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Low Latitude Spread-F Occurrence during June Solstice and September Equinox of Sunspot Minimum

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Ionosonde data from four low-latitude stations cutting across the two hemispheres have been employed to study the occurrence of spread-F. Quiet time ionograms for two months representing two seasons; June solstice and September equinox of the year 2010, a year of low solar activity (Rz = 16) were utilized. Results showed that the low latitude nighttime ionosphere is characterized by three different types of spread-F; range spread F, frequency spread F and mixed spread F. Spread F irregularity exhibits diurnal, seasonal and latitudinal dependence. Strong dependence on the magnetic dip latitude was observed in this study. At all the four stations, range spread-F (RSF) dominates the post-sunset period (1800 – 2200 LT) while the frequency type (FSF) dominates the post midnight period (0200 – 0400 LT). In general, the RSF has highest occurrence rate at all stations. The study revealed that occurrence of ESF is highest at Ilorin and lowest at Kwajalein with 33.9% and 16.8% respectively. Analysis of the total percentage occurrence of spread F revealed that the phenomenon exhibit hemispheric asymmetry during June solstice.

1. Introduction

Spread-F occurrence is an age-long topic of interest due to its potential to cause signal degradability or total loss of signal. It is an irregularity which is noticed on ionograms when an ionosonde attempts to measure the reflection height of the F region. If this exercise is being done at the same time with the period of occurrence of this irregularity, the resulting ionogram echo trace will be spread out in either frequency or range due to the multiple reflection paths created by the turbulent ionosphere, hence the term spread F [1].

Spread-F is observable on nighttime ionograms. It is a nighttime event which is triggered by the ionospheric instabilities after sunset and through the midnight when the F-layer is moved to high altitude through the action of the vertical plasma drift which results from the perpendicular action of E x B force that dominates the equatorial nighttime ionosphere. Generalized Rayleigh-Taylor instability has been identified as the primary mechanism for the generation of post-sunset plasma bubbles [2]. It is known that spread-F occurrence is greater around the low-latitude and high-latitude than the mid latitude [3,4] while it has latitudinal dependency in the EIA region [4]. Its rate of occurrence decreases away from the magnetic equator; while the equatorial region experiences a dominant occurrence of spread-F, its occurrence at other regions are minimal, thus the term Equatorial Spread-F (ESF) [4]. Rayleigh-Taylor instability could be suppressed by trans-equatorial neutral wind [5,6] due to the increasing Pedersen conductivity [7].

ESF are of different types (e.g. Wang et al. [8]) and different sizes; those observable from bottom-side-probing radars are in the magnitude of 100metres to a few kilometers and are therefore referred to as intermediate-scale ESF irregularities [9]. It has been observed by Zhang and Xiao [4] that magnetic declination played important role in exciting rapid variability in plasma density distribution and that the latitudinal extent of spread F ranged between $20^oN – 12.4^oS$. The occurrence of spread F phenomenon has also been reported to show seasonal, solar cycle and geomagnetic dependence. For instance Spread-F occurrence has been reported to be highest in the equinoxes especially during high solar activity epoch and lowest in June [10]. Seasonal variation in ESF is attributed to the seasonal variation in the magnitude of the evening pre-reversal enhancement (PRE) which is lowest during June solstice. Rayleigh-Taylor (RT) instability is known to be a major initiator of spread-F and it is triggered when the height of the F-layer reaches or surpasses a threshold. The lifting of the F-layer height is caused by the action of the vertical drift and lifting is most prominent after sunset due to the

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enhancement in the eastward electric field just before reversal, called the pre-reversal enhancement (PRE). However, high spread-F occurrence has been observed during June solstice in solar minimum due to other ionospheric background conditions such as the traveling ionospheric disturbances (TID) [11]. The geomagnetic activity dependence of ESF has also been established by several authors e.g., Bowman and Mortimer [12], Hysell and Burcham [13] Becker-Guedes et al. [14]. ESF can be broadly classified into three namely frequency spread F (F-ESF) in which there is spread of plasma across the frequency (frequency dependent); range spread F (R-ESF) in which the spread is across the height (height dependent) and mixed spread F (M-ESF) in which there is a mixture of both. There are limited published works on spread-F occurrence.

However, there are renewed commitments to understanding the appearance of these irregularities. This present study is aimed at quantifying the extent of different types of ESF occurrence at different latitudes and their period of occurrence.

2. Data and Method of Analysis

Ionograms recorded using ionosondes located at four low latitude stations (see Table 1) which were retrieved from the Global Ionospheric Radio Observatory (GIRO) (http://car.uml.edu/common/DIDBFastStattionList) during the year 2010, a year of low solar activity was employed in this study. GIRO provides data contributed from global network of ionosondes [15]. Quarter-hourly ionograms available for all the quiet days during the month of June (representing June solstice) and September (representing Sept. equinox) were used. Each ionogram was manually examined and the occurrence and type of ESF identified. The occurrence percentage for the particular ESF was then estimated using the relation:

$$\%Occurrence\ per\ hour = \frac{number\ of\ ionograms\ with\ ESF\ in\ the\ hour}{total\ number\ of ionograms\ in\ an\ hour\ over\ the\ month} x100$$

Table 1: Geographic and magnetic coordinates of the stations

Station	Abbrv.	Sector	Geographic Lat.	Geographic Long.	Geomagnetic Lat.	Geomagnetic Long.	dip
Ilorin	ILR	African	8.5 ^{o}N	4.5 ^{o}E	10.6 ^{o}N	78.4 ^{o}E	-7.94
Saoluis	SAO	S/American	2.6 ^{o}S	315.8 ^{o}E	6.2 ^{o}N	28.2 ^{o}E	-9.14
Fortaleza	FTZ	S/American	3.9 ^{o}S	321.6 ^{o}E	4.4 ^{o}N	33.9 ^{o}E	-11.56
Kwajalein	KWJ	Pacific Ocean	9.0 ^{o}N	167.2 ^{o}E	3.8 ^{o}N	121.5 ^{o}E	16.58

3. Results and Discussion

Fig. 1 presents the percentage occurrence of ESF at the four stations under investigation during the months of June (representing June solstice) and September (representing Sept. equinox) respectively. The plots reveal that the periods of occurrence of ESF falls within post-sunset (1800 LT – 2300LT) and night-time (0000LT – 0600LT). The period and percentage of occurrence however varied from station to station and from season to season. During June solstice, ESF commenced at 1900LT at Ilorin and increased in percentage occurrence until midnight. Although all the other stations except KWJ had commencement at 1900LT, the trend and percentage occurrence varied with latitude. Percentage occurrence decreased up the latitude toward the southern hemisphere and increased up the latitude towards the northern hemisphere. The post midnight segment of the plots (Fig.1a) shows that the period and percentage of occurrence decreased with increasing latitude towards the southern hemisphere and increased towards the northern hemisphere. SAO and FTZ had occurrence between two and three hours with percentages between 20% and 0% while ILO and KWJ recorded occurrence for six hours with percentages ranging between 75% and 5%. This result confirms existing literature e.g., Zhang and Xiao [4] that ESF is latitudinal dependent.

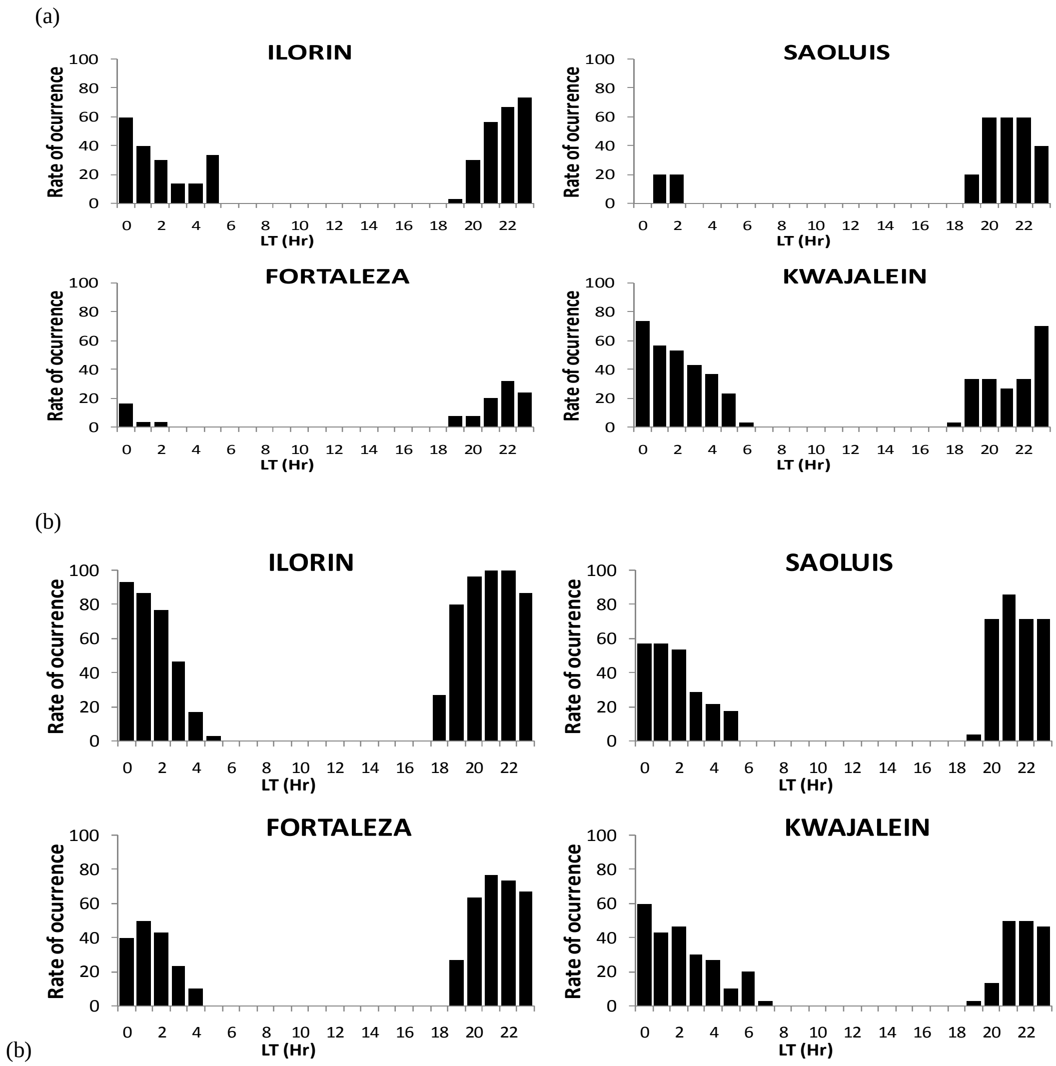

Fig.1: Occurrence rates of ESF at each hour for the four stations during (a) June solstice (upper panel) and (b) September equinox (lower panel)

Fig. 1 reveals that in addition to the diurnal and latitudinal dependence of ESF, the phenomenon is also seasonal dependent. All the stations showed evidence of increased period and percentage of occurrence of ESF. During post sunset period, ILO recorded commencement from 1800LT with increasing percentage into the midnight. It can be observed that the percentage occurrence for each hour was greater than the percentage for the corresponding hour during June solstice. This trend is the same for all the stations. The post midnight segment of the plots shows that for ILO, the period of occurrence was between 0000LT and 0500LT and the rate of decay was slower compared with June solstice. The trend decreased with increased latitude in the southern hemisphere. The situation was different in the northern hemisphere, where (at KWJ) the rate of decay was more gradual and took a longer time (eight hours as against seven hours for June solstice).

Fig.2 shows plots of the total percentage of ESF occurrence at the four stations during the two seasons under consideration. Occurrence of ESF is more prevalent during the equinox that the solstice at all the stations. The percentage of occurrence decreased with increasing latitude (from ILO to FTZ) in the southern hemisphere during the two seasons. The situation is however different as the latitude increased within the northern hemisphere; the percentage occurrence during the solstice month (about 21%) is observed to be higher than that of the equinox (about 17%). This is an evidence of hemispherical asymmetry.

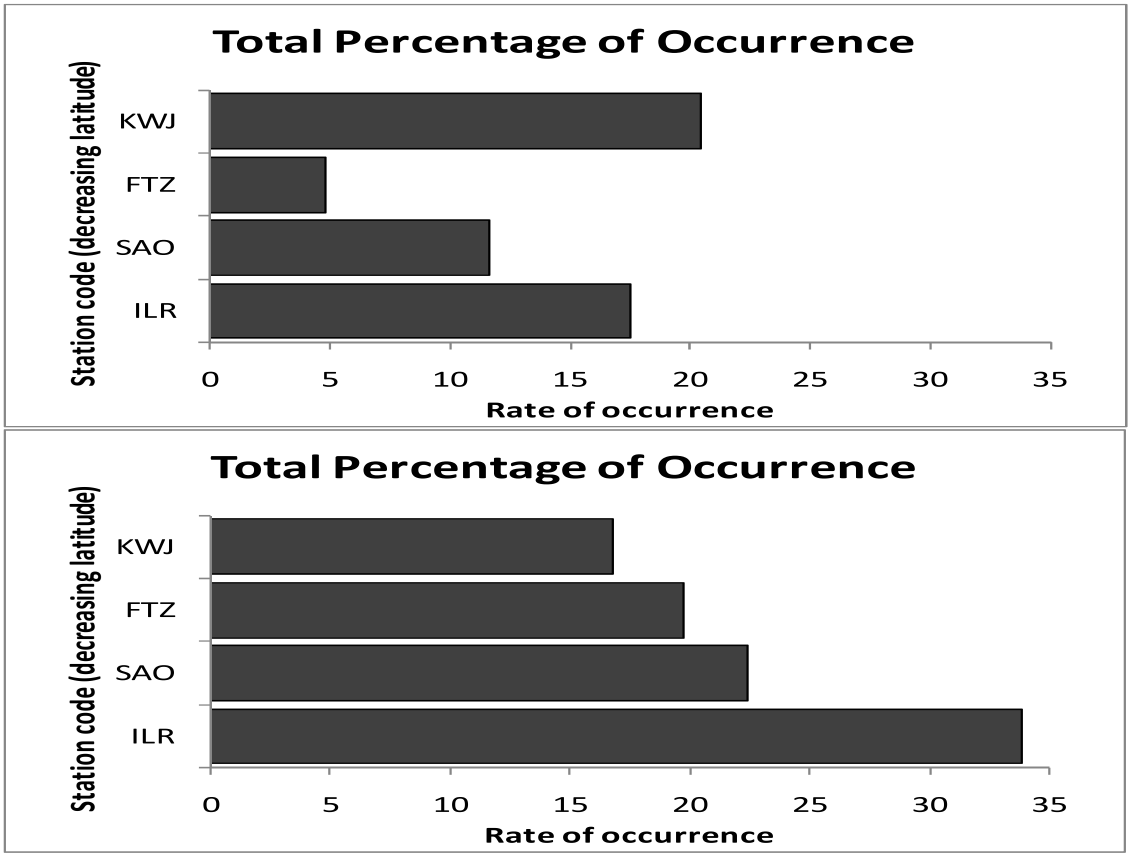

Fig.2: Occurrence of ESF across four stations in June (1st panel) and September (2nd panel)

Table 2 shows a breakdown of the type of ESF observed at the four stations during the seasons under consideration. The table reveals that of all the ESF recorded during June solstice, range spread F (RSF) was predominant at ILO, having 61.1% of occurrence compared to 13.5%and 25.4% occurrence of MSF and FSF. This is however not so as one moves away from the equator at the southern hemisphere. Both SAO and FTZ had FSF predominating with 85.7% and 55.2%, respectively. KWJ also recorded RSF as being the most predominant during the season with 45.6% compared to 17% and 37.4% for MSF and RSF. Thus there seem to be no pattern in the occurrence of the three types of ESF during June solstice. During Sept. equinox RSF predominated at all the stations with decreasing percentages as the latitude increased in the southern hemisphere while the trend was that of increase at the northern hemisphere.

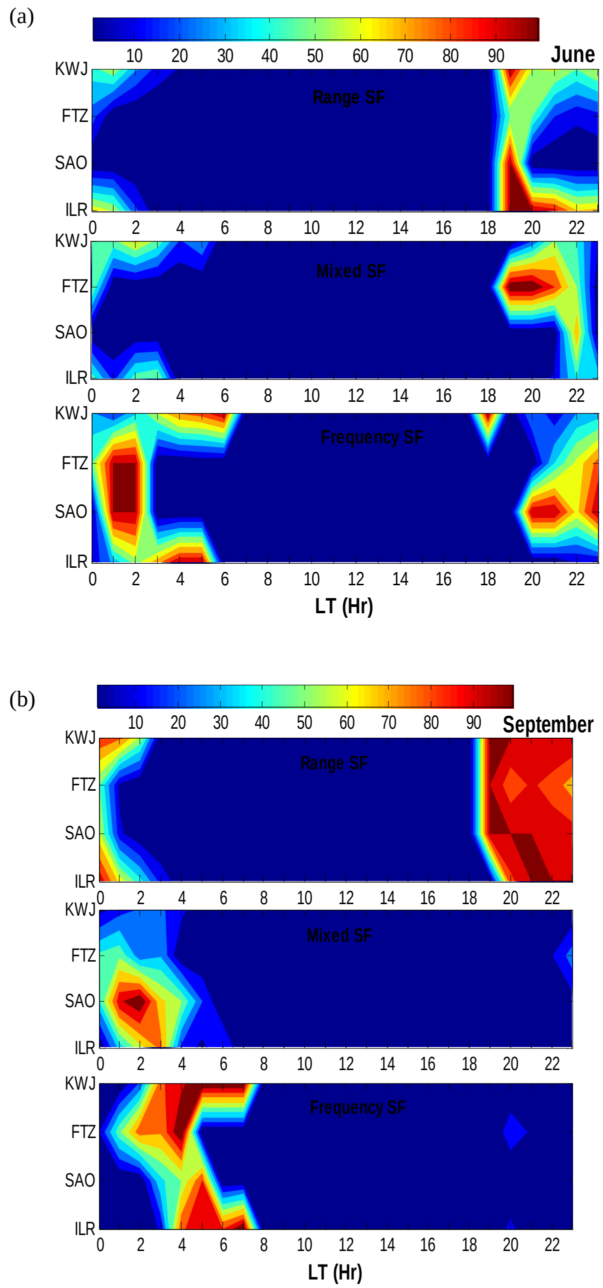

Fig.3: The contour plot of the occurrence of the different types of spread-F across the four stations in (a) June and (b) September [Upper panel – MSF; Centre panel – FSF; Lower panel – RSF]

Fig. 3 shows the contour plot for the distribution of the ESF among the three types. The plot shows that during June solstice, MSF (upper panel of Fig.3a) was predominant during post sunset hours and it decreases in percentage as one moves away from the equator in the southern hemisphere. Although only KWJ was studied in the northern hemisphere, the trend appears to be the same at both hemispheres. Frequency spread F (FSF) occurrence is concentrated at the low latitude (i.e., stations away from the magnetic equator), in this case FTZ, and the period of occurrence was post sunset. Range spread F (RSF) (lower panel, Fig. 3a) had occurrence both during the post sunset and post midnight periods at both the equatorial and low-latitudes. Percentage occurrence during post midnight period was however more than that of the post sunset period.

The situation was quite different during the equinox (Fig.3b). While high percentage occurrence of MSF predominated the post sunset period at all the stations (upper panel) the FSF and RSF were scarcely observed during the post sunset periods. The lower panel shows that the percentage occurrence of FSF decreases as one moves away from the equator at both hemispheres. These results confirm the findings of past efforts e.g., Becker-Guedes et al. [14] in which spread F occurrence was observed to have different level of occurrence for different seasons, thus leading to the classification of ESF occurrence into high occurrence, low occurrence, transition from high to low occurrence and vice versa. According to these authors, the seasonal variability in ESF is dependent on the variability of the causative factors such as the vertical drift.

Table 2: Percentage occurrence of the different types of spread-F

	June			September		
	MSF	**FSF**	**RSF**	**MSF**	**FSF**	**RSF**
Ilorin	13.5	25.4	**61.1**	20.5	16.4	**63.1**
Sao Luis	7.1	**85.7**	7.1	30.5	6.6	**62.9**
Fortaleza	24.1	**55.2**	20.7	16.9	22.5	**60.6**
Kwajalein	17.0	37.4	**45.6**	7.4	24.0	**68.6**

4. Conclusion

A statistical study of the occurrence of equatorial spread F have been done in this work using ionograms from four stations spread across the two hemispheres of the globe during June solstice and September equinox for the year 2010, a year of low solar activity. The results obtained from this study revealed that the occurrence of equatorial spread-F (ESF) varies with time of day, season and (magnetic dip) latitude. In agreement with some existing results; spread-F occurrence is strongly influenced by the dip latitude of a station, especially in the EIA region. The RSF, which is strongly related to equatorial plasma bubbles, dominates all the four stations, and its occurrence is most prominent during post-sunset and midnight periods. Our analyses revealed that spread-F occurrence varies with season, with higher percentage of occurrence in the equinoctial month for the four stations considered. The total percentage occurrence of the spread increases with decreasing absolute dip in September, while it increases with decreasing negative dip in June, these suggest that unlike September, the June spread-F occurrence shows hemispheric asymmetry. The RSF dominates Ilorin and Kwajalein while FSF dominates Sao Luis and Fortaleza in June; however, RSF dominates all the stations in September.

These results suggest that the PRE vertical drift is more responsible for the development of the RSF, while some other mechanisms such as the recombination process involving neutral wind and gravity waves may play substantial role in the occurrence of other types of spread-F.

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