Range and frequency spread $F$ at Huancayo

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Abstract. The mean occurrence of frequency type of spread $F$ at Huancayo has been shown to have practically no solar cycle dependence. The occurrence of range type of spread $F$ is shown to be inversely related to sunspot number. The range spread occurs mostly around 2000 LT for any of the solar epoch, while frequency spread has maximum occurrence between 2300 and 0000 LT in high sunspot years and between 0600 and 0900 LT in low sunspot years. The seasonal variation in the occurrence of either type of spread $F$ shows minimum in northern solstices (June months) and maximum occurrence in southern solstices (December months). The post-sunset rise of $F$ layer is most predominant during high sunspot years. These results point out the inadequacy of the theory of spread $F$ based entirely on the post-sunset upward rise of the $F$ region after sunset.

Keywords. Equatorial spread $F$; range frequency spreading.

1. Introduction

The spread $F$ at an equatorial station has been found to occur predominantly following the rapid rise of the $F$ region after sunset (Booker and Wells 1938; Osborne 1952; Wright et al 1956; Bhargava 1958; Chandra and Rastogi 1972). The occurrence of spread $F$ at Ibadan has been found to increase with increasing solar activity (Lyon et al 1961; Lyon 1965). The occurrence or the intensity of spread $F$ index at the equatorial stations Ibadan, Djibouti and Kodaikanal increases with the increase of solar activity (Lyon et al 1961; Chandra and Rastogi 1970). It is only Huancayo where the spread $F$ decreases linearly with sunspot number for any of the seasons, and the seasonal variation is much more pronounced than at any other equatorial station.

Examining critically, the ionograms at the equatorial station Thumba, Chandra and Rastogi (1972) found that the equatorial spread $F$ is basically of two types (i) Range spread which is more common during high sunspot years and it occurs in pre-midnight period and is well correlated with post-sunset increase of $h'F$. (ii) Frequency spread which is more common in summer of low sunspot years and it occurs usually in the predawn period.

Sastri and Murthy (1975) confirmed that the spread $F$ configuration at Kodaikanal during pre-midnight period was of range type and in the post-midnight period it was of the frequency type. Examining the ionograms at Kodaikanal for six years (1964-69), Sastri et al (1975) showed that both range and frequency spread have positive correlation with solar activity and the occurrence pattern of range and frequency
midnight hours, while during post-midnight hours the frequency spread was more frequent than the range spread $F$.

2.1. Seasonal variations

In figure 3 are shown the average seasonal variation of the range and frequency spread $F$, averaged for whole night as well as for the two hours around the time of maximum occurrence. It is seen that the whole night average occurrence of any of these spread $F$ types, for any solar epoch shows the maximum near December solstices and the minimum around June solstices. Examining the seasonal variation of the peak occurrence of range spread, one finds a small maximum around October of the high sunspot years. The curve for the low sunspot years shows distinct maxima during equinoxes rather than during December solstices. The seasonal variation of the peak occurrence of frequency spread is more or less minimum during May-June and maximum around November-December.

The occurrence of range spread $F$ is associated with the post-sunset rise of the $F$ layer and hence we now examine the daily variation of $h'F$ during periods of varying solar activity. In figure 4 are shown the yearly average daily variation of the minimum virtual height of the $F$ region, $h'F$ for years of average Zurich sunspot numbers 32, 54, 112 and 185. It is seen that the post-sunset rise of $h'F$ is more predominant during years of higher solar activity which is in contrast with the solar cycle variation of range spread.

3. Discussion

Since the earliest observations of the equatorial spread $F$ following the post-sunset rise of the $F$ layer, many investigations have been carried out by different workers on the post-sunset variations of $h'F$ and spread $F$ (Lyon et al. 1961; Rao and Rao 1961; Krishnamurthy and Rao 1963; Rangaswamy and Kapasi 1963; Rao 1966; Chandra and Rastogi 1972). The magnitude as well as the onset time of spread $F$ was shown to be closely associated with the rise of the $h'F$. Rastogi (1977) has shown that the rise of the $F$ region is associated with the pre-reversal peak of $F$ region electric field. Further the spread $F$ is absent and there is no large height rise of the $F$ region when the pre-reversal peak of the electric field is absent. These observations clearly indicated that the range spread is someway associated with the post-sunset height rise and with the pre-reversal peak of the $F$ region electric field. Now that the height rise

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{huancayo.png}
\caption{Yearly average daily variations of the minimum virtual height of the $F$ layer, $h'F$, at Huancayo during years of different Zurich sunspot number.}
\end{figure}
Range and frequency spread $F$ at Huancayo

is well as the pre-reversal electric field is positively correlated with the solar cycle Woodman et al (1977) it should be expected that the range type spread $F$ too be positively correlated with solar activity.

I. Conclusion

The seasonal variation in the occurrence of spread $F$ at Huancayo has been the most pronounced feature with practically no spread in June solstices and very common during December solstices. It is again at Huancayo where the occurrence of spread $F$ (now range type only) is inversely correlated with solar activity although post-sunset rise of the $F$ region and the pre-reversal peak of $F$ region electric fields are most pronounced during high sunspot years. For better understanding of the $F$ region regularities it is necessary to investigate whether the features of Huancayo spread $F$ are present at any other stations in the western zone. Further a detailed study of the frequency and range spread at other stations would also help in sorting out the anomalous feature of spread $F$ at Huancayo. The simplistic conclusion regarding the association of range spread $F$ with post-sunset rise of the $F$ region does not seem to be totally adequate and needs a critical scrutiny.

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References

Bharagava B N 1958 Indian J. Meteor. Geophys. 9 35
Booker H G and Wells H W 1938 Terr. Magn. Atmos. Elect. 43 249
Chandra H and Rastogi R G 1972 Ann. Geophys. 28 37
Osborne B W 1952 J. Atmos. Terr. Phys. 2 66
Rao B C N 1965 J. Atmos. Terr. Phys. 28 1207
SOLAR CYCLE EFFECTS IN EQUATORIAL SPREAD F.

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Abstract

The occurrence of Range type of equatorial spread F at Huancayo for the period 1957 to 1975 has been shown to inversely related to the Zurich sunspot number. The occurrence of Frequency type of spread F is practically independent of solar cycle. Both types of spread F show very large seasonal variation, being present on the average 40% of night time during December (local summer) months and only 5% of night time during June (local winter) months. The decrease in the occurrence of Range type of spread F during high sunspot years when the post-sunset rise of the F layer is most predominant poses problems in the simple theory of spread F on the F region rise after sunset.

Introduction

Recent interests in the ionospheric radio propagation between a satellite and a ground station have almost created explosive studies on equatorial spread F due to its effect on the VHF and UHF radio propagations. The ionospheric data collected during IGY-IGC period had clearly demonstrated the existence of a belt of intense spread F activity between 20° N and 20° S dip latitude (Shimazaki et al., Wright, Singleton). Chandra and Rastogi showed that the spread F index increased with solar activity at most of the equatorial stations Kodaikanal, Djibouti, Ibadan, but the spread F index at Huancayo during any of the seasons decreased with increasing solar activity. The examination of ionograms at Thumba, a station very close to the magnetic equator, revealed that the equatorial spread F is basically of two types (i) Range spread which occurs in the pre-midnight periods and is correlated with the post-sunset rise of the F region and (ii) Frequency spread which is usually seen in predawn periods (Chandra and Rastogi). Sastri and Murthy confirmed that the spread F at Kodaikanal was basically of Range type during pre-midnight period and of Frequency type during post-midnight period. Recently Rastogi and Vyas have shown that during the high sunspot years the predominant type of spread at Huancayo was Frequency type while during low sunspot years both the types were present. In this note we present the solar cycle variation of nightly average spread F of the two types at Huancayo for the period 1957 to 1975. These results have been extracted from the f-plots of Huancayo kindly supplied by the World Data Center A for Geophysics at Boulder (Colo.), U.S.A.

Results

In Fig. 1 are shown the seasonal variation of Frequency and Range spread averaged over the entire period of observation at Huancayo. It is seen that either type of spread is most frequent during December solstices (local summer) and minimum during June solstices (local winter) and no indication of any semi-annual variation is seen. Further on average Frequency spread is slightly more common than the Range spread.

In Fig. 2 are shown the relation between the occurrence frequency of Range and Frequency spread at Huancayo versus the corresponding Zurich sunspot number separately for the four different seasonal groups of the year (December to February, March to May, June to August and September to November). The least square fitting straight lines, through these data points, are also indicated in the diagram. It is seen from the diagram that the occurrence of frequency spread is practically
independent of sunspot number; the change in occurrence is only about 1 or 2% of the change of sunspot number. Regarding the Range spread, its occurrence frequency is negatively correlated with sunspot number. During September—November or December—February seasons, the sensitivity of the spread is about 20% of the sunspot number. During other seasons the sensitivity is relatively lower. Thus the sensitivity of Frequency spread to changes of sunspot number is higher for the months when the spread is more common and it is less sensitive when the occurrence of spread F is relatively lower.

The Range spread F is shown to be associated with the post-sunset rise of the F region generated by the evening peak of the eastward electric field in the F region (Rastogi3). The evening peak of the E-W electric field in the F region is most pronounced during high sunspot years when the Range spread is least pronounced. Thus whereas Range spread is closely correlated with the electric field on shorter term variations, it is not so with very long term variations. Evidently there are no simple causes for the equatorial Range spread and many aspects of its variations still need to be identified.

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8. Wright, R. W.; Ibid., 1959, 64, 2203.

![Diagram of HUANCAYO 1957-75 RANGE SPREAD vs FREQUENCY SPREAD](image-url)
Abstract. Geomagnetic disturbance effects on the occurrence of range and frequency spread at Huancayo are studied for the period 1957-74. The occurrence of frequency spread is decreased on disturbed days for D-months and E-months while during J-months an increase is noted in the post-midnight period. The occurrence of range spread is decreased on disturbed days in the pre-midnight hours during D and E-months. Post-midnight hours of D and E-months and all hours of night during J-months show an increase of range spread on disturbed days, which is most prominent during low sunspot years. The mean occurrence of frequency spread (2300-0100 LT) and range spread (2000-2300 LT) decrease with increasing ΔKp. On the other hand, occurrence of range spread (0300-0500 LT) increases with increasing ΔKp, and is suggested as the consequence of the change of the horizontal electric field in the F-region associated with the geomagnetic storms.
Figure 3. Mean nocturnal variations of the difference of the occurrence of frequency spread $F$ on disturbed days minus the same on quiet days for different solar cycle epochs (1972-74 and 1963-65) and for high sunspot years (1968-70 and 1957-59).
remained independent of sunspot number (Rastogi and Vyas 1977). Another notable feature of the equatorial spread has been the inverse correlation with the magnetic activity (Bhargava 1958; Lyon et al 1960; Rao and Mitra 1962; Chandra and Rastogi 1972 a,b). The analyses by Chandra and Rastogi (1972b) had shown that the post-sunset spread $F$ at Huancayo is negatively related to high geomagnetic activity for $D$ and $E$ months of the year while for the $J$ months (particularly sunspot minimum years) the relationship is not clear. Further for the post-midnight hours the effect was small and not clear. During the low sunspot years the spread $F$ was more on disturbed than on quiet days during post-midnight hours. These indicated that geomagnetic disturbance effect on equatorial spread $F$ depends on the time of the night as well as on season and solar epoch. Using a superposed epoch method, Bowman (1974) found a good correlation between days of high $A_p$. 

P.(A)—3
index and high spread $F$ occurrence for a pre-sunrise interval of a few hours. As the frequency and range spread have quite different nocturnal, seasonal and solar cycle variations, it was considered advisable to study the geomagnetic disturbance effect separately for range and frequency types of spread $F$ at Huancayo. The present paper is the result of such an enquiry.

2. Results and discussion

The results are based on the study of $f$-plots of Huancayo covering the period July 1957 to June 1974. The incidences of Range and frequency spread were noted separately, and the data were divided into three seasonal groups $E$ months (September, October, March and April), $D$ months (November, December, January and February) and $J$ months (May, June, July and August). The mean nocturnal variations of the occurrence of spread $F$ on five international quiet and five international disturbed days of each month were calculated separately for range and frequency spread. Figure 1 shows the seasonal curves of the occurrence of range and frequency spread on quiet and disturbed days averaged for the entire period of 1957-74. The peak occurrence of frequency spread for any of the seasons occurs around midnight hours with magnitude maximum during $D$-months, less during $E$ months and least during $J$ months. Range spread, however, is most common in $E$ months, less in $D$ months and least in $J$ months. The geomagnetic disturbance tends to reduce the frequency spread for all the hours of the night during $D$ and $E$ months and also reduces range spread during the pre-midnight hours of $D$ and $E$ months. The range spread is most common on disturbed than on quiet days for the post-midnight hours of $D$ and $E$ months and for all hours of $J$ months.

As the average occurrence of range spread has a strong solar cycle effect, the disturbance effect on the occurrence of spread $F$ was studied for different periods of solar activity. The periods chosen were around minimum solar activity 1972 to 1974 (mean Zurich sunspot = 47) and 1963 to 1965 ($R_s = 53$) as well as years of maximum solar activity 1968 to 1970 ($R_s = 104$) and 1957 to 1959 ($R_s = 180$). The frequency

![Figure 1. Mean nocturnal variations of the occurrence of range and frequency types of spread $F$ at Huancayo on five internationally quiet and five internationally disturbed days of the month for different seasons of the year, averaged over the years 1957-1974.](image)
Geomagnetic disturbance effects on equatorial spread F

Figure 2. Mean nocturnal variations of the difference of the occurrence of range spread F at Huancayo on disturbed and on quiet days for low sunspot years (1972-74 and 1963-65) and for high sunspot years (1968-70 and 1957-59).

Figure 3. Mean nocturnal variations of the difference of the occurrence of frequency spread F at Huancayo on disturbed and on quiet days for low sunspot years (1972-74 and 1963-65) and for high sunspot years (1968-70 and 1957-59).

of occurrence of range spread on disturbed minus the same on quiet days averaged for the different solar epochs is plotted against time in figure 2. The period when occurrence frequency is less on disturbed than on quiet days is shaded by horizontal lines while the periods when spread F is more frequent on disturbed than on quiet days are filled with dots in the diagram. It is clearly seen that during the pre-midnight hours for any of the solar epochs there is an decreased tendency of spread F on disturbed days than on quiet days. The enhanced occurrence of range spread on disturbed days is only a post-midnight phenomenon and again the event is predominant in low sunspot years. There is no occurrence of range spread F in post-midnight hours during 1957-59 period which characterises one of the most active solar epochs. Thus the occurrence of range spread during post-midnight hours is more common in low sunspot years than in high sunspot years. Figure 3 shows the nocturnal variations of the occurrence frequency of frequency type of spread F on disturbed minus the same on quiet days for different solar cycle epochs. During
associated with the geomagnetic disturbance and this type of spread $F$ is due to the gradient drift instability created at the base of the $F$ region.

A critical study of spread $F$ phenomenon over the magnetic equator in coordination with other ground based as well as the satellite borne data would help in understanding the coupling of the equatorial ionosphere with the magnetosphere and the interplanetary magnetic field.

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References

Bhargava B N 1958 Indian J. Meteor. Geophys. 9 35
Booker H G and Wells H W 1928 Terr. Magn. Atmos. Electr. 43 249
Bowman G G 1974 Planet. Space Sci. 22 1579
Chandra H and Rastogi R G 1972a Ann. Geophys. 28 37
Chandra H and Rastogi R G 1972b Ann. Geophys. 28 709
Osborne B W 1952 J. Atmos. Terr. Phys. 2 66
On the relationship between magnetic activity and spread-F at Huancayo

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ABSTRACT. Occurrences of range and frequency types of spread-F at Huancayo for the period 1957-74 have been examined separately in relation to the geomagnetic disturbance index Kp. It is noted that the occurrence of frequency spread as well as of the range spread in the pre-midnight period decreases with increasing Kp during D-months and E-months but increases with increasing Kp during J-months. However, the occurrence of range spread in the pre-sunrise period increases with increasing Kp during each season.

RESUME. Deux types d'échos dans la région F ("spread-F") détectés à Huancayo de 1957 à 1974 ont été examinés séparément en fonction de l'indice géomagnétique Kp. Le premier type ("Range Spread") d'écho est défini à partir des traces h-f et concerne les échos pour lesquels il existe un éclatement de l'ionogramme dans sa partie horizontale rendant ambigue l'évaluation de cet éclatement. Le deuxième type ("Frequency Spread") d'écho concerne les échos pour lesquels il existe un éclatement de l'ionogramme dans sa partie verticale (près de la fréquence de pénétration) rendant ambigue l'évaluation de cet éclatement. Il est noté que le pourcentage d'arrivée des 2 types "Frequency Spread" et "Range Spread" décroît lorsque croît le Kp avant minuit et pendant les mois D et E. Par contre, ce pourcentage d'occurrence croît lorsque le Kp croît pendant les mois J. Cependant, le pourcentage d'occurrence du type "Range Spread" dans les périodes antérieures au lever du soleil croît le Kp pour chaque saison.

Introduction

Spread-F in the equatorial region has been found to be associated with the rapid post-sunset rise of F-layer (Booker and Wells, 1938; Osborne, 1952; Wright et al., 1956; Bhurugra, 1958). Detailed investigations of the occurrence characteristics of equatorial spread-F based on published foF2 data bulletins have shown entirely different solar-cycle and seasonal variations to be present at Huancayo as compared to variations at the stations in India and Africa (Chandra and Rastogi, 1970; 1972a). Investigations based on ionograms at equatorial stations in India have shown that the occurrence characteristics of the two types of spread-F i.e. Range type and the Frequency type, are different with Range type occurring mainly in pre-midnight period and Frequency spread occurring mainly in the post-midnight period (Chandra and Rastogi, 1972b; Sastri and Murthy, 1975). Recently Rastogi and Vyas (1977) have obtained the solar cycle variations of the occurrence frequency of the two types of spread-F separately at Huancayo derived from the daily f-plots and found that only the range spread is inversely related to the sunspot number. The occurrence of frequency spread was shown to be independent of sunspot number by them. Another well known feature of the equatorial spread-F has been its marked inhibition due to magnetic activity (Lyon et al., 1958; Rangaswami and Kapasi, 1963; Chandra and Rastogi, 1972a). However, results at Huancayo have indicated increase in spread-F due to magnetic disturbances in the post-midnight periods of low sunspot years (Chandra and Rastogi, 1972b) as well as during pre-sunrise hours (Bowman, 1974). Rastogi et al. (1978) compared...
the occurrence of the two types of spread-F present at Huancayo obtained from daily f-plots on international quiet days and disturbed days and reported that the disturbance effects depend upon the time of the night as well as the season. In the present paper the relationship between the geomagnetic disturbance index \( K_p \) and the occurrence frequency of range and frequency types of spread-F at Huancayo during different seasons is examined using the data for the period 1957-74.

**Method of Analysis**

The study is based on quarter-hourly readings of the occurrence of spread-F from daily f-plots, marking the presence of range and frequency spread with different notations. The range spread is classified when there is spreading in the horizontal part of the \( h'-f \) trace so that ambiguity remains in finding the range spreading in the vertical part of \( h'-f \) trace close to the penetration frequency when there is ambiguity in finding the critical frequencies is classified frequency spread. If spreading in present at lower frequencies as well as near the critical frequency then presence of both the range and frequency spread will be marked.

From earlier study it is known that the nocturnal variation of the occurrence of frequency type of spread-F is shows a major peak around 2100 hr LT and another smaller peak around 0400 hr LT (Rastogi and Vyas, 1977). For comparison with \( K_p \), therefore, we have grouped data 2300-0100 hr LT for frequency spread while data in the period 2000-2300 LT and 0300-0500 LT have been grouped separately for range spread. Three hourly values of \( K_p \) nearest to these hour groups have been taken for comparing the occurrence of spread-F in different \( K_p \) groups. Three seasonal groups have been made by combining data of four months each viz. D-months (November through February), E-months (March, April, September and October) and J-months (May through August).

**Results**

Entire data in the period 1957-74 have been grouped together first and the variation with \( K_p \) of the mean percentage occurrence of frequency spread and range spread during different seasons are shown in Figure 1 along with error in mean. Due to large number of data used the magnitude of error is small and absence of error bars denote a very small value which cannot be shown in figure. The occurrence of frequency spread (2300-0100 hr LT) and range spread (2000-2300 hr LT) decreases with increasing \( K_p \) during D-months and except morning D-months but increases with \( K_p \) during J-months. The occurrence of range spread in the pro-sunrise period (0300-0500 hr LT) however increases with increasing \( K_p \) during each season.

To examine the dependence of the effect of magnetic activity on the occurrence of spread-F on sunspot numbers data have been further separated into the following groupings viz. 1957-59 with average \( R_2 \) equal to 180, 1968-70 with average \( R_2 \) equal to 104, 1963-65 with average \( R_2 \) equal to 53 and 1972-74 with average \( R_2 \) equal to 47. The mean occurrence of the frequency type of spread-F (2300-0100 LT) during different seasons is shown in Figure 2 as a function of \( K_p \). During D-months the occurrence of frequency spread remains constant initially up to a \( K_p \) value of 4 and then decreases with further increase in \( K_p \) except for the epoch 1957-59 when the variation is rather inconsistent. During E-months the occurrence of frequency type of spread-F decreases with increasing \( K_p \) for any of the sunspot epoch. The variations during J-months, however, show an increase with increasing \( K_p \) during different solar epochs.

Similar seasonal pictures during different solar epochs for range spread (2000-2300 hr LT) are shown in Figure 3. During D-months there is a decrease in the mean percentage occurrence of range spread for \( K_p \) value up to 4 and increase on \( K_p \) value of 4 for high sunspot epochs. During low sunspot epochs, mean occurrence is nearly independent of \( K_p \). Decrease with increasing \( K_p \) is in general clear for E-months while during J-months clear increase in mean occurrence is noticed for any of the epochs.

The variation with \( K_p \) of the mean percentage occurrence of range spread during pre-sunrise period.
Variations with $K_p$ of the mean percentage occurrence of frequency spread (2300-0100 LT) for different seasons during periods of different solar activity.

Variations with $K_p$ of the mean percentage occurrence of range spread (0300-0500 LT) for different seasons during periods of different solar activity.

shown in Figure 4 however shows for any season or any solar epoch occurrence of spread-F increasing with increasing $K_p$.

Discussion

Bowman (1974) studied the occurrence of spread-F at Huancayo for a twelve year period 1957-69 and found a good correlation between the high values of spread-F occurrence and high values of $A_p$ index in the pre-sunrise period. From these results Bowman suggested that the travelling ionospheric disturbances initiated in polar regions at times of high geomagnetic activity are responsible for spread-F at pre-sunrise periods. Chandra and Rastogi (1972b) found reduction on disturbed days in the mean spread-F index at Kodaikanal for different seasons as well as for different sunspot epochs. Sastri and Murthy (1975) from an examination of ionograms at Kodaikanal reported that occurrence of spread-F either in the pre-sunrise period or in the post-midnight period is reduced at storm night or the succeeding night. Thus even though the spread-F at Huancayo during pre-midnight period is generally inhibited by magnetic activity during $D$-months and $E$-months, during $J$-months it increases with the onset of magnetic activity. For the pre-sunrise type of range spread-F it always increases with magnetic activity. Investigations to examine the occurrence of both types of