Spread-F at Kodaikanal

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ABSTRACT. – *Quarter-hourly ionograms of Kodaikanal for the period January 1968 to December 1969 have been examined for occurrence of Spread-F. Spread-F occurrence as a feature on ionograms is more or less a regular nocturnal event with little seasonal variation. There is a significant positive correlation between Spread-F occurrence and mean value of the H-component of the magnetic field. The effect of SC type magnetic storms is in general to inhibit the Spread-F incidence either on the same night or the succeeding night for both the pre- and post-midnight Spread-F. Several instances have been noticed when there is disappeareance and subsequent appearance of Spread-F during a night within a span of a couple of hours or even less. Preliminary indication is that this feature is not dependent on the height of the layer crossing the threshold value for the production of irregularities and hence Spread-F.*

RESUME. – *On a examiné les ionogrammes de Kodaikanal pris à des intervalles d'un quart d'heure pour la présence du F sporadique pendant la période entre Janvier 1968 et Décembre 1969. La présence du F sporadique sur les ionogrammes est un événement nocturne plus ou moins régulier sans variation saisonnière importante. Il y a une corrélation positive significative entre la présence du F sporadique et la valeur moyenne du composant H du champ magnétique. L'effet des orages magnétiques du type SC est généralement d'inhiber la fréquence du F sporadique, soit dans une même nuit, soit dans la nuit suivante pour les F sporadiques, avant et après minuit. On a constaté plusieurs cas où une disparition est suivie d'une réapparition du F sporadique pendant une nuit dans un délai de quelques heures ou même moins. Une indication préliminaire est que ce caractère ne dépend pas de l'altitude de la couche qui dépasse le seuil pour la production d'irrégularités et donc du F sporadique.*

I. Introduction

The occurrence of Spread-F on ionograms is a well known observation at stations over a wide range of latitudes and is basically a night time feature. Several statistical studies have been made in the past to understand the morphological characteristics of Spread-F occurrence on a world wide basis. (Reber, 1956 ; Shimazaki, 1959 ; Singleton, 1960, 1968). A comprehensive review of Spread-F and related F-region phenomena has been given by Herman (1966). Wright (1959) pointed out that the incidence of Spread-F is high over a well defined belt of latitude about 40° wide and centered on the magnetic equator and is known as the equatorial zone. The equatorial zone may be divided into two regions : Electrojet region (5°N – 5°S of the magnetic equator) and non electrojet region (5-20°N

and S of the magnetic equator). As this paper is mainly concerned with the Spread-F at Kodaikanal, a station in the electrojet region, a brief summary of the characteristics of Spread-F in the electrojet region based on earlier work will be given in the following.

In the electrojet region, Spread-F usually occurs throughout the night with little nocturnal variation during magnetically quiet conditions. The seasonal variation is high in the American Zone with a maximum in December and minimum in June while in the African zone the seasonal variation is small with a trend opposite to that in the American zone and in the Asian zone there is very little seasonal variation. (Chandra and Rastogi, 1970). The Spread-F occurrence shows a positive correlation with solar activity in the African and Asian zones, while in the American zone it shows a negative correlation, indicating longitudinal effect (Chandra and Rastogi, 1970). Further the Spread-F occurrence is characterised by a marked inhibition on magnetically disturbed days compared to quiet days and this behaviour is most evident during periods of high solar activity. (Bhargava, 1958 ; Lyon et al, 1958 ; Rangaswamy and Kapasi, 1963 ; Skinner and Kelleher, 1971 ; Rao and Mitra, 1962 ; Chandra and Rastogi, 1972 b).

Most of the earlier investigations the major results of which have been mentioned above, were made using published monthly ionospheric data wherein the qualifying symbol F in tables of critical frequency of F-region was used to derive the Spread-F index. Only in the recent times investigations on Spread-F using original ionograms are carried out to avoid the weakness of the earlier procedures and to get a better understanding of the Spread-F configurations (Skinner and Kelleher, 1971 ; Chandra and Rastogi, 1972 (a)). In this communication are presented the results of a study of Spread-F at Kodaikanal (Geo. mag. Lat. 0.6°N, Dip 3.5°N) using the original ionogram data for a two year period of high solar activity (January 1968 – December 1969). The aspects studied include nature of Spread-F configurations on ionograms and their occurrence, nocturnal and seasonal variation of Spread-F as a feature on ionograms and the effect of magnetic activity on Spread-F occurrence.

II. Treatment of data

The quarter-hourly ionograms taken during the period January 1968-December 1969 have been examined. Spread-F index in the range 0-3 has been assigned to each ionogram based on the extent of the range and frequency spreading of the F-layer trace following accepted practice (Wright et al 1956 ; Skinner and Kelleher, 1971 ; Chandra and Rastogi, 1972 a). In Plate I are presented typical examples of ionograms showing Spread-F configurations corresponding to index. 0, 1, 2 and 3. It may be seen that index 0 corresponds to clear F-region traces with well defined fo F_2 cusps. Index 1 refers to conditions where there is range spreading only at the low frequency end of the trace. Indices 2 and 3 corresponds to conditions of frequency and range spreading respectively which are the well known Spread-F configurations in the equatorial zone. It is felt during our examination of ionograms that although the Spread-F configurations at Kodaikanal are usually of one of the types mentioned above, there are many occasions of complex Spread-F configurations and the index system that is in practice is rather inadequate and could help only to understand the gross features of Spread-F configurations.

The nocturnal and seasonal characteristics of the basic types of Spread-F configurations is studied by evaluating the percentage occurrence of Spread-F with Index 1, 2 and 3 at 15 minute intervals over the period 1800-0600 L.T. for the D-months (November, December, January and February), E-months (March, April, September, October) and J-months (May, June, July, August). To infer the gross characteristics of Spread-F as a feature on ionograms, the monthly median value of Spread-F index at 15 minute intervals has been evaluated and a contour plot is drawn showing the Spread-F occurrence over the two year period.

The effect of magnetic activity on Spread-F has been studied earlier by comparing the Spread-F occurrence during quiet and disturbed days. Further correlogram studies of the association between Spread-F and K-index have been made (Jagath Kumar et al 1967 ; Huang and Yeh, 1970). A slightly different approach has been adopted in the current study and the effect of magnetic activity has been studied in two ways. Firstly, Cross Correlograms between percentage Spread-F occurrence and the international character figure Ci and the mean value of the H-component of the magnetic field have been evaluated. Secondly, percentage Spread-F occurrence during six nights around several Sc type storms has been evaluated, as this aspect has not been studied earlier. Sc storms that occurred during 1968, 69 and also 1964, 65 have been used to infer the influence of the phase of the solar cycle on the effect of magnetic storms on Spread-F occurrence. A total of 38 storms have been studied, out of which 21 correspond to those of high solar activity period while 17 to those of low solar activity period. The Spread-F occurrence has been calculated separately for pre- and post midnight period as Spread-F during pre-midnight period is usually of the range type (Index 1 or 3) while during post-midnight is of the frequency Spread type (Index 2) as will be shown in

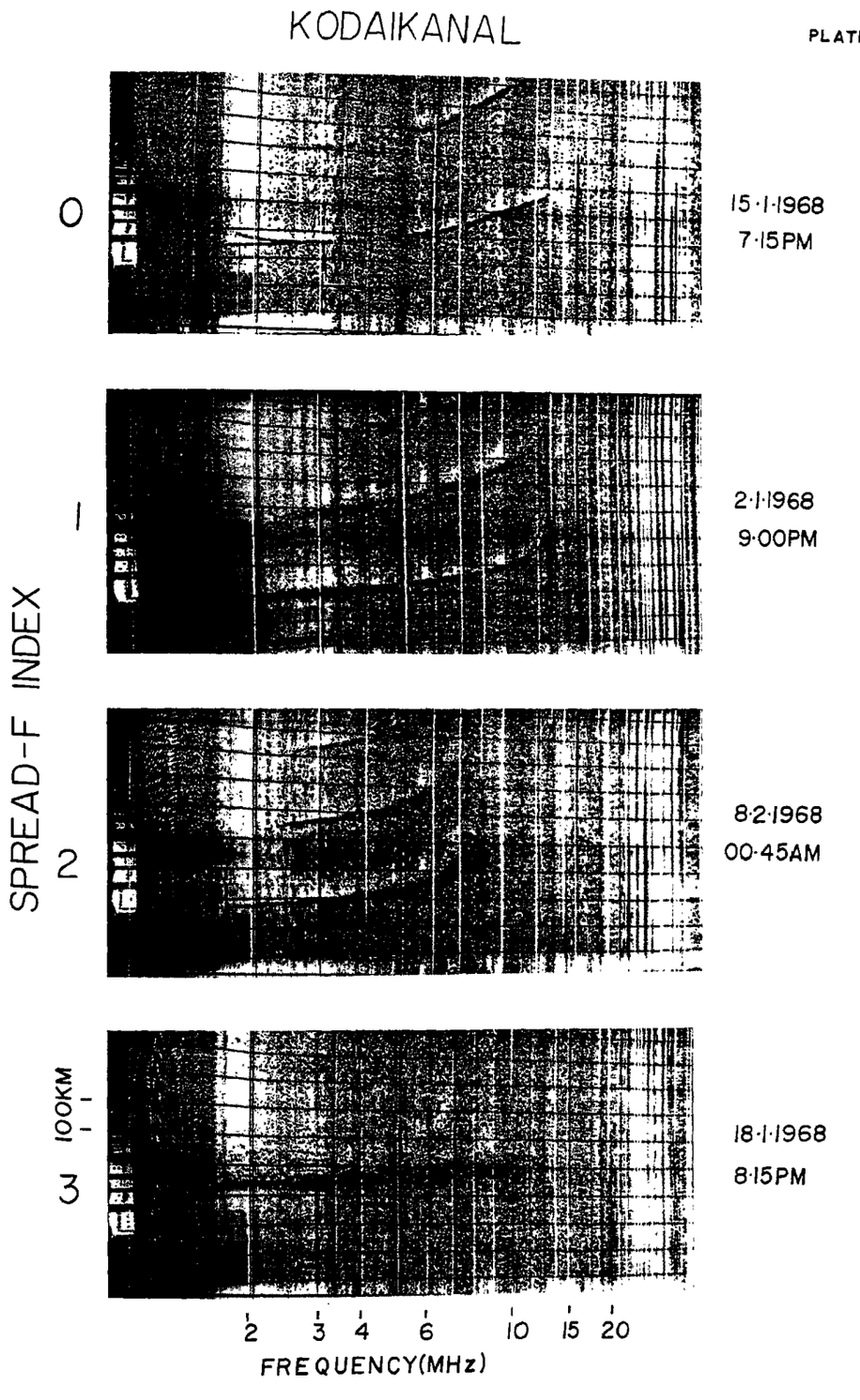

Plate I
Typical examples of Spread-F configurations corresponding to indices 0, 1, 2, 3 used in the analysis.

the next section. Besides the causitive mechanisms for the pre- and post-midnight Spread-F are considered to be different. The effect of magnetic storms on post-midnight Spread-F during the low solar activity period (1964-65) could not be studied because of scanty data due to no-echo conditions on ionograms, especially during pre-dawn periods. In the next two sections are presented the results of the present investigation and the salient ones are discussed in the last section in the light of earlier work and existing theories on equatorial Spread-F.

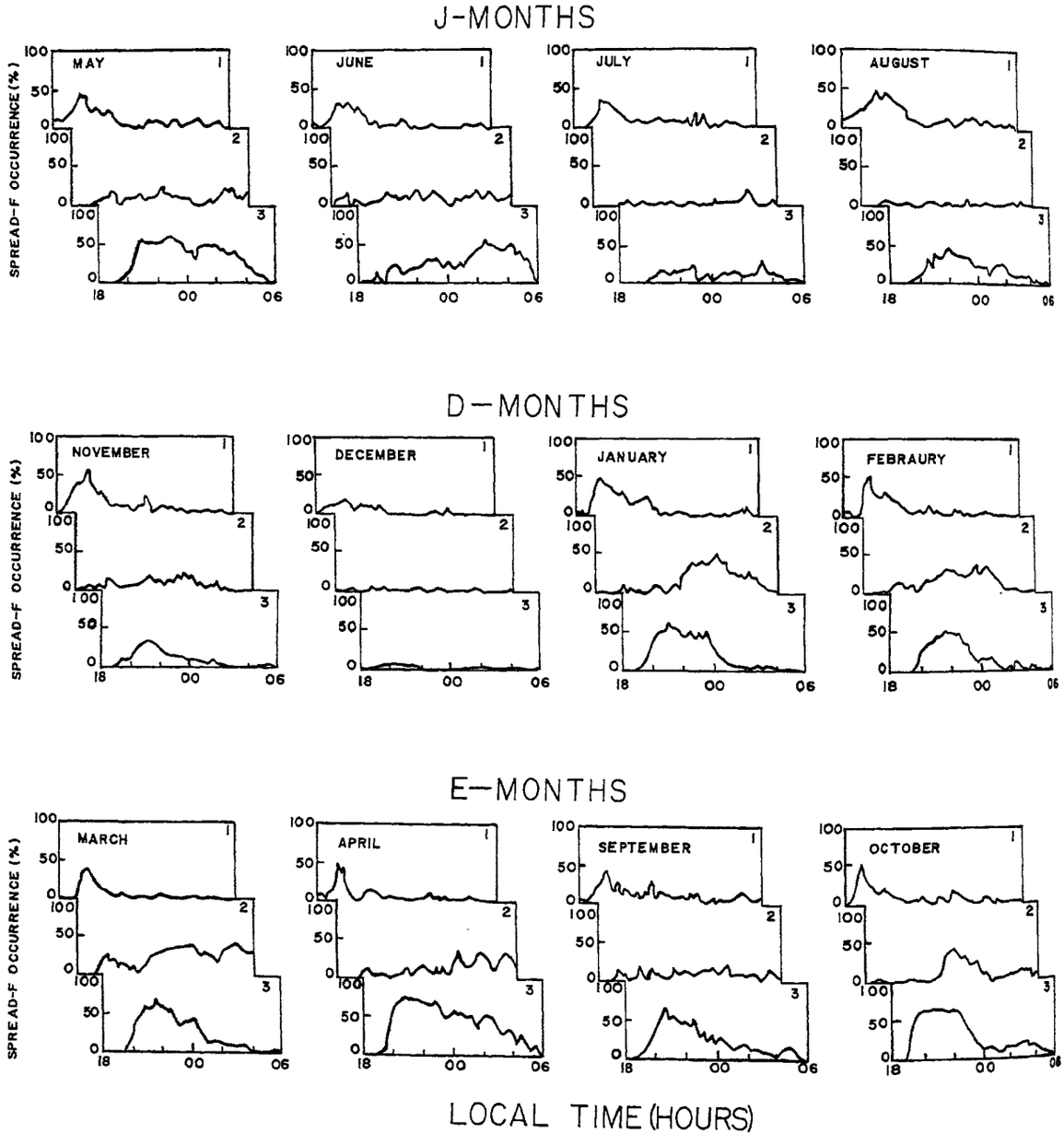

Fig. 1

Nocturnal variation of percentage occurrence of Spread-F configurations with index 1, 2 and 3 during J, D and E months for the year 1968.

III. Spread-F configuration and their occurrence

Figure 1 shows the percentage occurrence of Spread-F with index 1, 2 and 3 with local time for the D, E and J months of 1968 from which the nocturnal and seasonal variation of the three basic types of Spread-F configurations may be inferred. Similar plots for 1969 have not been shown as the features are found to be essentially the same. It may be seen that Spread-F with index 1 is essentially an early evening event with a maximum in occurrence around 2000 hours L.T. during all the seasons. Spread-F with index 2 is rather irregular in its nocturnal occurrence although a tendency to occur mostly in the post-midnight period may be seen during the months of January, February, March and April. Spread-F with index 3 occurs late in the evening with a maximum around the period 2000-0000 hours during most of the seasons. There is no marked seasonal variation in the occurrence of Spread-F with index 1 and 2, while Spread-F with index 3 occurs (consistently) frequently during the E-months compared to the D and J months. To sum up, the Spread-F configuration during the pre-midnight period is of the 'Range Spreading' type (Index 1 and 3) and during the post-midnight period of the 'frequency Spread' type (Index 2).

As already mentioned earlier, inaddition to the three basic types mentioned above, many rather unusual forms of Spread-F configurations have been noticed, a few examples of which are shown in Plate II. Example 'A' shows diffusiveness of the F layer trace around the high and low frequency range while the middle portion is conspicuously devoid of diffusiveness. 'B' is a typical example of the satellite trace of the 'frequency spread' configuration. Example 'C' shows the F region trace with marked spread over the entire frequency range with group retardation features. 'D' is a typical example of the satellite trace of the 'Range Spreading' configuration. These are only few of the complex Spread-F configurations noticed on ionograms, a detailed study of which is in progress and the results will be reported in a separate paper.

Another feature noticed through the examination of quarter-hourly ionograms is the disappearance and subsequent appearance of Spread-F within the duration of an hour or a couple of hours. A sequence of ionograms that illustrate this feature are presented in Plate III. It may be seen that at 2300 hours the ionogram shows the presence of frequency spread and within fifteen minutes the conditions have so changed that the ionogram at 2315 hours shows neat F-layer trace with clear fo F2 cusps which condition is found to continue on the ionogram at 2330 hours also. However within the next fifteen minutes the original conditions have set in and frequency spread is again seen on the ionogram at 2345 hours. Many such instances have been noticed in our data, the duration between the disappearance and subsequent appearance of Spread-F ranging from less than an hour to a couple of hours.

IV. Occurrence of Spread-F

Figure 2 shows the occurrence of Spread-F over the period January 1968 to December 1969 as a contour plot drawn from the monthly mean value of the Spread-F index. It can be seen that Spread-F usually appears around 1900 hours and continues throughout the night with no significant seasonal variation. These average nocturnal and seasonal characteristics are found to repeat over the two year period studied. The contour plot of Figure 2. vividly shows the characteristic of maximum occurrence of intense range spread during the E-months mentioned earlier, as an average Spread-F index greater than 2.0 (shown as blackned portion in Figure 2) means that intense Range spread with index 3 occurs most of the time.

V. Effect of magnetic activity

Figure 3 shows the cross correlograms between Spread-F occurrence and the international character figure Ci and the mean value of the H component of magnetic field for the years 1968 and 1969. It may be seen that the correlation between Spread-F occurrence and Ci is significant and negative for Zero time- lag (ie direct cross- correlation) and there is no significant delayed correlation between the two. However, the correlation between Spread-F occurrence and H component of magnetic field is significant and positive at zero time lag and the delayed correlation is not that significant as at zero time lag. This is rather an interesting result as it clearly shows the influence of the H magnetic field on Spread-F occurrence and the correlation is positive instead of negative as expected.

Bhargava (1958) reported that Spread-F occurrence is markedly reduced on the night following the storm day. As no detailed study exists beyond this single observation at Kodaikanal, the effect of Sc storms on Spread-F has been investigated on a day-to-day basis. In Figures 5 and 6 are shown the percentage occurrence of Spread-F during six nights centered on the storm day for the storms in 1968-69 for the pre- and post-midnight periods respectively. The general tendency for Spread-F occurrence to decrease either on the storm night or the succeeding night may be clearly seen for both the pre- and post-midnight periods. A similar effect for the pre-

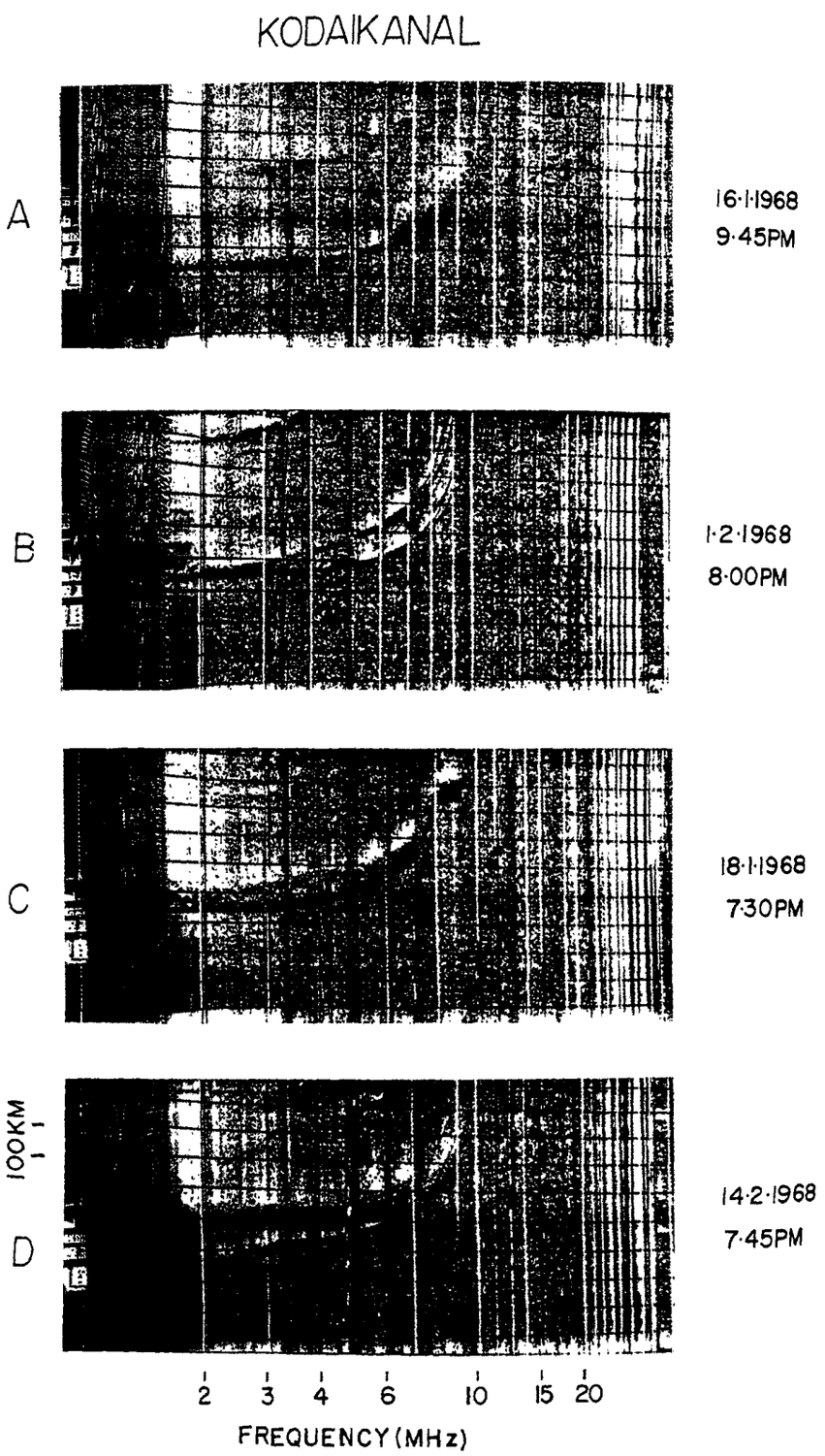

Plate II
A few examples of unusual forms of Spread -F observed at Kodaikanal.

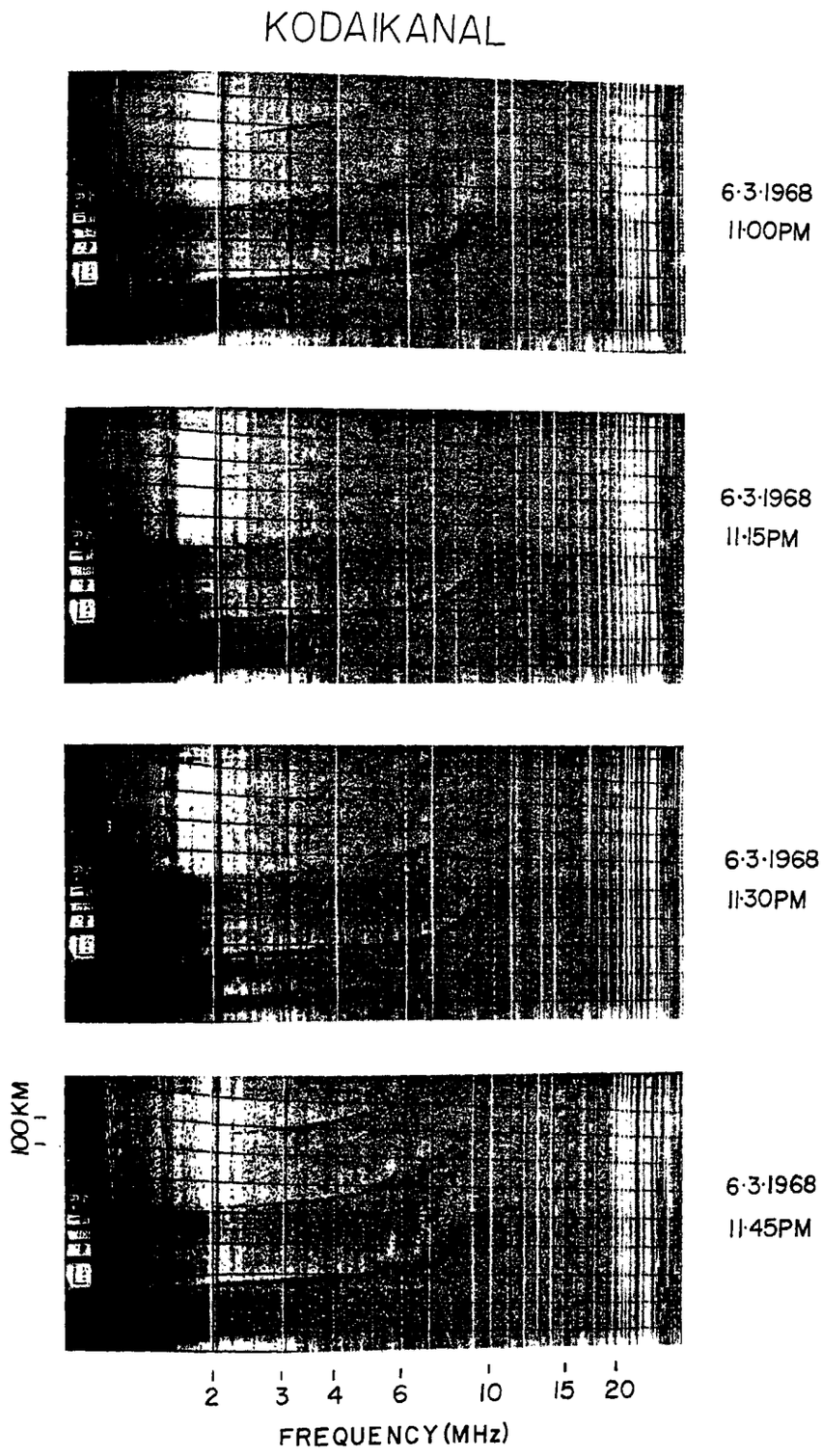

Plate III

A typical sequence of ionograms illustrating the disappearance and subsequent appearance of Spread-F.

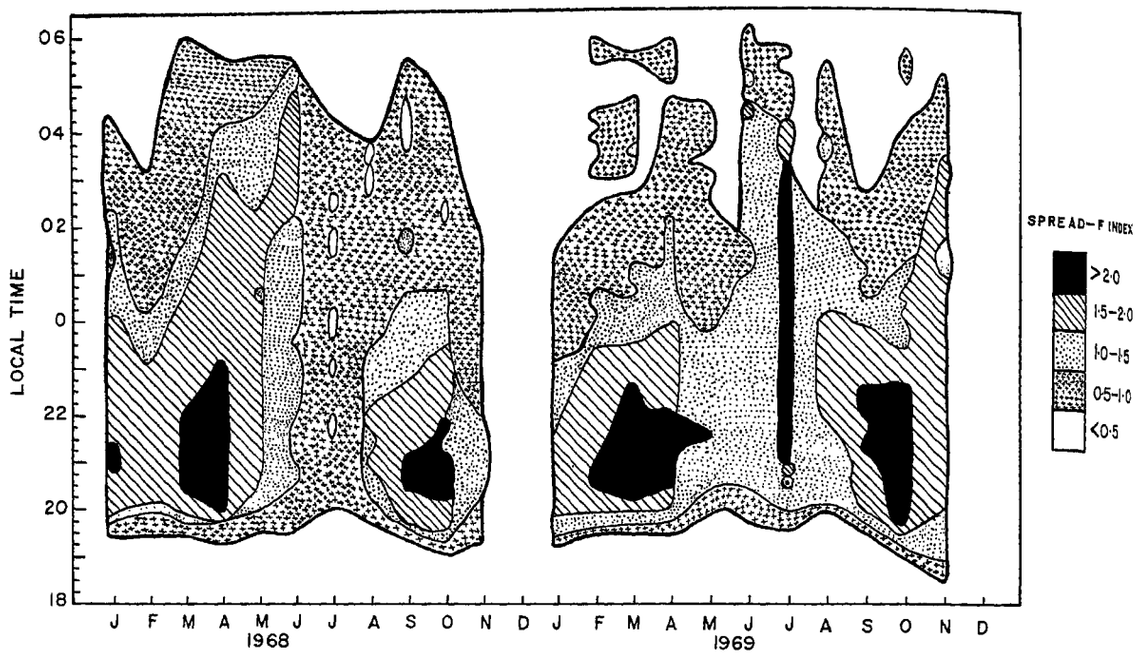

Fig. 2

Contour plot of monthly mean Spread-F indices as a function of local time and month of the year for the period January 1968 to December 1969.

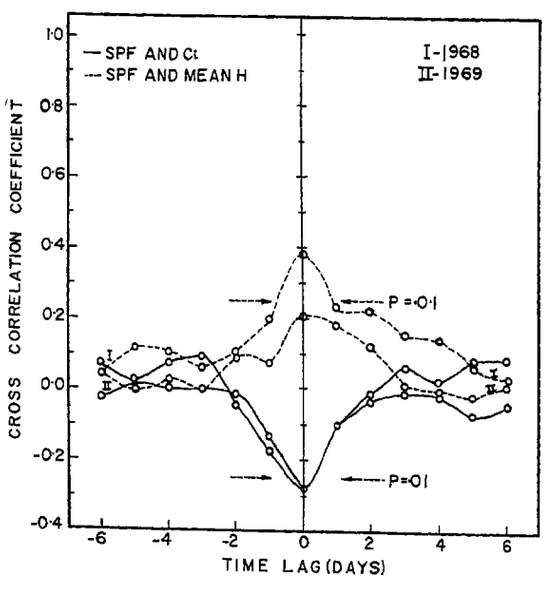

Fig. 3

Correlograms between Spread-F occurrence and Ci and mean H component of magnetic field for the years 1968 and 1969.

midnight Spread-F during 1964-65 is noticed as can be seen from Figure 4. No clearcut influence of the Sc storm time (ie day or night) on its effect on Spread-F occurrence is noticed. Further there is no significant correlation between the change in the percentage Spread-F occurrence (the magnitude of the storm effect) and the range of H for the storms considered. However the data sample is rather small to arrive at definite conclusions regarding these two aspects.

VI. Discussion

In this section are discussed the salient results of the present study in the light of earlier work and existing theories on equatorial Spread-F.

It is noticed that the Spread-F configuration is usually of the Range Spread type (Index 1 or 3) during the pre-midnight period while it is of the frequency spread (index 2) during post-midnight period. This characteristic is similar to those reported earlier for other equatorial stations ; for example, for Waltair by Krishnamurthy and Rao (1964), for Ibadan by Lyon et al (1961) and for Thumba by Chandra and Rastogi (1972 a). It is noticed that the occurrence of Spread-F configuration with

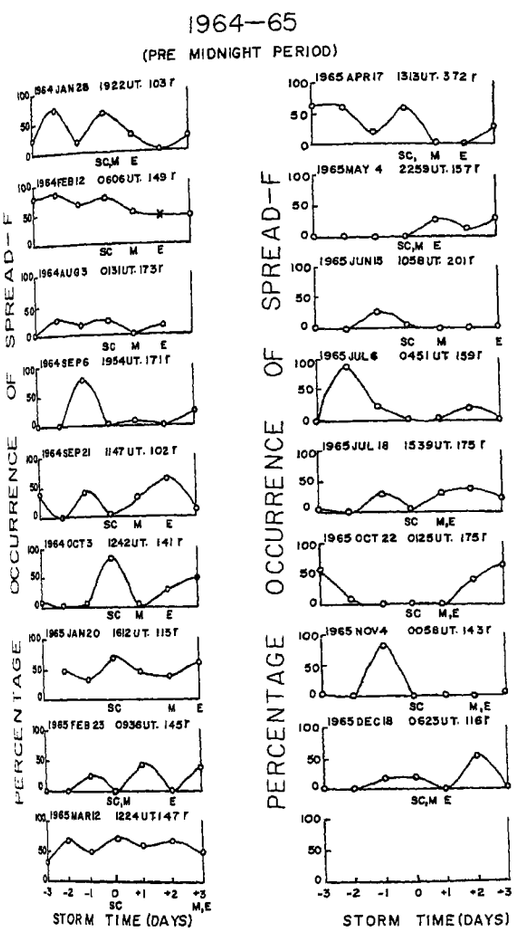

Fig. 4

Variation of percentage occurrence of pre-mid night Spread-F with storm time for the years 1964-65.

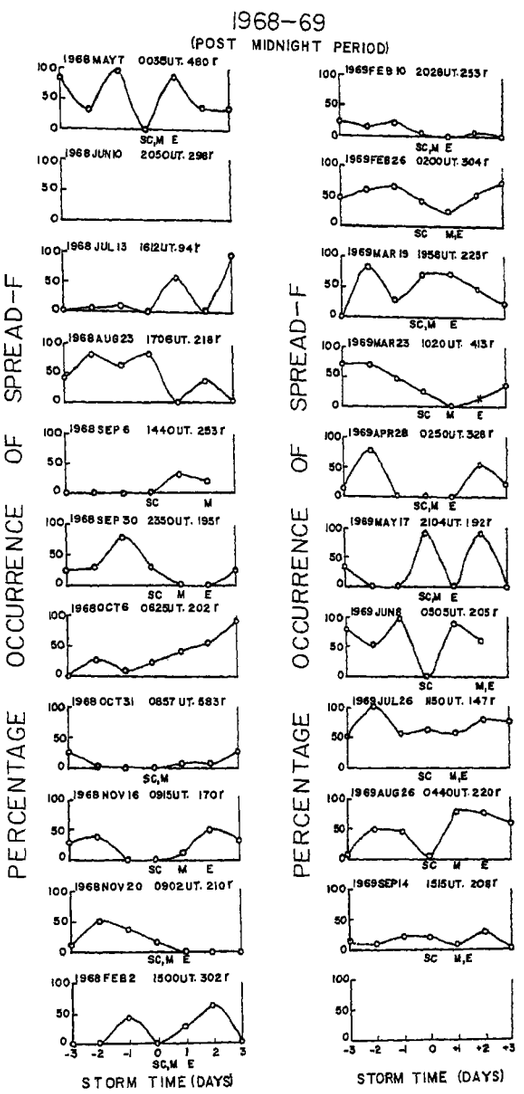

Fig. 5

Variation of percentage occurrence of post-midnight Spread-F with storm time for the years 1968-69.

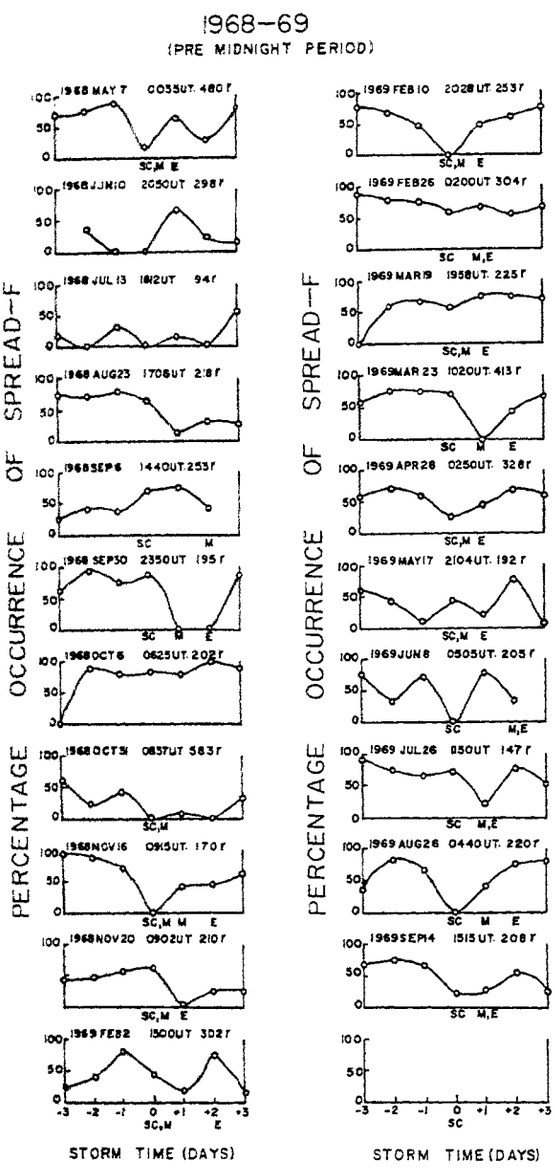

Fig. 6

Variation of percentage occurrence of pre-midnight Spread-F with storm time for the years 1968-69.

Index 1 which is essentially an early evening feature is closely associated with the post sunset rise of the layer. Chandra and Rastogi (1972 b) studied the h'F variations at Kodaikanal for the IGY-IGC period (a period of high solar activity). It can be seen from Figure 4 of their paper that h'F reaches a maximum around 2000 hours and there is a delay in the occurrence of h'f maximum during J months. It can be clearly seen from Figure 1 (of this paper) that the occurrence of Spread-F with index 1 reaches a maximum around the same period and there is a delay in the occurrence of this maximum during J-months. This observation leads to the inference that the post sunset Spread-F configuration (Index 1) is due to irregularities on the bottom side of the layer. When the layer is moving vertically upward either due to electromagnetic drift envisaged by Martyn (1959) or due to atmospheric cooling process proposed by Calvert (1963). A similar comparison of the occurrence of Spread-F with index 3 (Intense Range spread) observed in this study with the h'F variations reported by Chandra and Rastogi (1972 b) showed that the range spread is correlated with the downward movement of the layer after its initial rise in the early evening period. However, the origin of these irregularities when the layer is fast descending is not clear, as according to Martyn's theory when the layer is experiencing a downward drift its upper surface becomes unstable and produces irregularities and not the under surface. The origin of frequency spread is also not well established. Pitteway and Cohen (1961) explained it as due to thick irregularities which acts as a wave guide in the North – South plane causing trapped modes inside which various group delays could be introduced. The origin of these irregularities is however not known. Farley et al (1970) pointed out that the post-midnight on set of Spread-F does not seem to be correlated either with the height or vertical drift velocity of the layer. It follows therefore that the mechanism responsible for the production of irregularities causing Spread-F during pre- and post-midnight period is different, and the latter is yet to be identified.

The observation of many instances wherein disappearance and subsequent appearance of Spread-F within a span of couple of hours or even less is another feature revealed by the present investigation. It is known that Spread-F occurrence is a height controlled phenomenon. Rao (1966) indicated that the height of the layer should reach a threshold value of about 400 km for the occurrence of Spread-F. He argued that once the irregularities are formed due to plasma waves generated by upward lifting of the layer across the magnetic field (his proposition), they do not die out unless the layer comes to very low heights and there will be little association between changes in layer height and Spread-F activity. However Farley et al (1970) from VHF observations pointed out that the bottom of the layer must reach a threshold value for the irregularities to occur (Spread-F) and showed cases when the disappearance and subsequent appearance of the irregularities coincided with the bottom of the layer crossing the threshold height. Exceptions to this behaviour however have been pointed by them. A preliminary study of our data indicated the disappearance and appearance of Spread-F is not dependent on the changes in the layer height and its crossing the threshold value, as can be clearly seen from the

typical case presented in plate III. A definite conclusion on this aspect awaits a detailed study which is in progress and will be reported in a separate paper.

A pronounced geomagnetic control of Spread-F phenomenon is noticed through the observation of a significant positive correlation between Spread-F occurrence and mean value of H component of magnetic field at Kodaikanal. This is rather interesting in view of the fact that the maximum difference in H field between disturbed and quiet days will be of the order of a few percent and it is intruiging to understand how such a small change in H field could produce instability in plasma in the electrojet region giving rise to irregularities and hence Spread-F. An isolated observation of a similar nature has been reported earlier by Shirmazaki (1960).

Acknowledgements

The authors are thankful to Dr. M.K.V. Bappu for his encouragement and interest in this work and to Dr. J.C. Bhattacharyya for useful discussions.

Manuscrit reçu le 26 juillet 1974

References

Bhargava B.N., "Observations of Spread echoes from the F-layer over Kodaikanal – A preliminary study", *India J. Met. Geophys.* 9, 35-40, 1958.

Calvert W., "Instability of the equatorial F-layer after sunset", *J. Geophys. Research* 68, 2591-2593, 1963.

Calvert W. and Cohen R., "The interpretation and synthesis of certain Spread-F configurations appearing on equatorial ionograms", *J. Geophys. Research* 66, 3125-3140, 1961.

Chandra H. and Rastogi R.G., "Solar cycle and seasonal variation of Spread-F near the magnetic equator", *J. Atmosph. Terr. Phys.* 32, 439-443, 1970.

Chandra H. and Rastogi R.G., "Spread-F at magnetic equatorial station Thumba", *Ann. Geophys*, 28, 37-44, 1972(a) .

Chandra H. and Rastogi R.G., "Equatorial Spread-F over a Solar cycle", *Ann. Geophys.* 28, 709-716, 1972(b) .

Farley D.T., Balsley B.B., Woodman R.F. and Meclure J.P, "Equatorial Spread-F : Implications of VHF Observations", *J. Geophys ; Res.* 75, 7199-7216, 1970.

Herman J.R., "Spread-F and ionospheric F-region irregularities", *Reviews of Geophysics*, 4, 255-299, 1966.

Huang Y.N. and Yeh C.Y., "On the occurrence of Spread-F and the geomagnetic activity over Taipei, Taiwan" *J. Atmosph. Terr. Phys.* 32, 1765-1772, 1970.

Jagath Kumar V.R., Raju P.T.S., Rao B.R., "Relation between magnetic activity and Spread-F at Kodaikanal", *J. Atmosph. Terr. Phys.* 29, 1669-1672, 1967.

Krishnamurthy B.V. and Rao B.R., "Variation of Spread-F index with frequency in pre- and post-midnight periods at Waltair", *J. Atmosph. Terr. Phys.* 26, 783-784, 1964.

Lyon A.J., Skinner N.J. and Wright R.W.H., "Equatorial Spread-F and magnetic activity", *Nature*, 181, 1724-1725, 1958.

Lyon A.J., Skinner N.J. and Wright R.W.H., "Equatorial Spread-F at Ibadan, Nigeria., *J. Atmosph. Terr. Phys.*, 21, 100-119, 1961.

Martyn D.F., "The normal F-region of the ionosphere", *Proc. I.R.E.*, 47, 147-155, 1959.

Pitteway M.L.V. and Copen R., "A wave guide interpretation of temperate latitude Spread-F on equatorial ionograms", *J. Geophys. Res.* 66, 3141-3156, 1961.

Rangaswamy S. and Kapasi K.B., "A study of equatorial Spread-F", *J. Atmosph. Terr. Phys.* 25, 721-731, 1963.

Rao C.V.S. and Mitra S.N., "Spread-F and geomagnetic activity", *J. Geophys. Res.* 67, 127-134, 1962.

Rao B.C.N., "Control of equatorial Spread-F by the F layer height". *J. Atmosph. Terr. Phys.* 28, 1207-1217, 1966.

Reber G., "World wide Spread-F", *J. Geophys. Res.* 61, 157-164, 1961.

Singleton D.G., "The geomorphology of Spread-F", *J. Geophys. Res.* 65, 3615-3624, 1960.

Singleton D.G., "The morphology of Spread-F occurrence over half a solar cycle", *J. Geophys. Res.* 73, 295-308, 1968.

Shimazaki T., "A statistical study of world wide occurrence probability of Spread-F", I. Average state, *J. Radio Res. Lab. Japan*, 6, 669-687, 1959.

Shimazaki T., "The occurrence of Spread-F and the geomagnetic field", *J. Radio Res. Lab. Japan*, 7, 437-450, 1960.

Skinner N.J. and Kelleher R.F., "Studies of F-region irregularities at Nairobi I-Foom Spread-F on Ionograms 1964-1970, *Ann. Geophys.* 27, 181-194, 1971.

Wright R.W., Koster J.R. and Skinner N.J., "Spread-F layer echoes and radio star scintillation", *J. Atmosph. Terr., Phys.* 8, 240-246, 1956.

Wright R.W.H. and Skinner N.J., "Equatorial Spread-F", *J. Atmosph. Terr. Phys.*, 15, 121-125, 1959.