Seasonal & Sunspot-cycle Effects in the Occurrence of Equatorial Spread-F Configurations

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A study has been made of the seasonal and solar cycle changes in the occurrence of the range- and frequency-type of spread-F at Kodaikanal (geomag. lat., 0·6° N; dip, 3·5°N), using ionogram data for the period 1957-69. It is found that the range type of spread-F is the predominant configuration on ionograms at Kodaikanal at any time of year. The occurrence of the frequency type of spread-F shows a significant positive correlation with sunspot number irrespective of season while that of range-type spread-F shows such a behaviour only during local summer months. A comparison of the behaviour of spread-F configurations at Kodaikanal with those at Huancayo reported recently, indicates a striking longitudinal dependence of the seasonal and solar cycle effects in the occurrence of the two basic forms of spread-F on equatorial ionograms.

Ever since the appearance of diffuse traces (spread-F) on Huancayo ionograms was reported by Booker and Wells,[1] the phenomenon of equatorial spread-F has been a topic of extensive study by several workers. Excellent reviews on the phenomenon are available in literature.[2–4] The phenomenon, however, still remains poorly understood although some significant advances have been made in very recent years.[5–7] The earlier statistical studies have indicated a longitudinal dependence in the behaviour of equatorial spread-F.[8–9] At stations in the Indian (Kodaikanal) and African (Djibouit and Ibadan)

equatorial zones, the occurrence of spread-F shows positive correlation with sunspot activity, while in the American zone (Huancayo), it shows a negative correlation. These earlier studies were, however, based on analysis of published ionospheric data bulletins. The current approach makes use of the original ionogram data to provide information on the nature of spread-F and hence to gain a better insight into the phenomenon.[4,10–12] It is known that spread-F mostly manifests in two basic forms, i.e. range- and frequency-type on equatorial ionograms.[2] The range type of spread-F is characterized by the presence of diffuse traces either only at the low frequency end of the F-layer trace with clear cut f_0F2 cusps or over the entire frequency range of the F-layer trace, and it occurs mostly in the premidnight period. The frequency type of spread-F is characterized by the presence of diffuse traces only at and around the critical frequency of the F-layer trace and occurs mostly in the postmidnight period. Recently, Rastogi and Vyas[13] reported that at Huancayo, range-type spread is negatively correlated with sunspot number and frequency-type spread is practically independent of sunspot number, revealing that the negative correlation noticed in earlier studies is basically representative of the behaviour of range-type spread-F.

In this communication, we present the results of a study of the seasonal and sunspot-cycle effects in the occurrence of range- and frequency-type of spread-F at Kodaikanal (geomag.lat., 0·6°N; dip 3·5°N) in the Indian zone and highlight the differences that became apparent from the study of characteristics of these two basic forms of spread-F in the Indian and American equatorial regions. The original quarter-hourly ionogram data at Kodaikanal for the period 1957-69 have been used in the present study. The analysis consisted of a careful visual examination of the ionogram data for each night and noting down of the type of spread-F as and when it occurred. From these data, the monthly mean (for the whole night) percentage occurrences (defined as the nighttime ratio of the number of ionograms exhibiting spread-F to the total number of ionograms examined multiplied by 100) of range- and frequency-type of spread-F are calculated for each month for the 13-yr period considered. It is known that spread-F sometimes manifests in rather unusual forms on equatorial ionograms [10,11] and these have not been taken into consideration in evaluating the percentage occurrence of spread-F of either type.

Fig. 1 shows the monthly occurrence frequency of range- and frequency-type of spread-F at Kodaikanal averaged over the period 1957-69. One striking feature in Fig. 1 is that the range type of spread-F is the predominant configuration at Kodaikanal at any time of the year. This trend is markedly different from that at Huancayo where range- and frequency-type of spread-F occur with more or less the same frequency throughout the year (Fig. 1 of Ref. 13.) As regards seasonal variation, the occurrence of range-type spread at Kodaikanal is low in local winter and high in local summer and equinoxes. The occurrence of frequency-type spread at Kodaikanal shows a tendency of a semi-annual variation with maxima in equinoxes and minimum in local summer (the amplitude of the variation is, however, very small). These seasonal trends are again different from those of Huancayo where both range- and frequency-type spreads show a maximum in occurrence during local summer and a minimum in local winter (Fig. 1 of Ref. 13). Moreover, the amplitude of the seasonal variation is high at Huancayo compared to that at Kodaikanal.

Fig. 2 depicts the relationship between the monthly mean occurrence of range- and frequency-type spread-F at Kodaikanal with the corresponding sunspot number, separately for the three seasonal groups of months, viz. D (Nov., Dec., Jan., Feb.), E(Mar., Apr., Sep., Oct.) and J(May, June, July, Aug.). The lines of best fit drawn by the least square method are also shown. The relevant statistical details of the relationship between the variates shown in Fig.2 are presented in Table 1. Fig.2 and Table 1 clearly show that at Kodaikanal, the occurrence of frequency type of spread-F has a significant positive correlation with sunspot number irrespective of season. On the other hand, the occurrence of range-type spread-F shows a significant positive

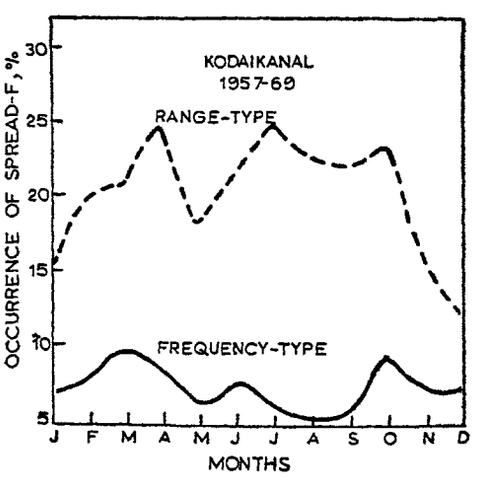

Fig. 1 — Seasonal variation of the occurrence of range- and frequency-type spread-F at Kodaikanal averaged over the period 1957-69

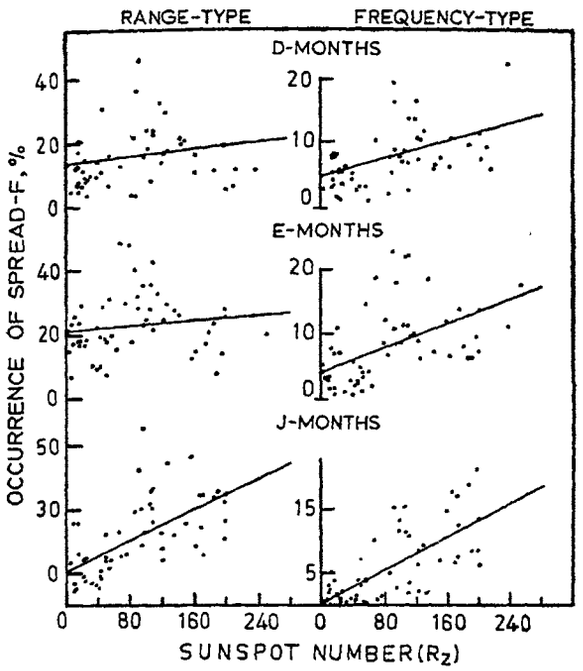

Fig. 2 — Mass plots showing the relationship between the monthly mean frequency of occurrence of range- and frequency-type of spread-F at Kodaikanal with the corresponding sunspot numbers for the three seasonal groups of months for the period 1957-69

Table 1 — Statistical Data on the Relationship of the Occurrence of Spread-F with Sunspot Number for Different Seasons

Type of spread-F	Months	Correlation coefficient	Level significance %	Slope of lines of best fit
Range	D	+ 0·18	—	0·03
	E	+ 0·11	—	0·019
	J	+ 0·59	99·9	0·121
Frequency	D	+ 0·52	99·9	0·037
	E	+ 0·46	99·8	0·048
	J	+ 0·68	99·9	0·064

correlation only during J-months (local summer). These solar cylce effects at Kodaikanal again differ from those at Huancayo where range-type spread-F shows a negative correlation with sunspot activity. The results of the present study together with those of Rastogi and Vyas,[13] thus establish a longitudinal dependence of the seasonal and sunspot cycle effects in the occurrence of the two basic forms of spread-F on equatorial ionograms.

It is generally accepted that scattering from small field-aligned irregularities in F-region ionization is the cause of range- type of spread-F. (Refs. 2 and 14). One well known feature of equatorial spread-F is the close association of the time of onset and its intensity with the postsunset rise of the F-region. The direct measurements of F-region vertical drift at Jicamarca often show the presence of a peak in the upward vertical drift just around the sunset period indicating the involvement of a true vertical uplift in the postsunset rise of the F-region.[15,16] It is known that the occurrence of range-type spread-F is mostly a premidnight event with a maximum around 2000-2100 hrs LT.[10,11] This suggests that the occurrence of the range-type spread-F is associated with the height rise and pre-reversal peak of upward vertical drift of equatorial F-region around sunset time. The postsunset rise of F-region is known to be positively correlated with the sunspot cycle. The recent observations show a positive dependence of the pre-reversal peak in upward vertical drift also with the sunspot cycle.[17] Thus one might expect a positive correlation of range-type spread with sunspot activity. The behaviour during J-months at Kodaikanal is in agreement with this inference. The absence of such a trend in D- and E-months at Kodaikanal and the negative correlation at Huancayo clearly indicates that the occurrence of the range-type spread-F is not uniquely dependent on the upward vertical drift in the postsunset period. This qualitative inference is in agreement with the recent radar measurements at Jicamarca which showed that spread-F occurs in the postsunset period when the vertical drift was upward, zero or downward.[5] The significant and consistent positive correlation of the occurrence of frequency-type spread-F at Kodaikanal with sunspot activity and the lack of a dependence, whatsoever, at Huancayo is a new and interesting feature of equatorial spread-F. The frequency type of spread-F has been explained earlier as due to ducting or waveguide propagation of radio waves due to thick field-aligned irregularities in F-region ionization.[18] Very recently, from a study of the back-scattering properties of the two basic forms of spread-F on equatorial ionogams, Rastogi and Woodman[19] suggested that the frequency-type spread-F is due to scattering from large scale irregularities near the peak of the F-region. However, not much is known as to the physical factors involved in the generation of such irregularities. Further theoretical work on the production of such irregularities is required in understanding the behaviour of the frequency-type spread-F.

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