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The statistical properties of spread F observed at Hainan station during the declining period of the 23rd solar cycle

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Abstract. The temporal variations of the low latitude night-time spread F (SF) observed by DPS-4 digisonde at low latitude Hainan station (geog. 19.5° N, 109.1° E, dip lat. 9.5° N) during the declining solar cycle 23 from March 2002 to February 2008 are studied. The spread F measured by the digisonde were classified into four types, i.e., frequency SF (FSF), range SF (RSF), mixed SF (MSF), and strong range SF (SSF). The statistical results show that MSF and SSF are the outstanding irregularities in Hainan, MSF mainly occurs during summer and low solar activity years, whereas SSF mainly occurs during equinoxes and high solar activity years. The SSF has a diurnal peak before midnight and usually appears during 20:00–02:00 LT, whereas MSF peaks nearly or after midnight and occurs during 22:00–06:00 LT. The time of maximum occurrence of SSF is later in summer than in equinoxes and this time delay can be caused by the later reversal time of the $\boldsymbol{E} \times \boldsymbol{B}$ drift in summer. The SunSpot Number (SSN) dependence of each type SF is different during different season. The FSF is independent of SSN during each season; RSF with SSN is positive relation during equinoxes and summer and is no relationship during the winter; MSF is significant dependence on SSN during the summer and winter, and does not relate to SSN during the equinoxes; SSF is clearly increasing with SSN during equinoxes and summer, while it is independent of SSN during the winter. The occurrence numbers of each type SF and total SF have the same trend, i.e., increasing as Kp increases from 0 to 1, and then decreasing as increasing Kp. The correlation with Kp is negative for RSF, MSF, SSF and total SF, but is vague for the FSF.

Keywords. Ionosphere (Equatorial ionosphere; Ionospheric irregularities)

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1 Introduction

The statistic properties of spread F (SF) have been studied since the spread F phenomenon on ionograms was first noticed by Booker and Wells (1938). Especially, as the equatorial spread F (ESF) named by Cohen and Bowles (1961), a kind of ionospheric irregularities with scale sizes ranging from several hundreds of kilometers to a few centimeters, often observed in the low latitude F region during the night-time, extensive studies over the last several decades have determined the main characteristics of ESF. The ESF is often associated with plasma bubbles, produced by the generalized Rayleigh-Taylor (GRT) instability which includes cross electric field instability, neutral wind effects and various drift mode instabilities (e.g., Dungey, 1956; Kelley, 1989; Sultan, 1996). ESF observations have been made through a variety of instruments over low and middle latitudes, such as ground-based ionosondes, Incoherent Scatter Radar, satellite borne topside sounders and in-situ measurements (Fejer and Kelley, 1980; Basu and Basu, 1985; Chandra, 1990; Mathews et al., 2001; Chen et al., 2006; Bhaneja et al., 2009). Their morphological characteristics at different longitudes of equatorial latitudes has been described as a function of spatial, temporal, solar cycle and magnetic activity variations (Aarons, 1993; Abdu et al., 1981, 1985, 1992; Cragin et al., 1985; Kil and Heelis, 1998). Recently several investigators have reported SF properties and ionospheric response during superstorm times (Becker-Guedes, 2004; Sahai et al., 2005; Abdu et al., 2007).

The earlier studies on the occurrence features of spread F at low latitude stations showed large longitudinal differences in the seasonal and solar cycle variations in the Peruvian, Brazilian and Indian sectors (Abdu et al., 1981; Chandra and Rasogi, 1972; Rastogi, 1980; DasGupta et al., 1982). Recently, in the Brazilian sector, the range spread F (RSF) occurrence at Cachoeira Paulista (22.5° S, 45° W, dip lat.

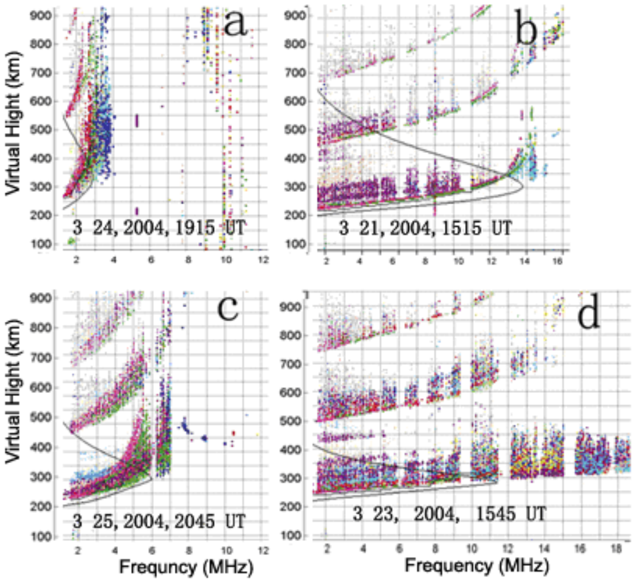

Fig. 1. Examples of the four types of spread F observed in Hainan, **(a)** for FSF, i.e., the intensity of spread increases with frequency and the critical frequencies are not definable, **(b)** for RSF, i.e., diffuse echoes at lower frequency with clear critical frequencies, **(c)** for MSF, which is mixed by FSF and RSF, and **(d)** for SSF, defined details in paper.

12.8° S) peaks at December to the solstice (summer) during high sunspot years (Chandra et al., 2003). In the Indian sector, Chandra et al. (2003) analyzed the spread F recorded by the Ahmedabad ionosonde (23.0° N, 72.4° E, dip lat. 14.0° N), and found that the occurrences of RSF is maximum at equinoxes, moderate in winter, and minimum in summer during high sunspot years. For the frequency spread F (FSF), they found that it appears frequently in summer. In the western Pacific sector, Huang (1970) analyzed the data of spread F at Chung-Li (24.9° N, 121.2° E; dip lat. 14.4° N) to study the F-region irregularities. He presented that, during high solar activity, the RSF occur most frequently at equinoxes, and the FSF occurrence has a maximum in summer and a minimum in winter. These results are similar to those found by Huang et al. (1987), which examined the ionosonde data observed at Chung-Li and Taipei (25.0° N, 121.5° E) stations during 1960–1982.

As mentioned above, the spread F near the equatorial ionization anomaly (EIA) crest and low latitude in different longitudes have been investigated by many workers. However, the study on spread F using ionosonde at low latitude, especially over the south of EIA crest in East Asian region, is seldom achieved. In this paper, we have used detailed digisonde observations to examine the statistical properties of the occurrence for the spread F during the descending period of the 23rd solar cycle (from March 2002 to February 2008) at Hainan station (19.5° N, 109.1° E, dip lat. 9.5° N).

In the following sections, we first briefly describe our measurements; then we will demonstrate and discuss the seasonal and diurnal variations of SF and the relationship between SF and sunspot number (SSN) during the magnetically quiet time, and investigate the variations of SF with geomagnetic active period as well. We will compare our characteristics with similar results available in published literature. Especially, the results of the (strong) range type of spread F over Hainan station are compared with the results of the same type at Chung-Li station in Taiwan, Ahmedabad in India, at Cachoeira Paulista in Brazil, at Huancayo (12° S, 75° W, dip lat. 1.7° S) and Jicamarca (11.95° S, 76.87° W, dip lat. 1° N) in Peru.

2 Data presentation

Since the DPS-4 digisonde was established at Hainan station in March 2002, ionograms were recorded at 15-min interval from March 2002 to February 2008 comprising a database of about 200 000 observations. Each detectable presence of frequency spread F, range spread F and mixed spread F (MSF) is just the same as shown by Cohen and Bowles (1961). Furthermore, another detectable presence of strong range spread F (SSF) in low latitude (the relevant ionograms are shown in Plate 1 in the paper of Sales et al., 1996) is indicative of equatorial topside plasma bubble irregularities (Abdu et al., 1983a, b; Whalen, 2002). Here, the SSF in Hainan is identified by two criteria, i.e., RSF following sunset that extends to such a high frequency (usually greater than 8 MHz) in the ionogram that it obscures measurement of *fo*F2 as reported in 15-min values, and its duration of at least 1 h. Figure 1 shows examples of the four types of spread F observed at Hainan station. In Fig. 1, (a) is for FSF, i.e., the intensity of spread increases with frequency and the critical frequencies are not definable, (b) is for RSF, i.e., diffuse echoes at lower frequency with clear critical frequencies, (c) is for MSF, which is mixed by FSF and RSF (Cohen and Bowles, 1961), and (d) is for SSF, as defined above. These four types of SF were first classified in 2006 in COSPAR meeting at Beijing. At the same time, Chen et al. (2006) have also reported their four types of SF (Fig. 2 in their paper) observed by digisonde at Jicamacar, named as FSF-I, RSF-I, FSF-II, and RSF-II, which are the same as the FSF, RSF, MSF, and SSF, respectively.

3 Results and discussion

The database enables determination of both the seasonal and half solar-cycle variations of low latitude spread F events at Hainan station. These variations can also be investigated as a function of geophysical indices such as magnetic activity index (Kp), 10.7 cm solar radio flux index (F10.7) and sunspot number. This section presents statistically significant patterns in the diurnal, duration and occurrence probability of each type SF in Hainan region.

3.1 Half solar-cycle variation of SF

The month and year average of F10.7 index and the percentage of duration of each type SF to the total SF duration in each year (which is from March to February of next year) are shown up and down in Fig. 2, respectively. From Fig. 2, we can see that total spread F duration is not decreasing as the average F10.7 is declining from solar maximum (2002) to solar minimum (2007). An interesting result is that the duration of SF in 2002 (high solar activity year) seems equal to the duration of SF in 2007 (low solar activity year). The more duration is about 600 h in 2002 and 2007, while the less duration of SF is about 400 h in 2003 and 2006. As for each type SF, except in 2003, the duration of SSF and RSF (MSF) are almost decreasing (increasing) as the F10.7 index is declining from 2002 to 2007, while the duration of FSF is increasing from 2002 to 2005 and then decreasing from 2005 to 2007.

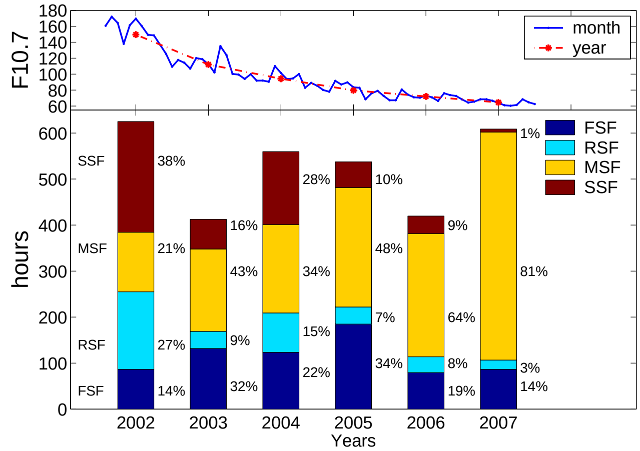

Fig. 2. Each type SF duration, total SF duration and the percentage of each type SF in total SF duration (hours) at Hainan station during the period from March 2002 to February 2008 (bottom side). The monthly and annual average of F10.7 index variations during the same period (top side).

3.2 Diurnal and seasonal variations of SF

We have divided our measurements into three seasons representing equinoxes (March–April and September–October), winter (November–February), and summer (May–August). The results of diurnal and seasonal variations in digisonde spread F was reported by Wang et al. (2008) based on the same digisonde data from March 2002 to February 2005. For a detailed study of spread F occurrence from March 2002 to February 2008, we have examined the nighttime (18:00–06:00 LT) variation in relative occurrence during the magnetic quiet conditions (the 0–6 h average Kp is less than 3- before sunset (∼18:00 LT)) for each type SF for the different seasons in the Fig. 3. The relative occurrence is the number of each type SF in a quarter (15-min) divided by the number of observed ionograms in the quarter for the given season. This relative occurrence is little different from the mean nocturnal occurrence rate used in Wang et al. (2008) which is the number of each type SF in an hour divided by the number of the days for the season.

In the Fig. 3, the dash line, dotted line, dash-dot line, and solid line denote the relative occurrence rate of FSF, RSF, MSF, and SSF during the equinoxes, summer and winter, respectively. From Fig. 3, we can see that for the equinoxes, in 2002 (high solar activity year) the relative occurrence of SSF is prominently higher than that of the other type SF from 20:00 LT to 02:00 LT, and has a maximum value of about 68% at 22:00 LT. The relative occurrence of MSF is higher than that of the other type SF after 02:00 LT and has a maximum value of 24% at 03:15 LT. The relative occurrence of RSF also mainly occurs from 20:00 LT to 02:00 LT and has a maximum value of 13% at 24:00 LT, while the relative occurrence of FSF is very low in night. In 2003–2004 (medium solar activity years), in general, the relative occurrence of each type SF is lower than that in 2002. Concretely, the relative occurrence of SSF is also outstandingly higher than that of the other type SF from 20:00 LT to 02:00 LT and has a maximum value of about 22% at 21:15 LT. The relative occurrences of FSF, RSF and MSF are very low (less than about 7%) all night. In 2005–2007 (low solar activity years), the relative occurrence of MSF is higher than that of the other type SF after 23:00 LT and has a maximum value of about 20% at 00:45 LT, whereas, the relative occurrences of FSF, RSF and SSF is very low (less than 7%) at nighttime.

For the summer, in 2002 the RSF and SSF mainly occur from 20:00 LT to 02:00 LT with a peak value of about 15% at 23:00 LT and 19% at 23:45 LT, respectively. The relative occurrences of FSF and MSF are very low (less than 6%) all night. In 2003–2004, however, the relative occurrences of FSF and MSF are higher than that of RSF and SSF, and their maximum values are about 12% at 05:15 LT and 20% at 01:15 LT, respectively. The higher occurrence rates of FSF and MSF also continue in 2005–2007, especially, the occurrence of MSF is outstanding from 22:00 LT to 06:00 LT with a peak value of about 48% at 01:15 LT. For the winter, the relative occurrence of each type SF is very low (less than 5%) from 2002 to 2007, except in 2005–2007 the MSF occurs after midnight with a peak value of about 15% at 03:45 LT.

From the above analysis, the following points about relative occurrence of SF at Hainan station may be noted:

1. In high solar activity year, the SSF is the most outstanding irregularities phenomenon in the four types of SF. The first onset of SSF during equinoxes is around 20:00 LT with the relative occurrence increasing rapidly to reach maximum nearly 70% with ∼2 h and SSF disappears after 02:00 LT, whereas during summer the first onset is the same but with the relative occurrence

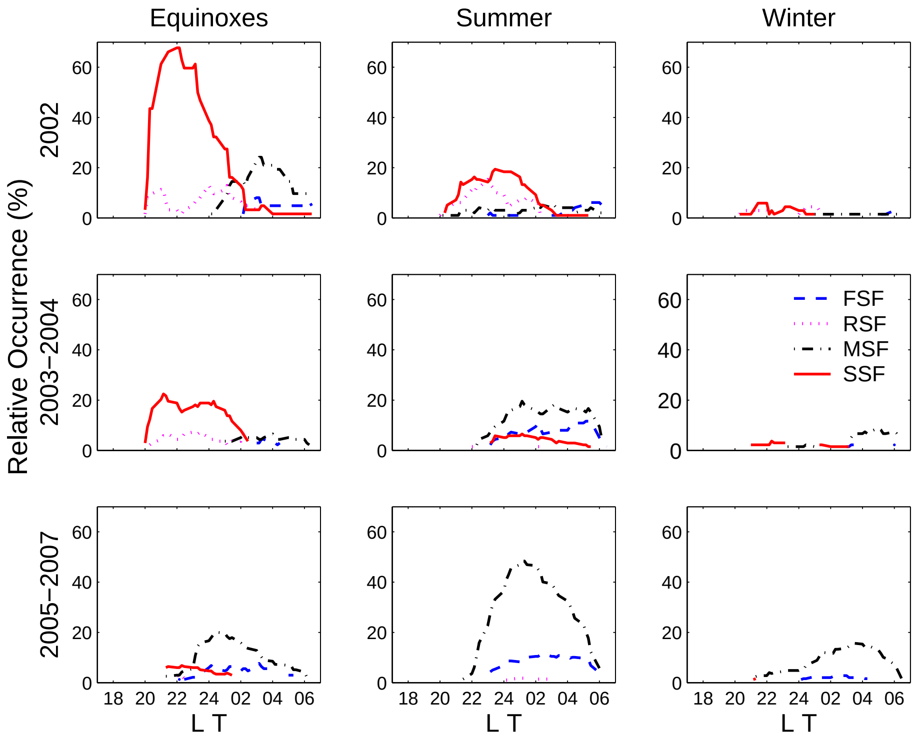

Fig. 3. The nighttime relative occurrence of each type SF observed at Hainan station in the different seasons during the magnetically quiet conditions from high solar activity year (2002) to low solar activity year (2005–2007). The 2003–2004 is the middle solar activity year.

increasing slowly to reach maximum nearly 20% with a long time about 3.5 h and also disappears after 02:00 LT.

2. In medium solar activity years, the SSF and MSF are the more outstanding irregularities than the others during equinoxes and summer, respectively. During equinoxes, SSF appears from 20:00 LT to 02:00 LT and reach the relative occurrence maximum 22% (lower than that in 2002) at about 21:15 LT, whereas in summer and winter SSF occurs very low. During summer, MSF is in the position of leading role, the onset of which is around 22:00 LT with the relative occurrence increasing slowly to reach maximum nearly 20% at about 01:00 LT, and it can last near the sunrise.

3. In low solar activity years, the MSF is the only active irregularity. The MSF appears from 22:00 LT to 06:00 LT, and reach the relative occurrence maximum about 20% at 00:45 LT during equinoxes, about 45% at 01:15 LT during summer, and about 15% at 03:45 LT during winter, respectively.

4. In totally seasonal variations, the MSF and SSF are the outstanding irregularities in Hainan, MSF mainly occurs during summer and low solar activity years, whereas SSF mainly occurs during equinoxes and high solar activity years.

There are many authors who have studied the diurnal and seasonal variations of SF through analyzing different data observed by digisonde and other instruments at the different sites during the different periods (e.g., Huang, 1970; Rastogi, 1980; Abdu et al., 1981, 1983a; Argo and Kelley, 1986; Fejer et al., 1999; Whalen, 2002; Chandra et al., 2003; Chen et al., 2006; Bowman and Mortimer, 2008). In the seventies of last century, using the vertical sounding data at Chung-Li station (which is near the crest of the equatorial ionization anomaly and is adjacent to Hainan station) from 1965 to 1969, Huang (1970) has shown that FSF is maximum at 03:00–05:00 LT during summer and at low solar activity years, whereas RSF is maximum at 21:00–01:00 LT during equinoxes and at high solar activity years. Note that the FSF (RSF) in their paper consists of FSF and MSF (RSF and SSF) in our paper. Their results about FSF and RSF distributions are similar to diurnal and seasonal variations of MSF and SSF at Hainan station, respectively. However, the maximum of relative occurrence of MSF and SSF at Hainan station are higher than that of FSF and RSF at Chung-Li, respectively. This difference may be due to the latitude difference between two stations, as Abdu et al. (1983a) suggested that the plasma bubble rise velocity over the dip equator determines the RSF development and extendibility to latitudes away from the dip equator.

In order to further study the latitude difference, we can also make a comparison of occurrence distributions of SF

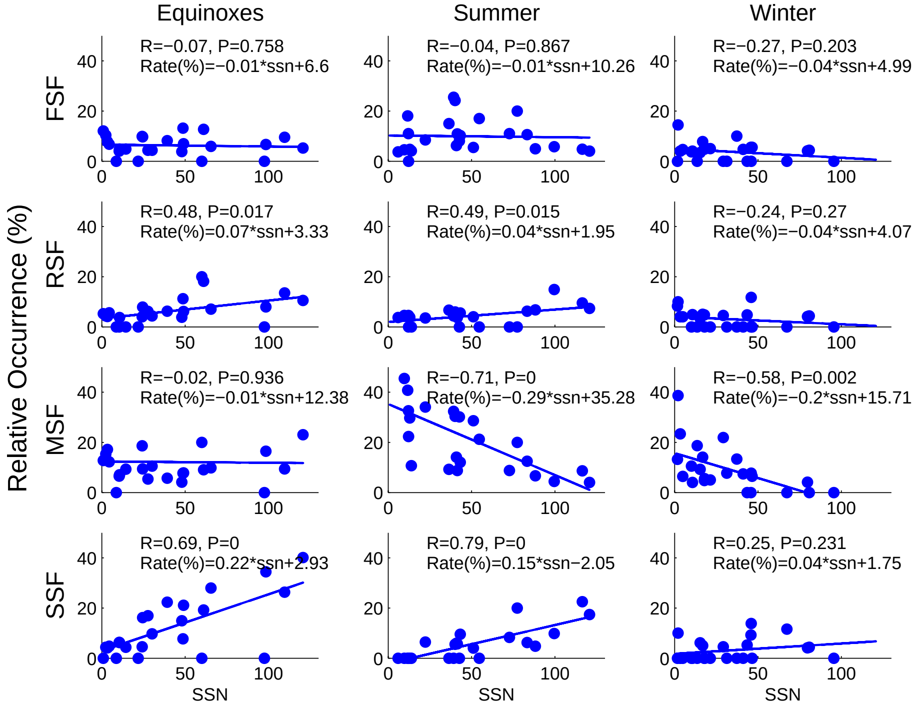

Fig. 4. Mean nocturnal monthly relative occurrence of each type SF observed at Hainan station during the magnetically quiet conditions in the different seasons from March 2002 to February 2008 scatter (big dots) with SSN. The straight lines denote the least squares fit to the relative occurrence of each type SF with SSN. The correlation coefficients R, P-values and fitting curve functions are also shown.

over Hainan station with that over Huancayo station located at nearly dip equator. Figures 3 and 4 (taken from Rastogi, 1980) show that RSF reaches the maximum diurnally at 21:00 LT (earlier than that of SSF) and seasonally around November and February (SSF more occurs in equinoxes) during high and low solar activity years (high solar activity years for SSF), a secondary peak develops around 05:00 LT during winter (no secondary peak for SSF during any season). At the same time, they showed that FSF reaches the maximum diurnally at 00:00 LT (earlier than that of MSF) and seasonally around summer (similar to MSF) during high and low solar activity years (low solar activity year for MSF). We can see that the onset and peak time (maximum value) of SF in Huancayo are usually earlier (higher) than that of SF in Hainan. We can understand this from physics. The plasma bubble mainly occurs in the dip equator region and can extend to low latitude region. The RSF development and extendibility to latitudes away from the dip equator is determined by the plasma bubble rise velocity (Abdu et al., 1983a). If the bubble rise velocity is lower, the RSF will not extend to higher latitude region or appear a lower peak value in the higher latitude region. Because it extends from the dip equator to low latitude region, if the RSF is observed in the different low latitude stations, the RSF occurrence time at higher latitude will be later than that at lower latitude. The Huancayo station is closer to dip equator than Hainan station, therefore, in general the onset and peak time of SF in Huancayo are earlier than that in Hainan.

Recently, Chen et al. (2006) reported the nighttime variations in the relative occurrence of four types of SF at Jicamarca station during solar maximum from April 1999 to March 2002. They showed (in their Fig. 3) that the values of the nighttime occurrence for each type of SF in summer were slightly higher than that in equinoxes. However, the value of the nighttime occurrence for SSF in summer is remarkably lower than that in equinoxes during high solar activity years. This difference may be also due to the different latitude. In fact, Fejer et al. (1999) found that during the quiet magnetic activity and high solar flux levels (in their Fig. 6), the occurrence of strong SF and the seasonal average of maximum prereversal $\boldsymbol{E} \times \boldsymbol{B}$ drift were greatest in equinoxes, less in summer, and least in winter, which is consistent with the results of SSF in this study. Although the strong SF in paper of Fejer et al. (1999) was identified by the strong radar echoes with wider scattering layer at higher altitude (thickness excess of ∼100 km), Whalen (2002) described it as strong bottowside spread F (BSSF) which is similar to SSF in this paper. The time of maximum occurrence of SSF is later in summer than in equinoxes. This time delay may be caused by the later reversal time of the $\boldsymbol{E} \times \boldsymbol{B}$ drift in summer (Fejer et al., 1999; in their Fig. 7). The $\boldsymbol{E} \times \boldsymbol{B}$ drift is the major factor for SSF development.

Table 1. Ratio of occurrence number of SF to observed days during the Quiet(Kp$<3^-$), Medium($3^- \leq$Kp$<6^-$), Disturb($6^- \leq$Kp), and Non-Quiet($3^- \leq$Kp) conditions.

Ratio	FSF	RSF	MSF	SSF	Total SF
Quiet	0.1717	0.1080	0.3247	0.1452	0.7496
Medium	0.1535	0.0745	0.2393	0.0903	0.5576
Disturb	0.2083	0.0139	0.2778	0.0972	0.5972
Non-Quiet	0.1612	0.0660	0.2447	0.0913	0.5631

Chandra et al. (2003) has made a comparative study of the occurrence features of SF at anomaly crest region in the Indian and American Longitudes. They concluded that FSF (RSF) over Ahmedabad (AH, India) is most frequent during summer (equinoxes) of low sunspot years (high sunspot years). However, the occurrence of RSF over Cachoeira Paulista (CP, Brazil) is more frequent during summer for both low and high sunspot years. The features of SF at Hainan station are similar to distributions of SF over AH and different from the characteristics of SF over CP. This longitude difference is contributed to the difference of declination angle between CP and Hainan station, which may be explained by the Abdu et al. (1981) and Tsunoda (1985).

Certainly, the diurnal and seasonal variations of SF at the different regions and during the different periods are very complicated, though many results of them have been achieved in quality and quantity statistical analysis. More detailed studies need to be conducted. Especially, the data sets comparing here belong to different epochs, so the consistency of this contrasting features needs to be checked by comparing concurrent data sets from the different sites.

3.3 SF variations with SSN

The Fig. 4 illustrates the mean nocturnal monthly relative occurrence of each type SF observed at Hainan station during the magnetically quiet conditions in the different seasons from March 2002 to February 2008 scatter with SSN. Each big dot presents the nocturnal monthly relative occurrence of SF. The straight lines denote the least squares fit to the relative occurrence of each type SF versus SSN. The correlation coefficients R, P-values and fitting curve functions are also shown. When the P-value is less than 0.05, the correlation between SF and SSN is significant. For the FSF, the relative occurrence is independent of SSN during each season. For the RSF, the relative occurrence is increasing slowly with SSN during the equinoxes and summer and is no relationship with SSN during the winter. For the MSF, the relative occurrence is significant dependence on SSN during the summer and winter, while it does not relate to SSN during the equinoxes. For the SSF, the relative occurrence is clearly increasing with SSN during equinoxes and summer, while it is independent of SSN during the winter.

Regarding the comparative study with AH (Chandra et al., 2003), the occurrence of FSF at AH remains independent of SSN for all three seasons (the same as FSF in Hainan), but the occurrence of RSF at AH with SSN showed a clear increase with SSN during equinoxes and winter but slight decrease during summer (a little different from RSF at Hainan). Therefore, the SSN dependence is different for different season and different latitude.

3.4 SF variations with Kp

The Fig. 5 shows the observed occurrence number of each type SF at Hainan station in the different seasons from March 2002 to February 2008 plotted as a function of Kp determined as the average during the 6 h prior to sunset (the same as Fejer et al., 1999), and the sum numbers of column, row and total of SF are also shown. During equinoxes, the occurrence numbers of FSF and SSF are pronounced decrease as Kp increases. The occurrence numbers of RSF and MSF are little increasing as Kp increases from 0 to 1, and then decrease with increasing Kp. The total numbers of SF during equinoxes is decreasing as increasing Kp. During summer, the occurrence numbers of each type SF have the similar trend, i.e., increasing as Kp increases from 0 to 1, and then decreasing as Kp increasing from 1 to 8, except for no occurrence numbers of each type SF when Kp is greater than 4. The total occurrence numbers of SF during the summer follows the same trend. During winter, the occurrence numbers of FSF, MSF and SSF have a similar trend, i.e., increasing as Kp increases from 0 to 2, and then decreasing as increasing Kp, except for no occurrence numbers of each type SF when Kp is greater than 4. However, the occurrence numbers of RSF increases with Kp increasing from 0 to 1, and then decreasing as Kp increases. The total occurrence numbers of SF during winter has a same trend as MSF. The reason is that the occurrence numbers of MSF is predominant over total occurrence numbers of SF during this season. In totality, from the bottom row of Fig. 5, we can see that the occurrence numbers of each type SF and all SF have the same trend, i.e., increasing as Kp increases from 0 to 1, and then decreasing as increasing Kp.

Note that the horizontal axis Kp=0 actually only includes two kind values, i.e., absolute quiet 0 and 0+, while the other Kp includes three kind values, for example, Kp=1 consists of 1−, 1 and 1+. Considering this situation, we calculate the ratio of occurrence number of each type SF to total observed days during the different magnetic activity conditions in Table 1. The ratios for the RSF, MSF, SSF and total SF (except FSF) are higher during the quiet magnetic activity than during the non-quiet, medium and disturb magnetic activity, we can say that the relation between the occurrence number of total SF and magnetic activity Kp index is an inverse association. In fact, Rama Rao and Rao (1961) reported a similar inverse relationship between the SF and magnetic activity at an equatorial station. Chandra and Rastogi (1972) further

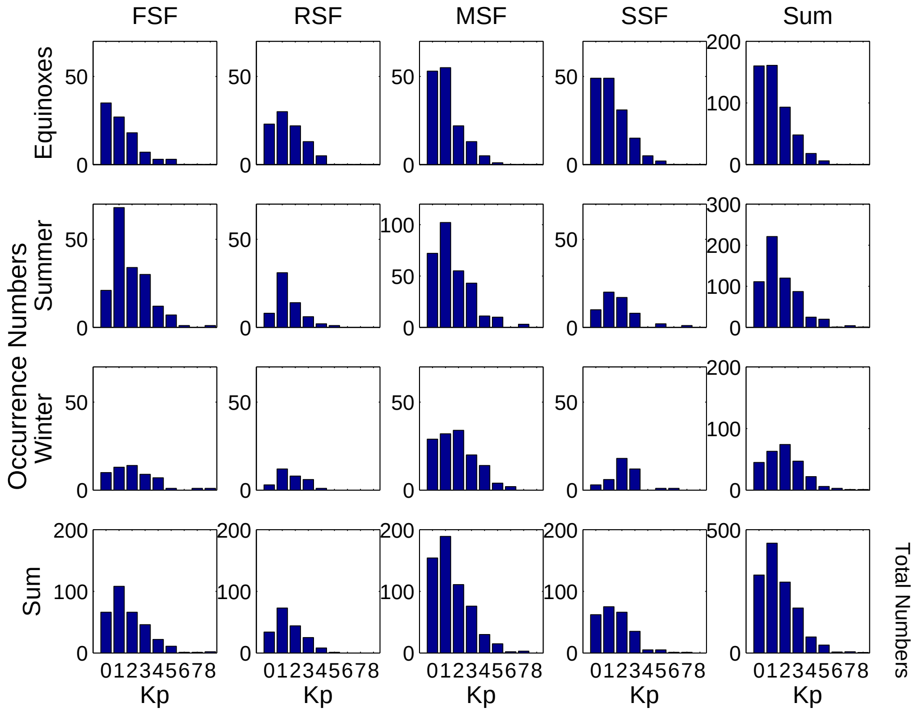

Fig. 5. Observed occurrence number of each type SF at Hainan station in the different seasons from March 2002 to February 2008 plotted as a function of kp determined as the average during the 6 h prior to sunset, i.e., about 14:00–20:00 LT (LT=UT+8). The sum numbers of column, row and total of SF are also shown.

confirmed that SF is generally suppressed by increased magnetic activity. Bowman (1995, 1998) has detected this inverse association by a series of analyses at high levels of statistical significance. Recently, many authors used the recordings from all kinds of instruments, such as airglow (Sobral et al., 2002), satellites (Su et al., 2006), and scintillations (Ray and DasGupta, 2007), to find well-defined inverse relation between SF and magnetic activity. The analysis here has shown over Hainan region the inverse relationship between total SF and magnetic activity as well. The more detailed analysis for each type of SF, for example, the relation between pre-midnight and post-midnight occurrence numbers of each type of SF and magnetic activity, needs further study in the future as the accumulation of data observed in Hainan increases.

4 Conclusions

In this study, the statistical features about spread F observed by the DPS-4 digisonde at Hainan station during the declining period of the 23rd solar cycle from March 2002 to February 2008 have been analyzed. Spread F were classified into four types, i.e., FSF, RSF, MSF, and SSF. They show completely different but quite simple characteristics. The main points are as following: (1) The MSF and SSF are the outstanding irregularities in Hainan, MSF mainly occurs during summer and low solar activity years, whereas SSF mainly occurs during equinoxes and high solar activity years. The SSF has a diurnal peak before midnight and usually appears during 20:00–02:00 LT, whereas MSF peaks nearly or after midnight and occurs during 22:00–06:00 LT. The time of maximum occurrence of SSF is later in summer than in equinoxes and this time delay may be caused by the later reversal time of the $\boldsymbol{E} \times \boldsymbol{B}$ drift in summer (Fejer et al., 1999). (2) The SSN dependence of each type SF is different. For the FSF, the relative occurrence is independent of SSN during each season. For the RSF, the relative occurrence is increasing slowly with SSN during the equinoxes and summer and is no relationship with SSN during the winter. For the MSF, the relative occurrence has significant dependence on SSN during the summer and winter, while it does not relate to SSN during the equinoxes. For the SSF, the relative occurrence is clearly increasing with SSN during equinoxes and summer, while it is independent of SSN during the winter. (3) The occurrence numbers of each type SF and all SF have the same trend, i.e., increasing as Kp increases from 0 to 1, and then decreasing as increasing Kp. Generally, the correlation with Kp is negative for RSF, MSF and SSF, but is vague for the FSF. Overall, the total SF has an inverse association with Kp. This relationship is similar to the results reported by many authors before.

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