Ilorin Journal of Science
Volume 4, Number 2, 2017, pp. 226 – 238 (Printed in Nigeria)
ISSN: 2408 – 4840 © 2017 Faculty of Physical Sciences, University of Ilorin
https://doi.org/10.54908/iljs.2017.04.02.003

ILORIN
JOURNAL OF SCEINCE

**ILJS-17-016**

# Occurrence statistics of Spread F at Ilorin

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## Abstract

This study is the first of its kind aimed at the statistical study of the occurrence of Equatorial Spread-F (ESF) using ionosonde data obtained with the aid of Digisonde (DPS-4) during the year 2010 at Ilorin (Geo. Lat. 8.47$^0$N, Long. 4.68$^0$E, and Dip. Lat. 7.867$^0$S): an equatorial station in the African sector. The study revealed that the ionosphere over Ilorin exhibit three types of equatorial spread-F i.e. frequency spread F (FSF), range spread F (RSF) and mixed frequency (MSF). ESF is observed to be a post-sunset and nighttime phenomenon; occurring within the hours of 2000LT and 0700LT with the range of hmF2 being between 230 and 405 km. ESF grows during the post-sunset periods and decays towards the sunrise hour. ESF is observed to be monthly/seasonal dependent. Occurrence of ESF is observed to be predominant during the equinox months. The results further show that RSF type is the most prevalent at this station.

**Keywords:** Equatorial ionosphere, Equatorial Spread-F, Plasma instability**,** F2-layer, Irregularity.

## 1. Introduction

Equatorial spread F is the name given to the nighttime irregularity observable within the equatorial ionosphere (Adeniyi *et al.*, 2017). The equatorial ionosphere has been known to be characterised by nighttime irregularities borne out of the peculiar nature of this region of the ionosphere. These irregularities which are of different scale sizes ranging from centimetres to kilometre are generated by plasma instability processes which take place during post sunset periods and are capable of causing fading and loss of lock of Global Navigation Satellite System (GNSS) signals (Abdu, 2012; Oladipo *et al.*, 2014; 2018; Adeniyi *et al.*, 2017). Although in recent times these irregularities are being studied using different techniques ranging from ground based and space borne remote sensing to in situ techniques (Abdu, 2012), the first discovery was made by Booker and Wells in 1938, using ionosonde located at Huancayo.

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The irregularity which was later named Spread F was originally observed by Booker and Wells as “diffuse echoes” from the F-region. They observed that (i) the ionogram traces showed a range of virtual heights as if the echoing region spread over a range of altitudes rather than a thin line which corresponds to the virtual height; this spread was called range spread and (ii) at other times the spread was recorded only at the high frequency end of the ionogram trace thus looking more like a spread in the frequency for a given virtual height; this was called frequency spread (Woodman, 2009). Early researchers have shown that Spread F occurs in two separate geographic regions with considerable different characteristics. These geographic regions fall within the high- and equatorial – latitudes ionospheres (i.e. regions of ionosphere located $\pm 60^0$ and $\pm 15^0$ of the geomagnetic equator) respectively. As a result, spread F have been grouped into two varieties namely; equatorial and high-latitude varieties (Wayne, 1962). Hence spread F occurrence is a function of geomagnetic latitude and local time. Spread F occurring in the equatorial and low latitude region is referred to as equatorial spread F (ESF). According to Woodman (2009), the appropriate name for this phenomenon is Equatorial F-Region Field Aligned Irregularities (FAIs) since the observation and detection of the phenomenon have been shown not to be peculiar to ionosondes alone.

Other techniques such as radio star scintillation, satellite scintillation and forward scatter have being used to study FAI. ESF are produced as a result of the rapid uplift of the F-region which leads to plasma instability in which magnetic flux tubes with reduced plasma density (plasma bubbles) and a wedge–shaped cross section rise upward from the bottomside F layer (Woodman and LaHoz, 1976; Tsunoda, 1980; Abdu *et al*., 2009). The lifting of the F-layer is caused by the action of the vertical drift, and lifting is most prominent after sunset due to the enhancement in the eastward electric field just before reversal, called the pre-reversal enhancement (PRE). Generalised Rayleigh-Taylor instability has been identified as the primary mechanism for the generation of these post-sunset plasma bubbles (Sastri, 1999, Abdu *et al*., 2009).

The Rayleigh-Taylor instability is triggered when the height of the F-layer reaches or surpasses a threshold. Since its discovery about four decades ago, several researchers have studied ESF over different sectors of the equatorial ionosphere using different techniques and have, based on observation, categorized spread F differently. For instance, Wayne (1962) categorized ESF into two categories namely (i) equatorial scatter spread F, comprising of three types and (ii) the equatorial waveguide spread F.The significant distinguishing feature between them being the presence or absence of steep striations in the traces. According to Woodman and Lahoz (1976), ESF is categorized into three namely; (i) the valley spread F, which can occur in the valley region of low electron density between the E and F layer (ii) weak bottom side spread F which is usually present in a thin layer on the bottom side post sunset density gradient and (iii) bubbles or plumes developed from the bottom side which extends from the weak bottom side region to the topside. Wang *et al*. (2008) categorized equatorial spread F into four groups namely (i) Range spread F (RSF), (ii) Frequency spread F (FSF), (iii) Mixed spread F (MSF) and (iv) Strong spread F (SFS).

This categorization has largely been dependent on the latitudinal difference in the different stations of study. Spread F variability has been broadly classified into three namely; long term variation which depends on solar activity, medium term variation which is both monthly and seasonal dependent, and short term variability lasting for a day or even less (Abdu, 2012). These three conditions are driven by different mechanisms. While the long term variation is believed to be driven mainly by the pre-reversal zonal electric field/vertical drift, the medium term variation is said to be dependent on both the magnetic longitude and latitude.

The day-to-day variability is believed to be connected to gravity waves (Abdu, 2012). According to Zhang and Xiao (2001) declination angle plays important role in exciting the rapid variability of plasma density distribution while latitudinal dependency of the occurrence is limited to magnetic latitude in the range $20.0^0$N – $12.4^0$S. Studies have shown that the rate of ESF occurrence decreases with increase in latitude away from the geomagnetic equator. While the equatorial region experiences a dominant occurrence of spread-F, other latitudes (with the exception of high latitude) show little or no manifestation of the phenomenon, hence the term Equatorial Spread-F (ESF) (e.g. Zhang and Xiao, 2001). Spread-F occurrence has also been reported to be highest in the equinoxes, especially during high solar activity periods and lowest in June solstice (Wayne, 1962; Koga *et al*., 2011; Wang *et al*., 2010) due to the seasonal variation in the magnitude of the evening PRE which have been found to be lowest in June solstice. Although high spread F occurrence have been observed during June solstice in solar minimum, this has been attributed to other ionospheric background conditions such as travelling ionospheric disturbances (TID) (Candido *et al*., 2011) and events related to geomagnetic disturbance (Becker-Guedes *et al*., 2004).

The fact that these plasma irregularities do interfere with radio waves propagating within the ionosphere causing disruption of radio signals (Oladipo *et al*, 2018; Bhattacharyya *et al*., 2000), coupled with the consequent effects on the operation of space borne and ground based technological systems, are reasons for the drive to understand the phenomenon. Statistical study of the occurrence of spread F is capable of providing information which can enhance our understanding of the phenomenon. There have been limited studies on ESF in the African sector probably due to the scarcity of remote sensing equipment such as ionosondes within the region. The digisonde (DPS4) installed in March 2010 at the University of Ilorin, an equatorial station in West Africa provides an opportunity for this type of study over the region. This study which is aimed at investigating the occurrence statistics of ESF over Ilorin, would therefore be the first of its kind from this Digisonde station.

## 2. Materials and Methods

Ionograms recorded using Digisonde (DPS-4) located at Ilorin (Geo. Lat. $8.47^0$N, Long. $4.68^0$ E; Dip. Lat. $7.867^0$S) for the year 2010, a year of low solar activity (R12 = 17.6) were employed for this study. This Digisonde which is controlled by the Global Ionospheric Radio Observatory (GIRO) was in operation between March and December, 2010. Auto scaled ionograms for the period between April and December, 2010 were selected for the purpose of this study. The ionograms which were recorded at 15 minutes interval over the 24 hours of each day were manually examined for the occurrence of spread F. Ionograms with appearance of spread-F were identified. Each spread F observable was classified based on the classification of Wang *et al*. (2008). Fig.1 shows the three types of spread that are observable at Ilorin, they include range spread F (RSF), frequency spread F (FSF) and mixed spread F (MSF) (Adeniyi, 2017). The number and period of occurrence of each type of spread per day was recorded. The rate of occurrence of each type of spread was then calculated as the percentage of the number of days with spread-F to the total number of days with data using the relation:

$$\%occurrence = \frac{number\ of\ ionograms\ with\ spread}{total\ number\ of\ ionograms} x100$$

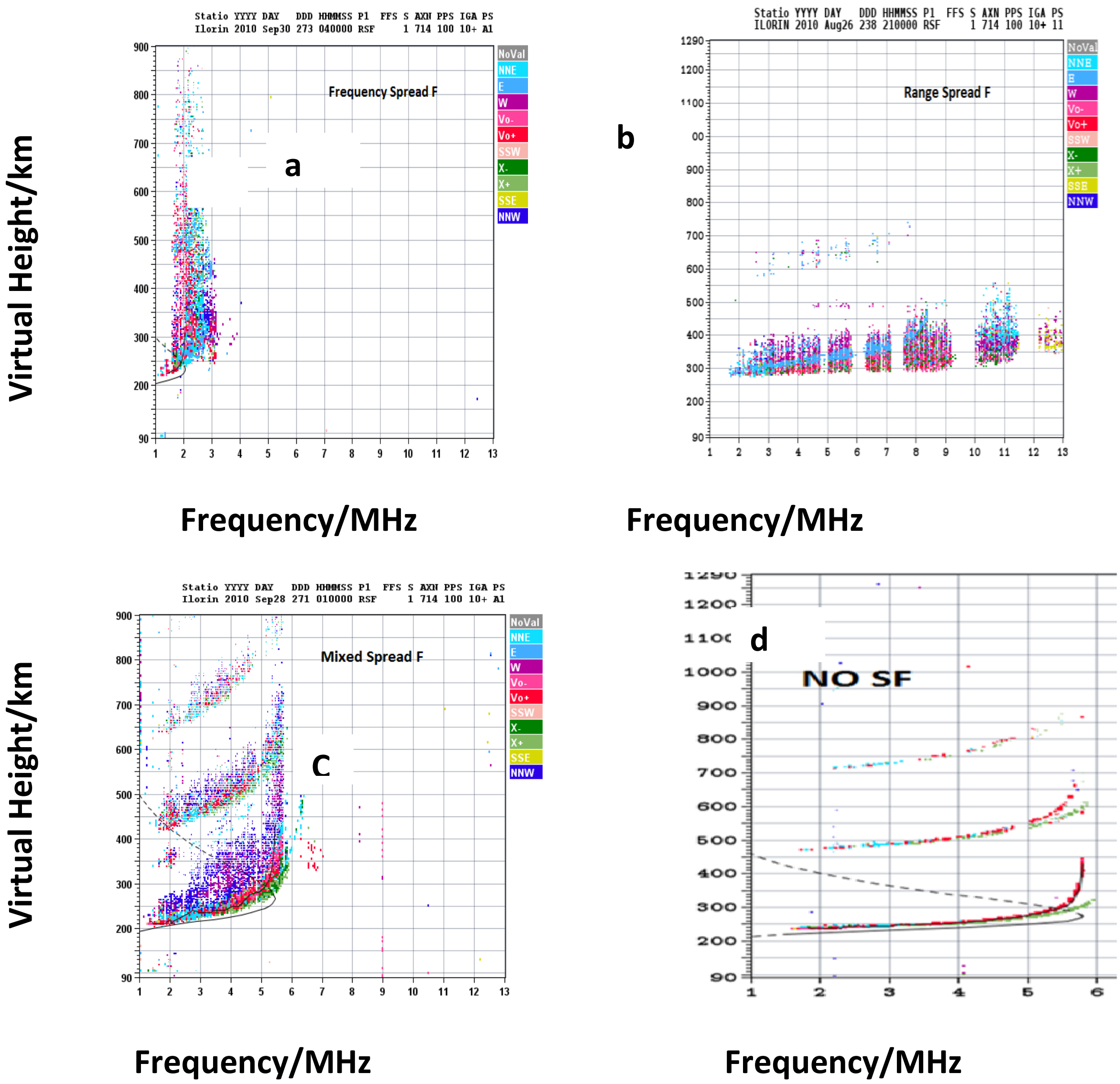
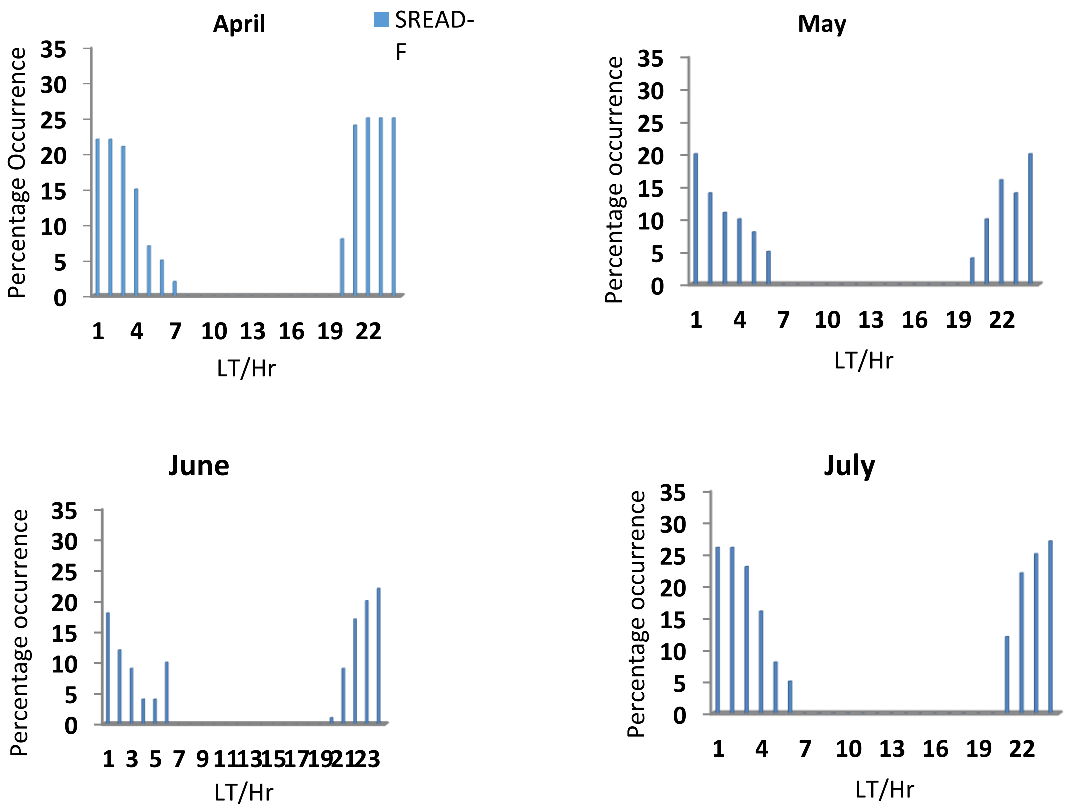



**Fig. 1:** Sample ionograms showing the three types of spread-F observable at Ilorin. (a) Frequency spread F, (b) Range spread F, (c) Mixed spread F while, (d) shows a sample ionogram with no spread.

## 3. Results and Discussion

Fig. 2 shows plots of daily percentage occurrence of spread-F over Ilorin during each of the eight months studied i.e. April – November 2010. The first observation from the plots is that ESF is obviously a post-sunset/nighttime phenomenon. This result is in line with existing results that ESF is a nighttime phenomenon. ESF is completely absent during daytime and early part of the post sunset hours throughout the eight months i.e. between 0700LT and 1900LT. ESF is observed during the post sunset and the post-midnight periods between 1900LT and 0700LT. Percentage occurrence of ESF increases with time during the post sunset hours and decays as the sunrise hour approaches after midnight. During the post-sunset period, percentage occurrence ranged between 0% (at 1900LT) and 31% (at 2300LT) while during the post-midnight period (0000LT -0700LT) percentage occurrence decreased from around 31% to 0%. Maximum daily percentage occurrence of 31% was recorded in October during the post-sunset hours of 2200LT and 2300LT while the minimum daily percentage occurrence of 1% was recorded during the post-midnight hours in September and November.

The least monthly percentage occurrence was recorded during the month of November (December solstice) when the highest percentage occurrence was less than 10%. The highest percentage occurrence was recorded in the equinox months of August, September and October (September equinox) when the value was as much as 31%. These results reveal the seasonal characteristics of ESF, thus confirming literature. Highest values of occurrence percentage (30% -31%) were recorded during the equinox months of August, September and October while the maximum percentage occurrence recorded during the solstice months of May, June and July ranged between of 20% and 27%.



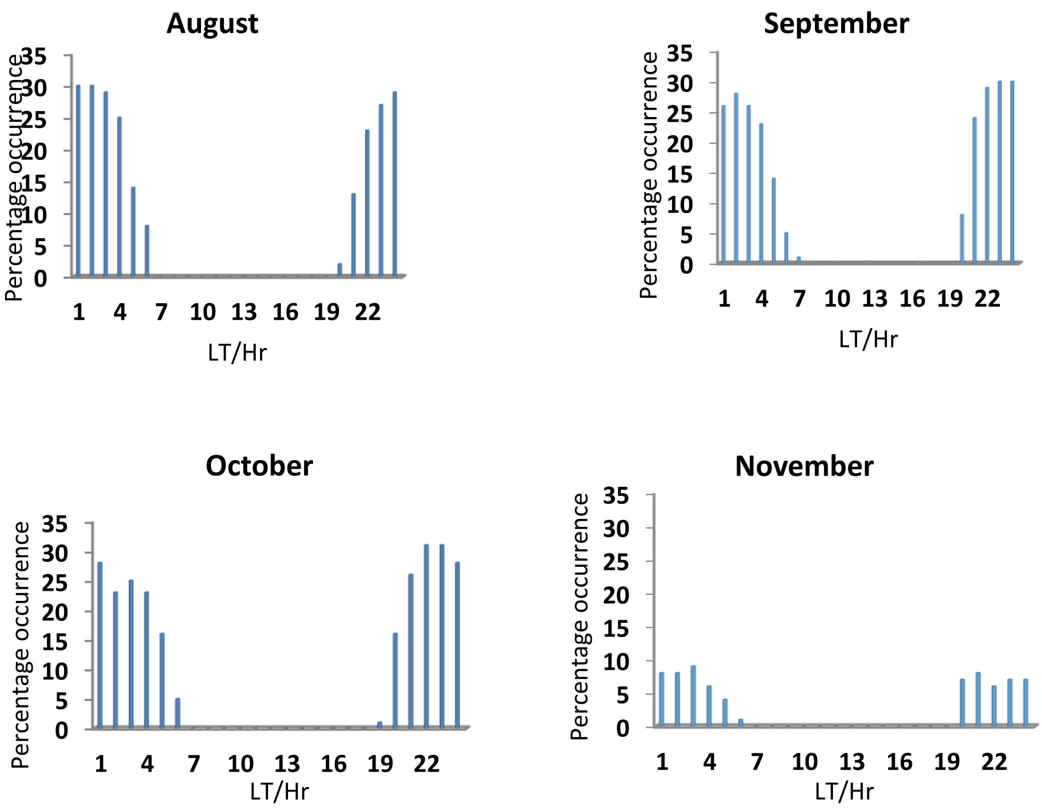



**Fig. 2:** Diurnal percentage occurrence of spread F over the months (Data for January and December were not available.

A summary of the monthly/seasonal percentage occurrence of ESF is shown in Fig.3. It is observed from the Figure that, while September equinox recorded 32.9% of occurrence, June solstice recorded 20.26%, being the least. A higher percentage of occurrences (29.8%) are observed during December solstice compared with June solstice; this cannot be unconnected with the well-known December anomaly, in which December solstice is observed to receive higher intensities of solar radiation than normal.

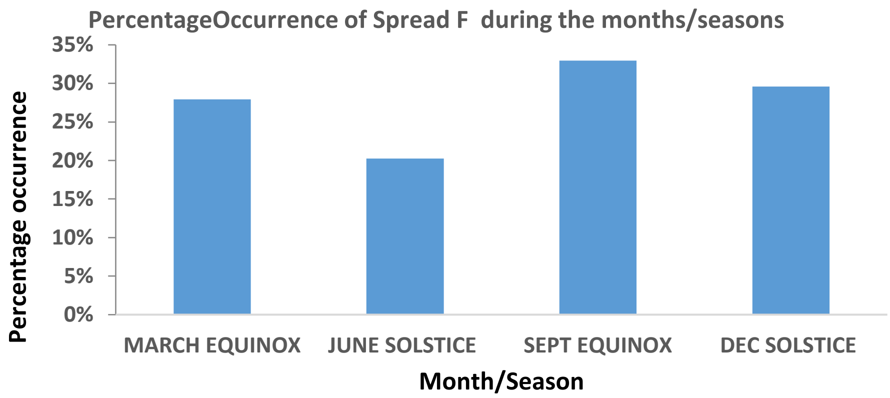
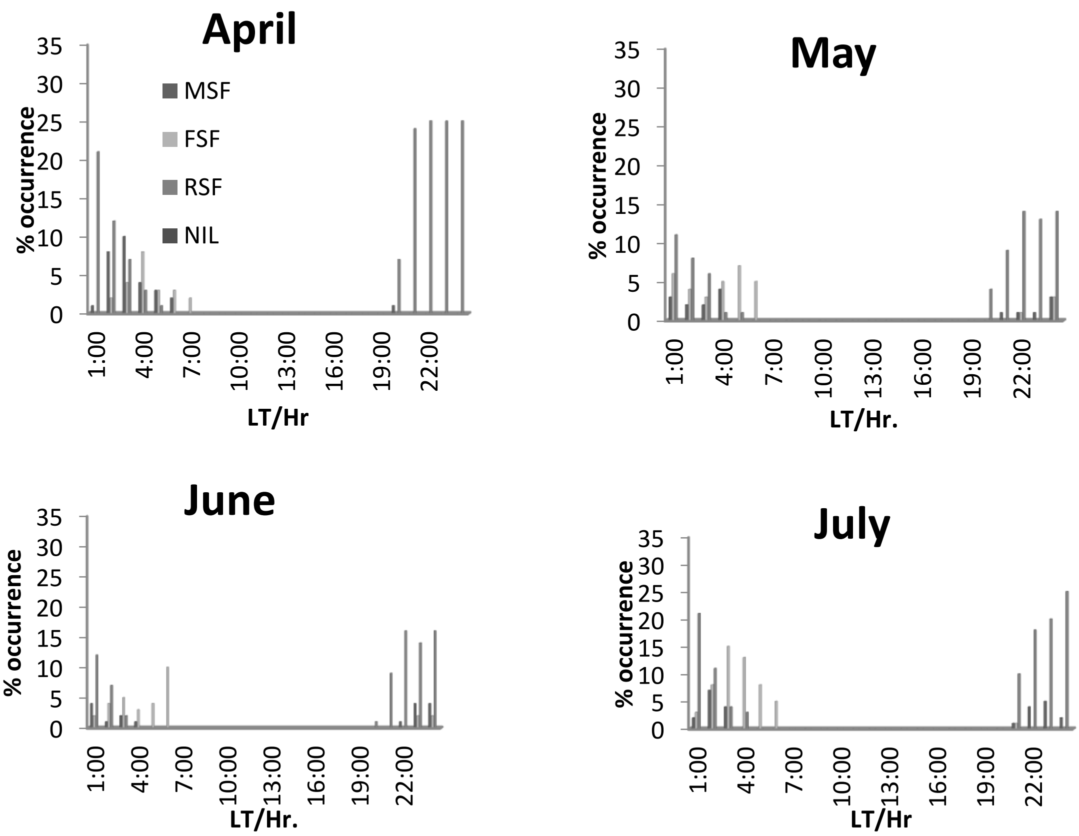



**Fig.3:** Plot of the summary of Monthly/Seasonal percentage occurrence of ESF at Ilorin during 2010.

The relative occurrence percentages of the three types of spread are as shown in Fig. 4. RSF is observed to be predominant in occurrence particularly during the post sunset hours. The FSF and MSF types are more of post- midnight phenomena with FSF showing more tendency of occurrence than MSF.



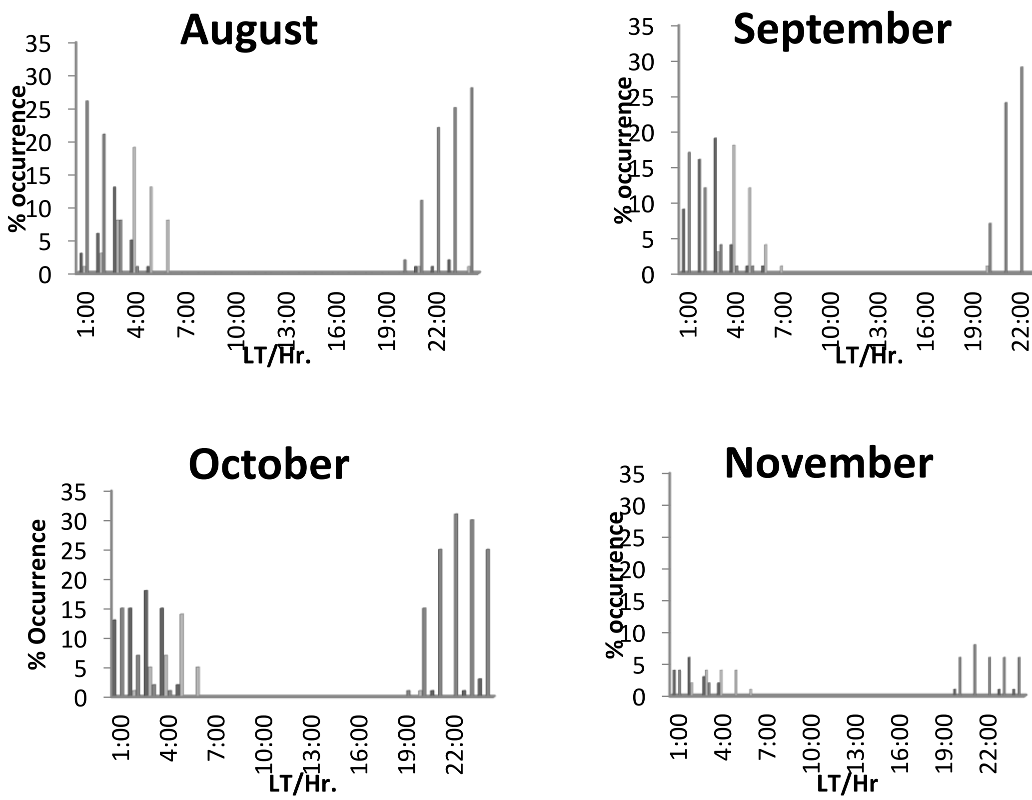



**Fig. 4:** Plots showing relative daily percentage occurrence of the three types of spread F, RSF, FSF and MSF during the months under study.

The plots in Fig. 5 show the relative percentage occurrences of the different types of spread F during the year under consideration. RSF is observed to be dominant over the other two types with declining percentage occurrence from 75% in April to 53% in November. RSF also exhibits the tendency to be higher during the equinox months compared to the solstice months. FSF and MSF are anti-correlated and exhibit seasonal dependence. While FSF has its maximum occurrence (of 23.5%) during the solstice months of July, MSF has its maximum occurrence (of 25%) during the equinox month of October. Table 1 below is the summary of the percentage of occurrences of these various types of spread F for each month of the year. RSF occurrence ranged between 53% and 75% during the months under study while the other two types ranged between 11% and 27% in occurrence.

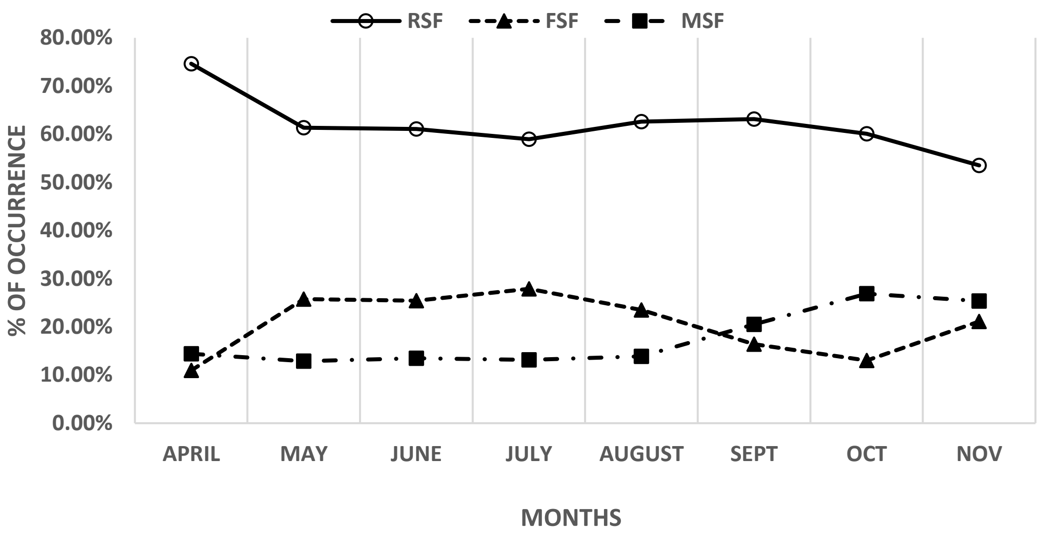



**Fig. 5:** Plot showing the relative percentage occurrences of the three type of spread.

**Table 1.:** Monthly Percentage occurrence of different types of spread-F.

| Month | RSF(%) | FSF(%) | Msf(%) |
|---|---|---|---|
| APRIL | 74.63 | 10.95 | 14.43 |
| MAY | 61.36 | 25.76 | 12.88 |
| JUNE | 61.11 | 25.4 | 13.49 |
| JULY | 58.95 | 27.89 | 13.16 |
| AUG | 62.61 | 23.48 | 13.91 |
| SEPT | 63.11 | 16.39 | 20.49 |
| OCT | 60.08 | 13.04 | 26.88 |
| NOV | 53.52 | 21.13 | 25.35 |

Generally, it is known that ESF is a nighttime event that is triggered by ionospheric instabilities after sunset and through the midnight. Results from this study are quite in line with existing literature. All the three types of spread F observed in this study have their occurrences during post sunset and post midnight periods. The mechanisms and formation of ESF have been discussed by earlier researchers (e.g. Abdu *et al*., 2006; 2009; Woodman 2009) and need not mentioned here. According to Abdu (2009), the most important single factor as a precursor condition for the post sunset equatorial spread F (ESF) development is the evening pre-reversal electric field enhancement (PRE) that causes a rapid uplift of the F region which eventually results in the development of plasma bubbles (Abdu, 1998; 2009; Whalen, 2002; Becker-Guedes *et al*., 2004; Candido *et al*., 2011).

Variability in the intensity and the occurrence of ESF can therefore be attributed to the variability in the evening pre-reversal vertical drift and the ambient ionospheric dynamics (Abdu *et al*., 2009). Variations in the occurrence of ESF, as observed in this study, displayed dependence on local time and seasons. The seasonal dependence in the occurrence of ESF and the low percentage occurrence observed in June solstice is consistent with the results of Sahai *et al.* (1998, 2004); Abdu *et al.* (1998) and Candido *et al*. (2011). Our results also revealed that the RSF, which is strongly related to equatorial plasma bubbles, dominates all the months, and its occurrence is most prominent between post-sunset and midnight periods. These results suggest that the pre-reversal enhancement, PRE vertical drift is more responsible for the development of the RSF, while some other mechanisms such as the recombination process may play substantial role in the occurrence of other types of spread-F.

## 4. Conclusion

A study on the occurrence characteristics of ESF has been done using data from Ilorin, an equatorial station in the African sector for the year 2010, a year of low solar activity. This is the first time this type of study would be carried out for this station. The significance of a study like this is threefold: (i) it helps in further understanding of the characteristic features of the nighttime equatorial ionosphere within the African sector as compared to the other sectors (ii) it provides ionosphere end users the information regarding nighttime communication challenges within the equatorial ionosphere and (iii) can be of great resource to ionospheric researchers and modelers. The results from the study have further confirmed ESF as a nighttime phenomenon and have shown specifically for the Ilorin station that ESF occurrence is usually between 1900LT and 0700LT. The duration of occurrence is between 10 and 11 hours. Three different types of ESF were identified with RSF type being the most prevalent.

In conclusion, results from this study revealed that (i) ESF commencing period is usually between 1900LT and 2100LT, while the time of disappearance is between 0600 and 0700LT. Minimum percentage occurrence during the post-sunset periods is between 0.5% and 10% while the maximum ranges between 8% and 31%. Minimum percentage of occurrence during the post midnight period ranges between 0.2% and 8% while the maximum is 10%-31%. (ii) ESF shows evidence of seasonal dependence. The percentage occurrence during the equinoxes are higher (being highest in March equinox) than the solstices, except for December solstice. ESF therefore reflects the usual December anomaly which characterizes the equatorial ionosphere and (iii) FSF and MSF are anti-correlated. This suggests that the mechanisms producing the two types of spread F are opposite in their effects.

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