency types of spread-*F* at Kodaikanal show a preference for different local time sectors, their seasonal pattern and dependence on solar and geomagnetic activities are very much similar (Sastri *et al.*, 1975*c*; Sastri *et al.*, 1978).

Careful scrutiny of the data reduced in the above manner showed the presence of a distinct seasonal variation in the discontinuous occurrence of spread-*F* during years of high sunspot activity. This feature may be seen from the monthly pattern in the average number of spread-*F* events per night depicted in figure 2(*a*) for the period 1957-59. The mean values of the number of quarter-hourly ionogram frames in which spread-*F* was seen per night in each month are also indicated in figure 2(*a*). On nights during the June solstice (northern summer) particularly in June and July, spread-*F* activity is usually continuous and persists for several hours (average number of patches per night close to 1), while in equinoctial months particularly in September and October, spread-*F* activity is frequently discontinuous with more than one patch occurring on individual nights (average number of patches per night close to 2). The seasonal dependence of the patchy occurrence of ESF may also be seen from figure 3(*a*) which shows the distributions of the duration of ESF patches in June-July and September October months of the period 1957-59. The predominance of patches of short duration (2 hrs and less) in September-October is quite obvious. Geomagnetic activity is well known to inhibit the occurrence of ESF during periods of high sunspot activity (Skinner and Kelleher, 1971 and references therein; Sastri *et al.*, 1978). With a view to ascertain the role of geomagnetic activity in the evidenced seasonal pattern, the analysis is repeated deleting from the data sample all disturbed days ($Ap > 15$) and the results are shown in figures 2(*b*) and 3(*b*), in the same format as figures 2(*a*) and 3(*a*). That geomagnetic activity does not contribute to the seasonal variation in the patchy occurrence of ESF may be seen from figures 2(*b*) and 3(*b*). In fact, a perusal of figures 2(*a*) and (*b*) and 3(*a*) and (*b*) shows that the seasonal variation is all the more striking when the analysis is restricted to days other than disturbed days. That the seasonal pattern does not manifest during years of low sunspot activity is clear from the data presented in figure 2(*c*). The substantial reduction in the level of spread-*F* activity during 1961-63 as compared to 1957-59 is the well documented sunspot cycle effect on ESF occurrence at Kodaikanal (Sastri *et al.*, 1975; Sastri *et al.*, 1979*a*).

DISCUSSION

The marked seasonal dependence of the patchy nature of spread-*F* activity in ionograms at Kodaikanal during years of high sunspot activity, and the conspicuous absence of the same during years of low sunspot activity are the principal findings of the present statistical study, and these trends have not been reported before. As the morphology of ESF is widely documented to exhibit considerable longitudinal variation (e.g. Rastogi

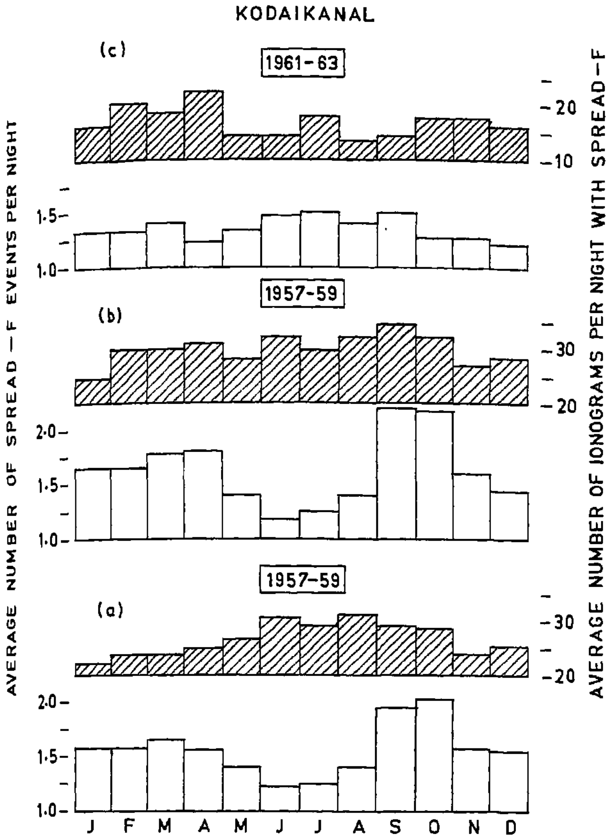

Figure 2.

Occurrence of spread-F events at Kodaikanal as a function of month during the high sunspot activity period 1957-59. *The hatched histogram represents the average number of quarter-hourly ionogram frames per night with spread-F in each month.* (*b*) *same as in* (*a*) *but excluding geomagnetically disturbed days from the data sample and* (*c*) *same as in* (*a*) *but for the low sunspot activity period* 1961-63.

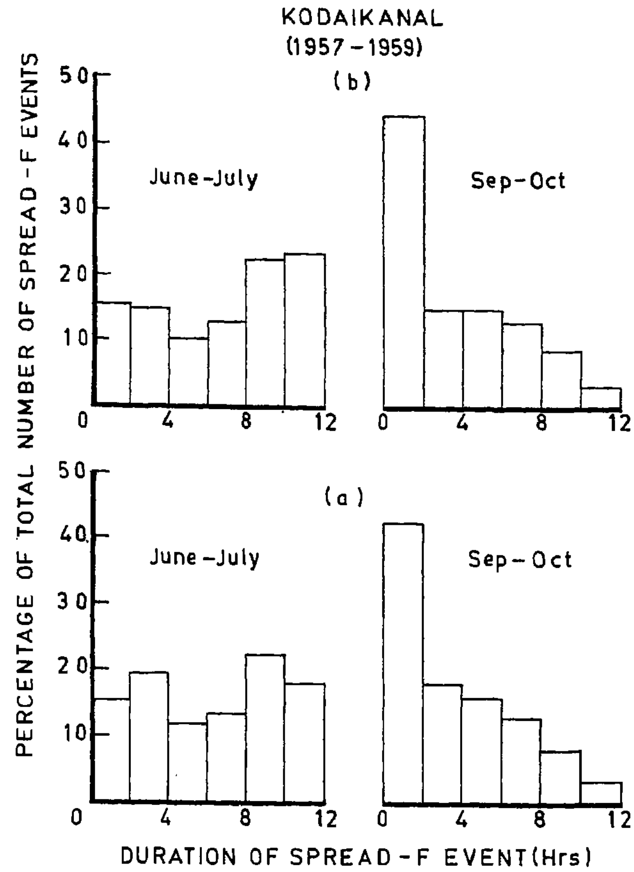

Figure 3.

Histograms showing (*a*) *the distribution of duration of spread-F patches in June-July and September-October months of the period* 1957-59. (*b*) *same as in* (*a*), *but excluding geomagnetically disturbed days from the data sample.*

and Vyas, 1977, 1978; Sastri *et al.*, 1979*a*, *b*), it would be interesting to study the patchy occurrence of ESF in ionograms of locations particularly, in the American equatorial region. The seasonal pattern reported here is similar to the one noticed in VHF scintillation activity at Arequipa, Peru, during the recent solar maximum by Dasgupta *et al.* (1983). They did not, however, study the dependence of the seasonal pattern on the phase of the sunspot cycle.

Recent studies have shown that ESF in ionograms and plumes in VHF radar backscatter maps are due to irregularities generated at the steep edges or walls of rising plasma depleted regions or bubbles in the post-sunset equatorial ionosphere and that the bubbles are essentially the patches responsible for scintillation (Woodman and La Hoz, 1976; McClure *et al.*, 1977; Tsunoda *et al.*, 1979; Weber *et al.*, 1980). Coordinated multi-technique observations showed that though the kilometer and meter scale length irregularities coexist during the generation phase of ESF, the larger scale irregularities outlive the smaller ones by several hours, and that the eastward drifting irregularity structures detected around midnight contain spectral power only at kilometer scale lengths and not at meter scale lengths (Basu *et al.*, 1978; Basu *et al.*, 1980). The similarity in the seasonal pattern of patchy occurrence of ESF in ionograms at Kodaikanal and in scintillation activity at Arequipa hints at the possible co-existence, in general, of kilometer and decameter scale length irregularities in ESF patches that form in the later part of the night under high sunspot activity conditions. It needs to be emphasized at this juncture that, although the seasonal pattern of the patchy occurrence of ESF is similar in scintillation and ionogram data, there is a basic difference in the nature of ESF patches as seen in the two types of data. While the scintillation data indicate the presence of numerous patches with short periods of tens of minutes of scintillations in equinoxes (Dasgupta *et al.*, 1983), in ionogram data no more than 2 or 3 patches are seen in a night. This suggests that the patches studied here may correspond to entire disturbed regions that contain the multiple patches seen in scintillation data or they represent the persistence of bottomside spread-*F* in the absence of bubble or plume development. Data from coordinated multiple technique observations covering a common ionospheric volume are needed to resolve this issue.

The rise of velocity and percentage depletion of the bubble and the resultant strength of ESF irregularities generated under conditions of collisional Rayleigh-Taylor instability have been shown from numerical simulation studies to depend on the altitude of *F*-layer peak and bottom side electron density scale length (Ossakow *et al.*, 1979). Studies of ionogram data of Fortaleza (dip lat. 1.8° S) in the American equatorial region indicated that the post-sunset onset of ESF is dependent on local ionospheric parameters such as bottomside electron density scale length and ion-neutral collision frequency at the base of F-layer, and that a positive relationship exists between the degree of range spreading in the pre-midnight period and the pre-reversal peak in F-layer vertical upward drift, V_z (Abdu *et al.*, 1982; 1983). The duration of ESF in ionograms at Kodaikanal (when seen continuously) is very recently found to depend on the peak amplitude as well as the width of the pre-reversal enhancement in V_z, and hence on the altitude of bottomside F-region in the evening hours (Sastri, 1984). Seasonal changes in the gross characteristics of the post-sunset build up in V_z may, therefore, contribute to the observed difference in the duration of ESF patches between equinoctial and local summer months. But, changes in V_z alone cannot account for the seasonal trend as they cannot explain as to why another patch of irregularities has to form frequently after the first patch has decayed, on nights during the equinoctial months of high sunspot activity years. Since the ionogram data studied here indicate that the number of patches in a night usually do not exceed two, it seems that the patchy occurrence of ESF in ionograms basically represents the recurrence of spread-F after it's formation and decay in the post-sunset hours, and is not related to plasma bubbles. This is in contrast with the discontinuous occurrence of VHF scintillation activity which is due to eastward drifting patches of irregularities associated with plasma bubbles. The underlying mechanism in both the cases, however, is the same namely, initiation, quenching and reinitiation of irregularities. In the case of bubbles, the mechanism is considered to be « seeding » by atmospheric gravity waves (Rottger, 1978; Booker, 1979). In the case of irregularity patches responsible for ESF in ionograms, a larger scale mechanism is to be involved, although it's nature is not apparent at the moment. Further studies are needed to lead to a proper understanding of the patchy occurrence of ESF irregularities of different scale sizes.

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