Seasonal and Solar Cycle Variations of Spread $F$ at the Equatorial Anomaly Crest Zone

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The spread $F$ data obtained at Taipei ($25.00^\circ$N; $121.53^\circ$E geographic and $14.04^\circ$N; $191.47^\circ$E geomagnetic) and Chungli ($24.95^\circ$N; $121.23^\circ$E geographic and $13.98^\circ$N; $191.19^\circ$E geomagnetic) during the period from 1960 to 1982 were used to analyze the seasonal and solar cycle variations of frequency and range type spread $F$ at the equatorial anomaly crest zone. By use of superposed epoch method, the geomagnetic activity effects on the occurrences of frequency and range type spread $F$ were also analyzed.

1. Introduction

The spread $F$ phenomenon, observed as diffuse echoes on the ionograms, is a well known feature occurring during nighttime over a wide range of latitude. Generally speaking, $F$ layer spread echo starts to appear in the ionograms after sunset and diminishes quickly around sunrise. According to their diffusion characteristics on the vertical incidence ionogram, spread $F$ echoes are usually classified into two types: frequency spread $F$ and range spread $F$ (McNICOL et al., 1956). If the diffusion is pronounced along the section of the trace that sweeps upward and makes the critical frequency of $F_2$ layer difficult to estimate, the spread $F$ is classified as 'frequency spread $F$'. If the diffusion appears only along the horizontal part of the trace and is more or less independent of frequency, then it is classified as 'range spread $F$'. In some earlier works, the spread $F$ has been divided into two types of equatorial type and temperate-latitude type when considering spread $F$ occurrence at equatorial latitudes (e.g. CLEMESHA, 1964). Recently, an intensive study has been made to compare the midlatitude and equatorial spread $F$ characteristics (BOWMAN, 1984b). The irregularities generated in the $F$ region of the equatorial ionosphere is also termed as equatorial spread $F$. However, in this report, we use spread $F$ to mean the diffuse echoes observed on the ionograms as mentioned above. It should be noted that most of the early work on the morphological features of equatorial spread $F$ was done with the help of ionosonde (SASTRI and MURTHY, 1975).

In equatorial latitudes, the nocturnal, seasonal and solar cycle variations of the occurrence of different types of spread $F$ have been studied by many workers. KRISHNA MURTHY and RAO (1964) noted that range spread $F$ at Waltair occurs
mainly during the pre-midnight period and frequency spread $F$ in the postmidnight period. However, at Huancayo, during high solar activity period, the maximum occurrence of range spread $F$ appears in the pre-midnight hours of equinoctial months while the maximum occurrence of frequency spread $F$ appears around midnight hours of December solstice (RASTOGI, 1980). At Fortaleza, ABDU et al. (1981a) reported that the yearly maximum of range spread $F$ appears around the southern summer months and the minimum appears in the southern winter months. Considering both types of spread $F$ all together, CHANDRA and RASTOGI (1970) pointed out that, in American zone, the occurrence of equatorial spread $F$ decreases with solar activity with seasonal maximum appearing in December solstice and the minimum appearing in June solstice for any epoch of solar cycle. In the African zone, the occurrence of equatorial spread $F$ is directly related to solar activity, the seasonal maximum appearing in June solstice and the minimum appearing in December solstice.

The above mentioned observational results show that the nocturnal, seasonal and solar cycle variations of the occurrences of different types of spread $F$ at equatorial region are highly variable from one station to another. Even at the same station, the results may be different if the data were taken from different epoch of solar cycle or different types of spread $F$ were considered (e.g. CHANDRA and RASTOGI, 1972a, b; RASTOGI, 1980).

Although the characteristic variations of the occurrence of different types of spread $F$ at the equatorial region have been studied by many workers; and the mid-latitude spread $F$ occurrence has also been studied by many workers (e.g. BOWMAN, 1960a, b, 1968, 1981, 1984a, b), the characteristic variations of the occurrence of different types of spread $F$ at the equatorial anomaly crest have never been investigated. An intensive study by use of long term data (at least one solar cycle) seems worthwhile to clarify the characteristic variations of the occurrence of different types of spread $F$ at equatorial anomaly crest region.

In this report, the spread $F$ data obtained in Taipei (25.00°N; 121.53°E geographic and 14.04°N; 191.47°E geomagnetic) during the period from March 1960 to June 1965 and in Chungli (24.95°N; 121.23°E geographic and 13.98°N; 191.19°E geomagnetic) from July 1965 to August 1982 have been used to investigate the nocturnal, seasonal and solar cycle variations of the occurrence of different types of spread $F$ at the equatorial anomaly crest. Frequency and range spread $F$'s are scaled separately from the $C2/C4$ ionograms by one scaler in order to avoid the personal difference in scaling.

2. Nocturnal, Seasonal and Solar Cycle Variations of Different Types of Spread $F$ at Equatorial Anomaly Crest

Figure 1 shows the nocturnal variations of seasonal mean percentage occurrences of frequency spread $F$, range spread $F$ and both types of spread $F$ for summer (May, June, July and August), winter (January, February, November, and December) and equinoxes (March, April, September and October) at three different solar activities as
Fig. 1. Nocturnal variations of percentage occurrence of frequency spread $F$ (dashed line), range spread $F$ (dotted line) and both types of spread $F$ as a whole (solid line) at different season and different solar activity. The mean nocturnal variations of the virtual height of $F$ layer, $h'F$, are also shown by solid lines.
classified in Table 1. For the frequency spread $F$, the nocturnal variation patterns are the same for all seasons. The percentage occurrence increases gradually after sunset, reaches its peak occurrence around 0400 LT and diminishes quickly before dawn. The nocturnal maximum is largest in summer and smallest in winter. It is evident that the occurrence of frequency spread $F$ increases with decreasing solar activity. The most frequent occurrence of frequency spread $F$ appears during the summer of low solar activity period. During the winter and equinoxes of medium and high solar activity periods, frequency spread $F$ rarely appears before midnight and is mainly a post-midnight phenomenon.

For range spread $F$, the nocturnal variation patterns are different for different seasons. In summer, the percentage occurrence increases gradually after sunset, reaches its maximum around midnight and then decreases gradually. The rate of increase is faster than that of decrease during low and medium solar activity. However, in equinoxes of high and medium solar activity, range spread $F$ increases rapidly after sunset, reaches its maximum within a short time and maintains a flat maximum for several hours, then decreases gradually. In winter, the range spread $F$ becomes a rare phenomenon except in low solar activity. The nocturnal maximum is largest in summer and smallest in winter during low and medium solar activity; whereas the nocturnal maximum appears at the equinoxes during high solar activity. The most frequent occurrence of range spread $F$ occurs in summer at low solar activity and in equinoxes at high solar activity.

If both types of spread $F$ are considered together, the nocturnal patterns in summer and winter are similar to those of frequency spread $F$ due to more frequent occurrence of frequency spread $F$ than range spread $F$ during these seasons. However, in equinoxes of high and medium solar activity, the nocturnal pattern of spread $F$ is similar to that of range spread $F$ because of more frequent occurrence of range spread $F$ than frequency spread $F$.

Figure 2 shows the seasonal variations of different kinds of spread $F$ at different solar activities in pre-midnight (1800–0000 LT), post-midnight (0000–0700 LT) and

<table>
<thead>
<tr>
<th>Solar activity</th>
<th>High solar activity</th>
<th>Medium solar activity</th>
<th>Low solar activity</th>
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</thead>
<tbody>
<tr>
<td>Smoothed sunspot number</td>
<td>$130 \leq R$</td>
<td>$70 \leq R &lt; 130$</td>
<td>$R &lt; 70$</td>
</tr>
<tr>
<td>Number of months</td>
<td>36</td>
<td>89</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>Feb. 1982–Aug. 1982</td>
<td></td>
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</tbody>
</table>
Fig. 2. Seasonal variations of percentage occurrence of different kinds of spread $F$ in different time intervals and different solar activities. The solid, dashed and dotted lines represent the low, medium and high solar activity periods respectively.

whole night (1800–0700 LT) periods. The following are the major characteristics: (i) The seasonal variation of the range spread $F$ is characterized by a maximum occurrence in summer and a minimum occurrence in winter during low solar activity period. However, as the solar activity increases, the seasonal variation changes so that two maxima appear in equinoctial months and two minima appear in solstitial
months. (ii) The seasonal variation of frequency spread $F$ is characterized by a primary maximum occurrence in summer and a subsidiary maximum in winter with two minima appearing in equinoctial months during low solar activity. As the solar activity increases, the winter maximum disappears and the seasonal pattern changes to have a maximum occurrence in summer and a minimum occurrence in winter. (iii) When both types of spread $F$ are considered, the seasonal pattern is similar to that of frequency spread $F$ during low solar activity period and similar to that of range spread $F$ during high solar activity period.

The seasonal variations of the monthly percentage occurrence of frequency and range type spread $F$ at different time intervals of 20–22, 22–00, 00–02, 02–04, 04–06 and pre-midnight and post-midnight hours are plotted as full lines in Figs. 3(a) and (b) respectively. The seasonal variations at different time intervals can be seen more clearly in these figures. The dotted lines represent the 12-month running average values of the monthly percentage occurrences. The 12-month running average sunspot numbers are also plotted. The correlation between the smoothed percentage occurrence of frequency spread $F$ and sunspot number shows a negative correlation. However, the correlation between the smoothed percentage occurrence of range spread $F$ and sunspot number is not clear.

Figure 4 shows the correlation diagram between the smoothed percentage occurrences of the different types of spread $F$ and the smoothed sunspot number. The dotted, solid and ‘x’ lines stand for 19th, 20th and 21st solar cycle. The solar cycle proceeds in the direction indicated by arrows. The solar cycle variation of the frequency spread $F$ occurrence exhibits a hysteresis loop. The percentage occurrence of frequency spread $F$ in the rising half cycle is usually smaller than that in the falling half cycle. The hysteresis loops are different for different solar cycles. The percentage occurrence of range spread $F$ is too small to identify its solar cycle variation.

3. Post-Sunset Rise of $h'F$ and Spread $F$ Occurrence

The relationships between the occurrence of equatorial spread $F$ and the postsunset rise of virtual height of $F$ layer, $h'F$, have been studied by many workers (FARLEY et al., 1970; CHANDRA and RASTOGI, 1972a, b; RASTOGI, 1978; ABDU et al., 1981a, b, 1982, 1983). FARLEY et al. (1970) found that the onset of spread $F$ in Jicamarca VHF results was associated with the upward motion of $F$ layer and suggested that the bottom of the $F$ layer must attain some threshold altitude before the meter scale irregularities causing spread $F$ is to occur. CHANDRA and RASTOGI (1972a, b) reported that the range spread $F$ is well correlated with the postsunset rise of $h'F$ at equatorial station Thumba; whereas the frequency spread $F$ does not seem to have much dependence on $h'F$ variations. RASTOGI (1978) also suggested that the onset of range spread $F$ occurs around the periods of prereversal maximum in the $F$ region upward drift velocity, $V_z$. ABDU et al. (1981a, b, 1982, 1983) found that the $F$ layer bottom height, $h'F$, as well as the vertical upward drift velocity, $V_z$, should attain certain threshold values before the range spread $F$ can occur at equatorial station Fortaleza for southern solstice and equinoctial months but not for the northern
Seasonal and Solar Cycle Variations of Spread $F$

solstice months. They also found that high probability of range spread $F$ occurrence is associated with a sharp prereversal peak of $V_z$; whereas high probability of frequency spread $F$ occurrence is associated with a broader prereversal peak of $V_z$ caused by the large difference in sunset time between the conjugate $E$ layers.

It is interesting to see if there is any correlation between spread $F$ occurrence and post-sunset rise of $h'F$ at equatorial anomaly crest as was reported by CHANDRA and RASTOGI (1972a, b) at equatorial station. In Fig. 1, the mean nocturnal variations of the virtual height of $F$ layer, $h'F$, are given for each season of each solar activity period. No significant post-sunset rise of $h'F$ as reported by CHANDRA and RASTOGI (1972a, b) at equatorial region can be found at equatorial anomaly crest. Although a very broad peak can be seen in summer of all solar activity periods and equinox of low solar activity period, they are clearly different from the post-sunset rise of $h'F$ at equatorial region reported by APPLETON (1960), NARASINGA RAO (1963), HUANG (1964) and CHANDRA and RASTOGI (1972a, b). There seems no simple and direct relation between the occurrence of spread $F$ and $h'F$ at the equatorial anomaly crest.

The above conclusion was derived based on the mean $h'F$ variations. To obtain more rigorous result, the same method as used by ABDU et al. (1983) was used to examine the behavior of the $F$ layer height in relation to the spread $F$ occurrence at equatorial anomaly crest. For each season of each solar activity periods, the days on which a specified type of spread $F$ occurs continuously for at least 90 minutes without any spread $F$ occurrence on preceding or following days are selected to obtain mean variation of $h'F$ on those selected days. In Fig. 5(a) are shown the mean variations of $h'F$ on spread $F$ occurrence day (solid line) and on non-spread $F$ occurrence day (dotted line) for the high solar activity period. The number in parenthesis indicates the number of cases used. Although the virtual height, $h'F$, starts to increase at afternoon hours and reaches its maximum value at evening hours, the sharp rise of $h'F$ after sunset as reported by APPLETON (1960) and NARASINGA RAO (1963) can not be found at the equatorial anomaly crest. Moreover, the peak height of $h'F$ is much lower than the threshold value of $h'F$ for the occurrence of spread $F$ as reported by NARASINGA RAO (1966) and ABDU et al. (1983). Although the virtual height around the evening $h'F$ peak is slightly larger in spread $F$ nights than in non-spread $F$ nights (except for frequency type spread $F$ in equinoxes), the difference is much smaller than that reported by ABDU et al. (1983). There also seems no significant difference in $h'F$ variations between frequency type and range type spread $F$. The above results seem to show that unlike the case observed in the equatorial region, there seems no simple and direct relation between $h'F$ and spread $F$ occurrence at the equatorial anomaly crest.

In Fig. 5(b) are also shown the mean variations of $h'F$ obtained for low solar activity period. It is interesting to note that except for summer, the evening peak of $h'F$, which appeared in high solar activity period, disappears or becomes a minor peak (see winter case); and another larger peak appears in the late evening hours. This disappearance of evening $h'F$ peak may have some relation with the disappearance of evening prereversal enhancement of equatorial vertical drifts (FEJER et al., 1979). Clearly, there also seems no simple and direct relation between $h'F$ and occurrence of spread $F$ at the equatorial anomaly crest during low solar activity.
Fig. 3. Monthly variations of percentage occurrence of (a) frequency spread $F$ and (b) range spread $F$ for the given time intervals as indicated.
4. Geomagnetic Activity Effect on the Occurrence of Spread F

The geomagnetic activity effect upon the spread F occurrence has also been studied by many workers. In the midlatitude stations, spread F activity increases after the increase of geomagnetic activity (BRIGGS, 1965). In the equatorial anomaly crest, the spread F activity shows a negative correlation with geomagnetic activity (HUANG and YEH, 1970). HUANG (1970) also reported that the range spread F has negative correlation with geomagnetic activity while the correlation of frequency spread F is vague. Using the superposed epoch technique, BOWMAN (1982) showed that, in high latitude regions, a delayed peak in spread F occurrence is found in high geomagnetic activity while a delayed dip is found in low geomagnetic activity. In low latitude
regions, no significant delayed peak or dip in the occurrence of spread $F$ is found with respect to geomagnetic activity. At Huancayo, RASTOGI et al. (1981) reported that on disturbed days during the equinoctial and December solstitial months, the occurrence of range spread $F$ reduced during the pre-midnight hours but increased during the post-midnight hours, while the occurrence of frequency spread $F$ decreased at any hours of the night. However, on June solstitial months, both range spread $F$ and frequency spread $F$ are more frequent on disturbed days than on quiet days at any hour of the night.

In this report, the superposed epoch method was used to investigate the effect of geomagnetic activity on the occurrence of different types of spread $F$ at the equatorial anomaly crest. The zero days were defined as those days on which the geomagnetic $Ap$ index greater than or equal to 30 had been reported. For each of these days, data consisting of spread $F$ occurrence for the zero days and for the three preceding and the eleven following days were tabulated. The mean values of spread $F$ occurrence were obtained from these sets. In order to avoid the statistical contamination of the successive geomagnetic disturbances, only those zero days which were not preceded or followed by other zero days within five days had been chosen for the present study. In total, 252 zero days were selected during the time period from March 1960 to August 1982. In order to see the possible dependence of the geomagnetic activity effects on season and solar activity, the 252 zero days were further divided into three different seasonal groups and three different solar activity groups. The analysis was made, by use of quarter hourly values of spread $F$, for the whole night interval.

Figure 6 shows the superposed epoch analysis of range spread $F$ occurrence during winter time. The thick solid line represents the day to day variation of the mean occurrence on each day. The abrupt increase of mean occurrence can be observed. In order to test the significance of the increase from the average level, the 95% confidence interval of the mean occurrence for each day was calculated by use of the method proposed by HANSEN et al. (1958) and is shown by a solid vertical line. The mean occurrence for all days is shown by a horizontal thin line. The 95% confidence limit for mean occurrence is also calculated and shown by two horizontal dotted lines. If part of the vertical solid line goes into the area bounded by the two dotted lines, the observed increase of occurrence has come about simply through random fluctuations of spread $F$ occurrence. If, however, the vertical solid line does not go across the upper horizontal dotted line, it is likely that the observed increase of occurrence is statistically significant.

In Fig. 6, it can be seen that the location of 95% confidence interval for peak occurrence of spread $F$ is far apart from that for mean occurrence. This means that the increase of spread $F$ occurrence is statistically significant and not merely due to the random fluctuation of sampling. Same method was used to analyze the possible effect of geomagnetic activity on the occurrence of spread $F$ for different season and solar activity groups. Table 2 summarizes the results. The right column shows the number of zero days for each group. The letter $Y$ indicates that the significant increases of the spread $F$ occurrence have been found on the day indicated by the number following the letter $Y$. 
It can be seen that the geomagnetic activity effects on the spread \( F \) occurrence depend on season, solar activity and type of spread \( F \). If all data, regardless of season and solar activity are used for analysis, no significant geomagnetic activity effect can be found both for frequency and range spread \( F \). However, if they are divided into
different season and solar activity groups for analysis, significant increase of occurrence is found in some groups. It is also interesting to note that a significant increase of occurrence can appear on the days preceding the zero day, especially during high solar activity period. This seems to show that the increase of spread $F$
Fig. 6. Superposed epoch of percentage occurrence of spread $F$ on days around the occurrence of high geomagnetic activity with $Ap > 30$ in winter period for range spread $F$.

Table 2. Statistical results showing the significant increase of spread $F$ occurrence at different season and solar activity groups. The letter $Y$ appeared on some groups indicates that the statistically significant increase of the spread $F$ occurrence has been found at these particular groups on the day indicated by the number following the letter $Y$.

<table>
<thead>
<tr>
<th>Frequency spread $F$</th>
<th>Range spread $F$</th>
<th>Total spread $F$</th>
<th>Number of zero day</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R &lt; 70$</td>
<td></td>
<td></td>
<td>132</td>
</tr>
<tr>
<td>$70 \leq R &lt; 130$</td>
<td></td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>$130 \leq R$</td>
<td></td>
<td>$Y - 1$</td>
<td>38</td>
</tr>
<tr>
<td>Summer</td>
<td></td>
<td></td>
<td>81</td>
</tr>
<tr>
<td>Equinox</td>
<td></td>
<td></td>
<td>92</td>
</tr>
<tr>
<td>Winter</td>
<td>$Y 0$</td>
<td></td>
<td>79</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td></td>
<td>252</td>
</tr>
</tbody>
</table>
occurrence appears not only on geomagnetically very active days but also on geomagnetically quiet days.

5. Discussions and Conclusions

Investigations of spread $F$ characteristic variations at midlatitude and equatorial latitude have been conducted independently in the past. Recently, an intensive study has been made to compare the midlatitude and equatorial latitude spread $F$ characteristics (Bowman, 1984b). In low solar activity, similar diurnal and annual variations of spread $F$ occurrences have been found between mid-latitude and equatorial stations. The sunspot cycle variations of post-midnight spread $F$ occurrence was also found to be similar at both mid-latitude and equatorial stations (Bowman, 1984b). These results lead Bowman (1984b) to propose a model that the primary spread $F$ structures for mid-latitudes as well as equatorial regions are large scale wave-like structures; and the small scale plasma instabilities in plasma depletions or plasma depleted bubbles would simply increase the diffuseness of the equatorial spread $F$ echoes. It has also reported that the precedence of satellite traces in the ionogram is a necessary condition for the generation of the irregularities giving rise to the range spread $F$ at equatorial station Fortaleza (Abdu et al., 1981a).

The mechanism of generation of equatorial spread $F$ has been studied by many workers (e.g. Kelley, 1979; Kelley and McClure, 1981; Ossakow, 1979a, b, 1981). The equatorial spread $F$ irregularities occur at regions of steep electron density gradients associated with plasma depletion or bubbles in the equatorial ionosphere (McClure et al., 1977) which is probably generated by Rayleigh-Taylor instability mechanism and, perhaps, also the gradient drift mechanism operating on an initial perturbation or seed in the ionosphere at the bottom side of $F$ layer of the equatorial ionosphere (e.g. McClure et al., 1977; Aarons et al., 1980; Tsunoda et al., 1982; Basu et al., 1983; Chen et al., 1983). It has been established that, after sunset, the equatorial irregularity regions develop from the bottom side of the ionosphere. Once these irregularities are triggered, they will cause a plasma depletion or depleted plasma bubble which rises into region above the peak of $F2$ layer extending to well over 1000 km in altitude. Such an irregularity usually occurs in field aligned clouded patches and conjugates over north-south distances of about 3000 km (Weber et al., 1982, 1983), and drifts eastwards with a velocity ranging from 30 to 300 m/s (Woodman, 1972; Basu et al., 1977; Aarons et al., 1980). The field aligned, banana shaped plasma depletions have also confirmed by topside sounder measurements on ISIS (Dyson and Benson, 1978); plasmaprobe measurements aboard ESRO 4 (Heron and Dorling, 1979); steerable radar at Kwajalein (Tsunoda, 1980a, b); and in situ measurement by DMSP $F2$ and $F4$ satellite (Young et al., 1984). These irregularities give rise to spread $F$ echoes in ionograms; plumes in the backscatter echoes and scintillations associated with ionospheric electron content depletions.

The occurrence of such plasma depletions or bubbles have been observed at several degree north or south of magnetic dip equator by use of the topside ionospheric sounder on board the Ionosphere Sounding Satellite b (Maruyama and
MATUURA, 1984); and at equatorial anomaly crest (KLOBUCHAR et al., 1978; KLOBUCHAR and AARONS, 1980; HUANG, 1985) and even near the northern region of the equatorial anomaly crest (KOPARKAR and RASTOGI, 1984) by beacon satellite technique. All of these results seem to show that the spread F echoes in the ionogram at equatorial anomaly crest are not only due to irregularities generated locally at equatorial anomaly crest but also due to irregularities inside the field aligned banana shaped plasma depletions or bubbles which extends from the equator to the equatorial anomaly crest and even beyond.

A new category of equatorial F region plasma irregularities other than plasma depletions or bubbles, being revealed as nearly sinusoidal waves in the ion number density and called as bottom side sinusoidal (BSS) irregularities, has been identified by VALLADARES et al. (1983). These irregularities are observed mostly in the bottoms ide ionosphere at night in a belt extending approximately ±12° from the dip equator and up to 7500 km or more in the east-west direction, and can exist from soon after sunset until after sunrise. Nighttime equatorial ionograms frequently exhibit either range type or frequency type spread F (COHEN and BOWLES, 1961; CALVERT and COHEN, 1961) with latter type resulting from the decay of former type (RASTOGI, 1980). A coincidence between the presence of bottomside sinusoidal and of frequency type spread F on Huancayo ionograms (VALLADARES et al., 1983); and an association between frequency spread F at Huancayo and BSS produced scintillations without beacon satellite ionospheric total electron (TEC) depletions at Peru (DAS GUPTA et al., 1983) have been reported. The result obtained by VALLADARES et al. (1983) that TEC depletions are associated with range spread F; and bottom side sinusoidal (BSS) irregularities are associated with frequency spread F has also been confirmed at equatorial anomaly crest (HUANG, 1985).

In this report, the spread F data obtained for every 15 minute interval at Taipei and Chungli during the period from 1960 to 1982 were used to analyze the seasonal and solar cycle variations of frequency and range type spread F at the equatorial anomaly crest. By use of superposed epoch method, the geomagnetic activity effects on the occurrences of frequency and range spread F were also analyzed. The major findings are summarized as follows:

1. The percentage occurrence of frequency spread F was much larger than that of range spread F except for equinoxes in high and medium solar activities. The nocturnal variation patterns of range and frequency spread F occurrences are different. There seem two different sources: the former seems to be associated with the irregularities inside the field aligned banana shaped plasma depletion which extends from the equator to the equatorial anomaly crest; and the latter one seems to be generated, perhaps, locally and further study is required.

2. The seasonal and the nocturnal variation patterns of the occurrences of frequency and range type spread F vary with solar activity. The appearance of two maxima in equinoxes of range spread F occurrence at high solar activity also seems to show the transportation of irregularities from the equator.

3. A hysteresis variation was found in the solar cycle variation of frequency type spread F. The reason is still not known.
(4) The geomagnetic activity effects on the occurrences of frequency and range type spread $F$ were not unique but depend on season and also on solar activity. The reason is yet not known and a further study is required.

(5) Unlike the case occurring in equator, there seems no simple and direct relationship between the occurrence of spread $F$ and $F$ region virtual height, $h'F$, at the equatorial anomaly crest because of different generation mechanisms of irregularities between the equatorial anomaly crest and the equator.

REFERENCES


Seasonal and Solar Cycle Variations of Spread F