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The Signature of Sporadic E of an Equatorial Ionosphere of the Low Latitude Region

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Abstract:- Sporadic E is usually referred to as the large unpredictable formation of regions of very high electron density in the E region as one of the anomalies that is present in the equatorial region. This work studies the variability of sporadic E in the region with respect to the propagation of low frequency communication and impact on the equatorial region during the occurrence of this anomaly. Hourly data for the year 2010, a year of low solar activity obtained in-situ from a Digisonde Portable Sounder (DPS-4) from the African sector, Ilorin, Nigeria (8.5oN, 4.5oE, -2.96 dip) and the Southern American sector online at Jicamarca, Peru (12 oS, 76.8 oW, 0.74 dip) and Fortaleza, Brazil (3 oS, 38 oW, -7.03dip) were used for this study. The result obtained shows that sporadic E is usually observed at the region during the daytime and early evening (0600-1700 local time) and is more prevalent during solstice months. Two types of sporadic E were observed in the region: blanket and transparent sporadic E. 12% of the transparent sporadic E was observed during the March equinox while 9% of blanket sporadic E was observed during this period; September equinox shows 15% of transparent and 7% blanket sporadic E respectively, while June solstice has 21% transparent and 7% blanket sporadic E. During the December solstices, 14% transparent and 7% blanket sporadic E was observed. During the March equinox, the blanket sporadic E was observed around 0200 hour local time, and that of the transparent sporadic E at about 1000 hour local time. Observation during the September equinox shows that it occurs around 1100 hour and 0200 hour respectively. It was observed that there is no correlation between sporadic E and geomagnetic storm. Sporadic E has been observed to be one of the anomalies that are responsible for the scintillation and scattering of the lower frequency signal in the said region when present.

Keywords:- *Sporadic E, Low Frequency And Equatorial Region.*

I. INTRODUCTION

Sporadic E (E_s) layer is plasma formation with a high degree of ionization which appears at altitude of 90-130 km and also a protracted transmission returned from the E region of the ionosphere by some mechanism other than the normal reflection process from day time when E layer is observed (Smith, 1957; Skinner, et. al., 1957 and Rishbeth, et. al., 1969). It can be distinguished from other regular D, E and F layers of the ionosphere at 300 m to several km in thickness and can have a horizontal extension of 20-200 km (Riggin et. al., 1989, Whitehead, 1989, Mathew, 1998, Yigit, et. al.; 2008 and Shi, et. al., 2009). E_s can be uniform in horizontal plane or as blanket covering regions of ionosphere, while some are semitransparent consisting of ionization cloud (Rao, et. al., 1994; Abdu, et. al., 1997 and Kamil et. al., 2021). It is a layer of increased ionization that appears at the heights of the E-region of the ionosphere. This sporadic layers in the E-region, has been observed to occur at all latitudes and have been studied for many decades. Solar eclipse has been described as a phenomenon that provides a very unique opportunity to study the responses of the ionospheric Es to the rapid solar radiation variation (Le et. al., 2010, Liu et. al., 2000, Wu, et. al., 2018 and Chen, 2021). Currently, Es layers are being investigated using modern digital ionosondes, incoherent scatter radars (ISR), very high frequency (VHF) and partial reflection (PR) radars, rocket probes, and signals from GPS and GLONASS navigation satellite systems (Arras, et. al., 2009; Hawk, 2001 and Yusupov, et. al., 2021). The formation of E_s layer has been reported to be as a result of wind shears and can also be created by diurnal and semi-diurnal tides as well as by gravity waves; the zonal neutral wind has also been reported as the primarily responsible for inducing the vertical ion drifts. Gradient instability also plays an important role in the creation of sporadic E at the equatorial region. Typical E_s are very narrow of few kilometers in height and are usually characterized by large day-to-day variability and distinct features depending on the altitude and latitude of its observation (Jayachandran, et. al., 1999; Niranjan, et. al., 1999 and Resende and Denardini, 2022). E_s layers are detected in ionograms due to reflections in the thin layer of plasma density enhancement due to long-lived metallic ions such as Fe^{2+}, Mg^{2+}, Ca^{2+} and Na^{+} (Tsunoda, 2008). The density of the layer can be up to an order of magnitude greater than

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background densities, mainly because of their lifetime that is longer than the dominant species (O^+, NO^+, O_2^+) at the height of the E-region (Kopp, 1997). E_s have been classified primarily on their appearance ionogram either transparent or blanketing, nature and the location (Resende and Denardini, 2022). It has been reported that ionospheric E_s has a significant impact on the global positioning system (GPS)/Global navigation satellite system (GNSS) signals. These influences on the signals of GPS/GNSS have been used to study the occurrence and characteristics of the E_s layer on a global scale (Yu, et.al., 2020).

Scholarly studies have been taken over the occurrence of Es, reports from crest region Bhopal an equatorial station, shows its occurrence between 00:00-04:00 UT and 11:00-16:00 UT (Hafsa, et.al., 2018, . Yusupov, et. al., 2021, Elias, et. al., 2022). In another study, the occurrence frequency of Es layer was reported to increase from the equator to high latitude (Prasad, et. al., 2012). The relationship between the critical frequency (f_oE) of the region and the maximum usable frequency is as presented in equation 1. The angle of incident has been observed to inversely vary with the (M.U.F).

$$\text{(M.U.F)} = \frac{f_o E}{\cos\theta} \qquad (1)$$

Where M.U.F is the Maximum usable frequency

θ is the angle of incident of the signal

The study of E layer is very significant because the layer serves as alternative for propagation of high frequency (HF) and very high frequency (VHF) radio waves in a disturbed ionospheric conditions or when reflections from F layer are not visible. Also, investigating the equatorial region of the ionosphere poses a lot of challenges to scientific community in understanding the mechanism of the region due to the presence of the ionospheric anomalies. Most studies are usually concentrated along the high and mid-latitudes, few are for the low latitude and very scanty are in the equatorial region of the ionosphere, although recent deployment of instrument has made significant improvement in the region. There is a need for further study on the region for adequate modeling of the ionosphere and improvement on the LF propagation.

In this study the stations which are close to the crest of the anomaly in the African and Southern American sector is used, and variability of sporadic E will be studied using data from the African and Southern America of the equatorial region. Correlation of the occurrence of sporadic E and geomagnetic storm is also studied.

II. DATA AND METHODOLOGY

Hourly data for the year 2010, a year of low solar activity obtained from a Digisonde Portable Sounder (DPS-4) from the African sector, Ilorin, Nigeria (8.5ºN, 4.5ºE, -2.96 dip) and the Southern American sector, Jicamarca, Peru(12 ºS, 76.8 ºW, 0.74 dip) and Fortaleza, Brazil (3 ºS, 38 ºW, -7.03dip) were used for this study. Good and scalable ionogram files were carefully chosen. The data was carefully chosen to avoid non-scalable ionogram and edited (Huang, et. al., 1996a; Huang, et. al., 1996b). Table 1 shows the data source. Calculation for each station was done from Universal Time (UT) to location time (LT) for ease of comparison. Four months of which significant geomagnetic storm were observed: April, October (March and September equinoxes) May, August (June and December solstices) respectively were choosen. The months chosen are those in which relative storm was observed, since we are interested in the correlation of Es and geomagnetic storm, fig. 1. The data of the disturbed period were carefully separated from the quiet period. The Disturbed storm time (Dst), K and Ap indices used to distinguished data of quiet and disturbed period is as presented: -20 nT > Dst > -100 nT or K ≤ 4 and Ap < 20) (German Research centre , 2010). Table 2 shows the number of days and which of the day are used for the study. Five ionospheric parameters used to describe E layer were used in the study, table 3 shows the descriptions of the parameter used. Fig. 1 shows the plot of Dst index against days for the months used (WDC, 2010).

Table 1: Data Source

Geographic Coordinate	Geomagnetic Coordinate
Ilorin Nigeria (8.5 ºN, 4.5 ºE)	(-1.82, 76.80, -2.96 dip)
Jicamarca, Peru (12 ºS, 76.8 ºW)	(0.77, 354.33, 0.74dip)
Fortaleza, Brazil (3 ºS, 38 ºW)	(-3.64, 34.21,-7.03dip)

Table 2: Data of Months Used with Selected Days

Month	Days Used	
	Quiet Days	Disturbed days
April	21,26,27	6,7
May	11,12,13,14	2,3,29,30
August	11,12,14,21	4,5
October	1,21,26,27	11,12

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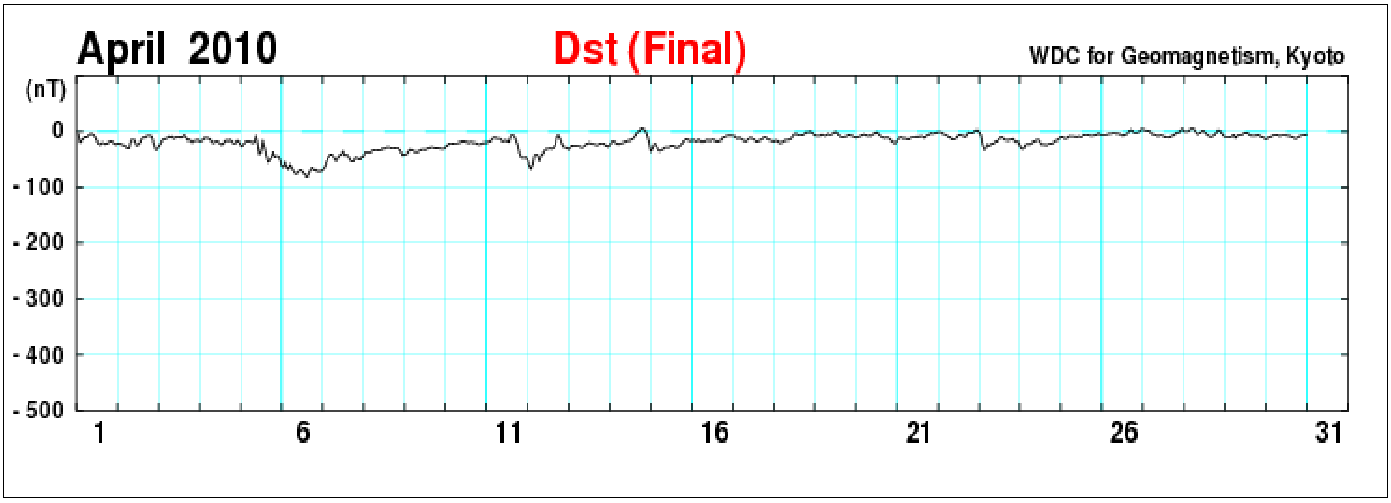
Table 3: Parameter Used

Parameter Used	Description
foE	E layer critical frequency
h'E	Minimum virtual height of E trace
foEs	Sporadic E critical frequency
h'Es	Minimum virtual Es trace
fbEs	Blanketing frequency of Es layer



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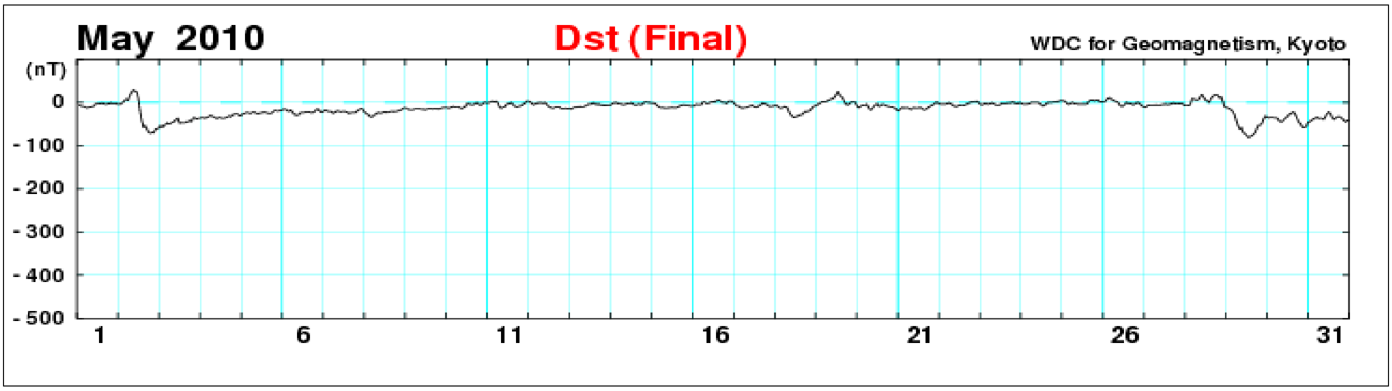

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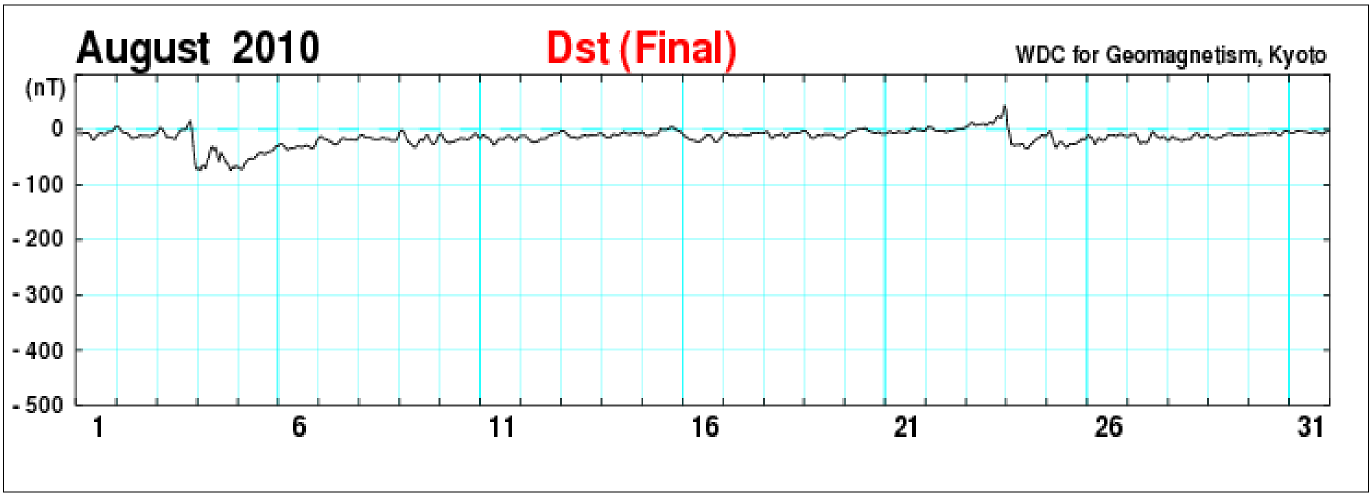

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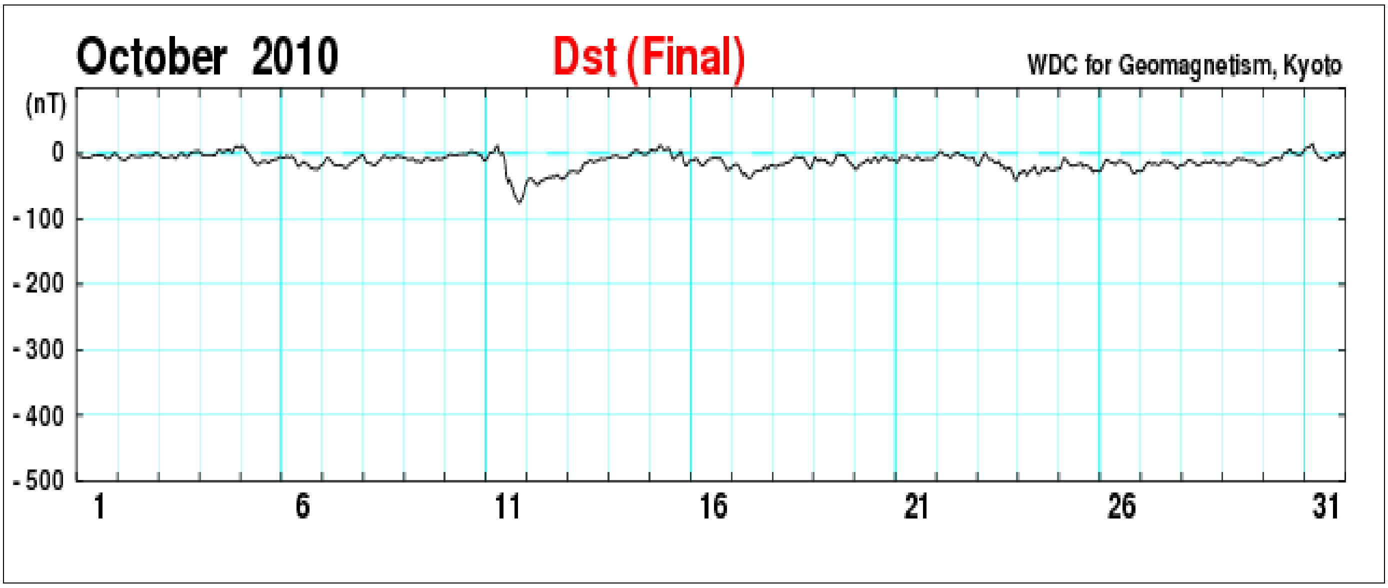
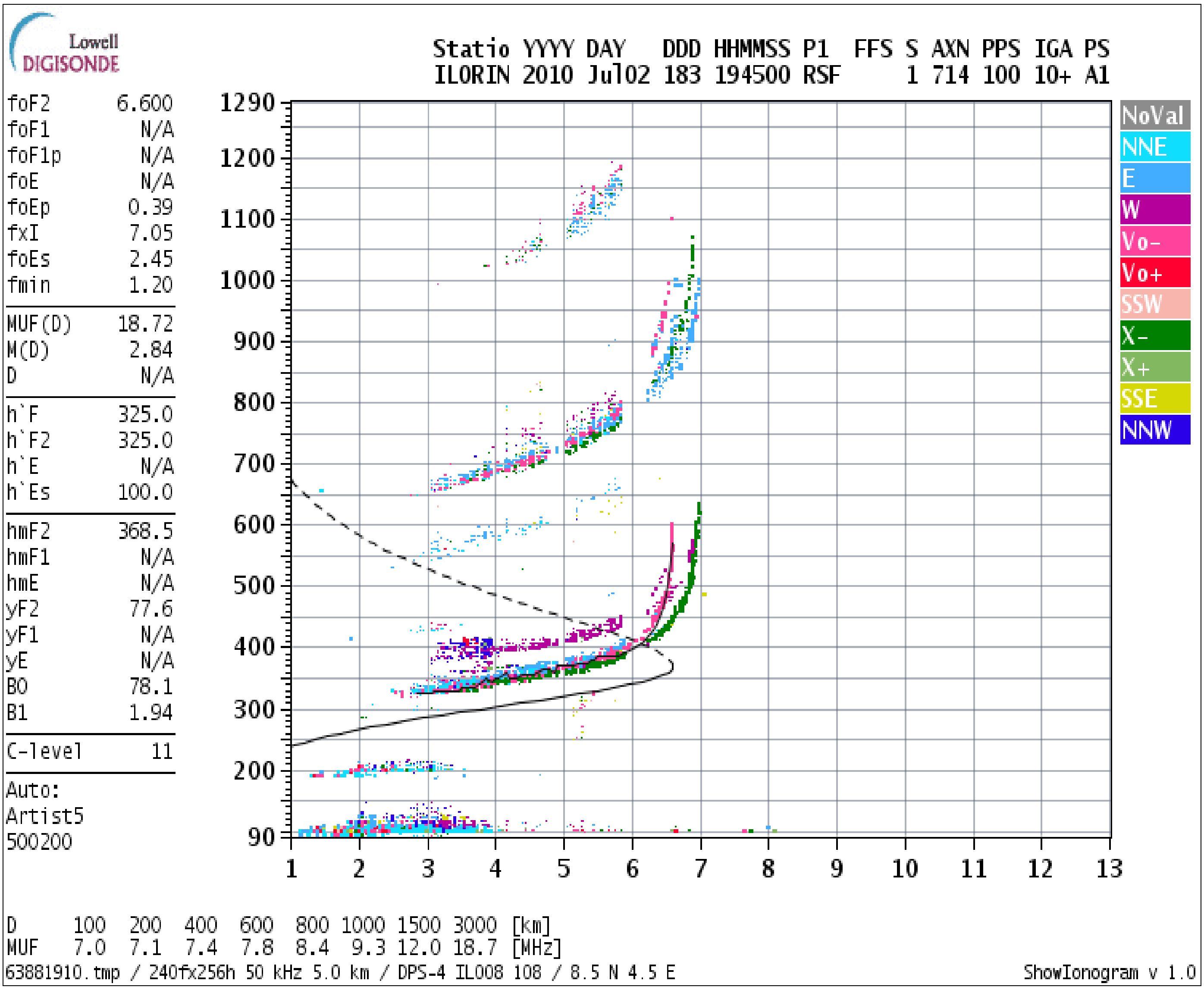


(d)
Fig 1: DST-Index Plots for the Months used (Word Data Centre, Kyoto)



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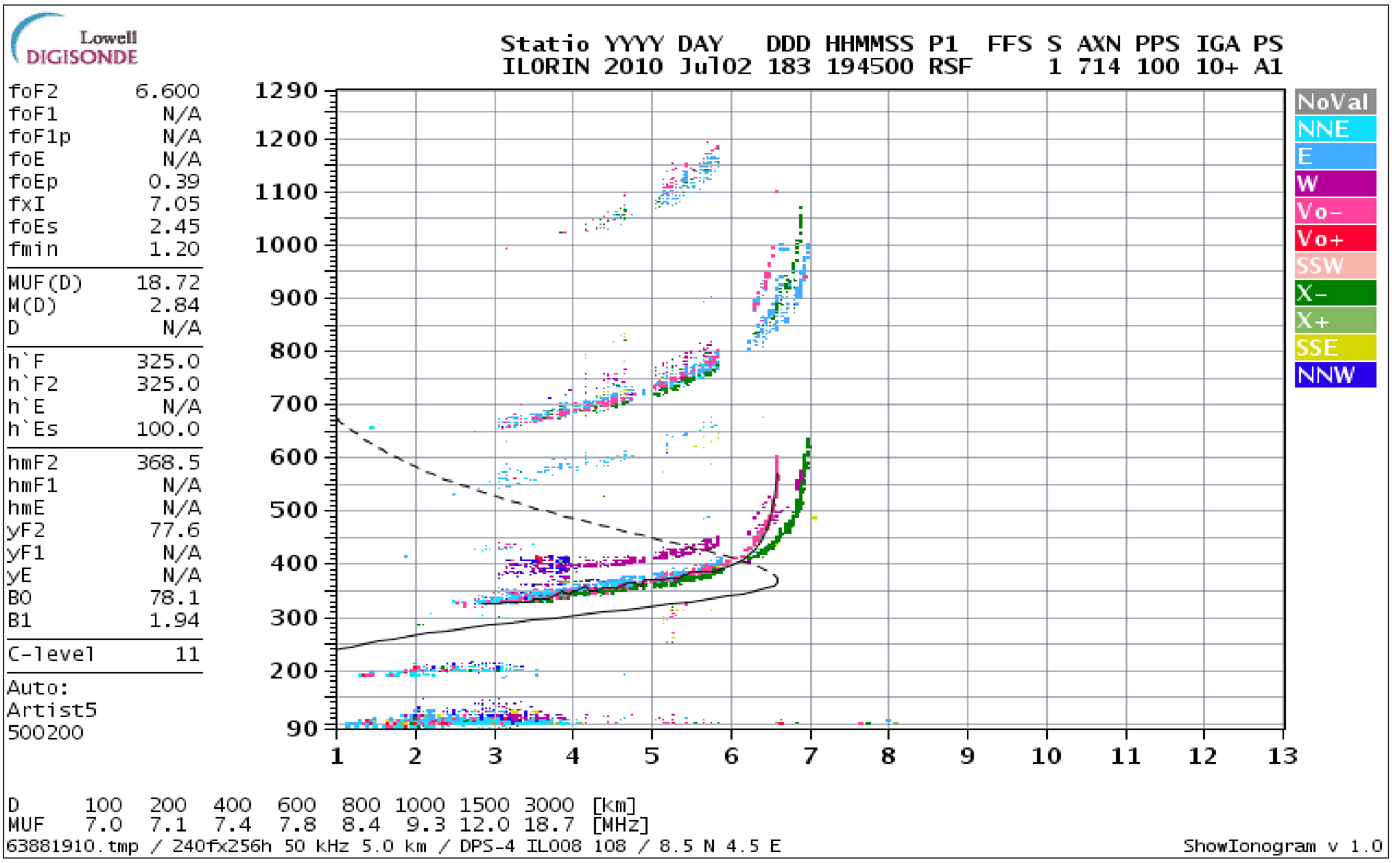

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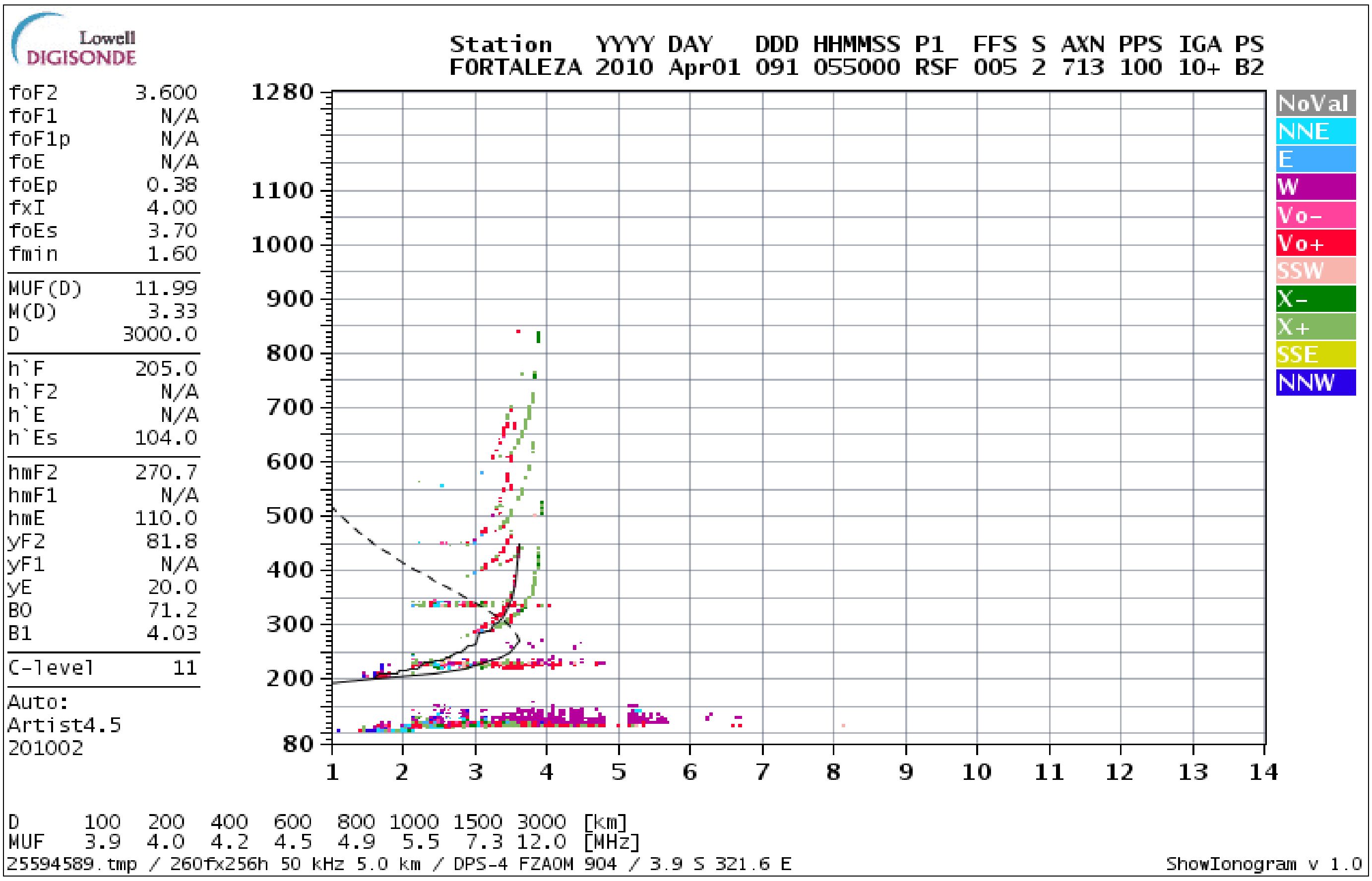

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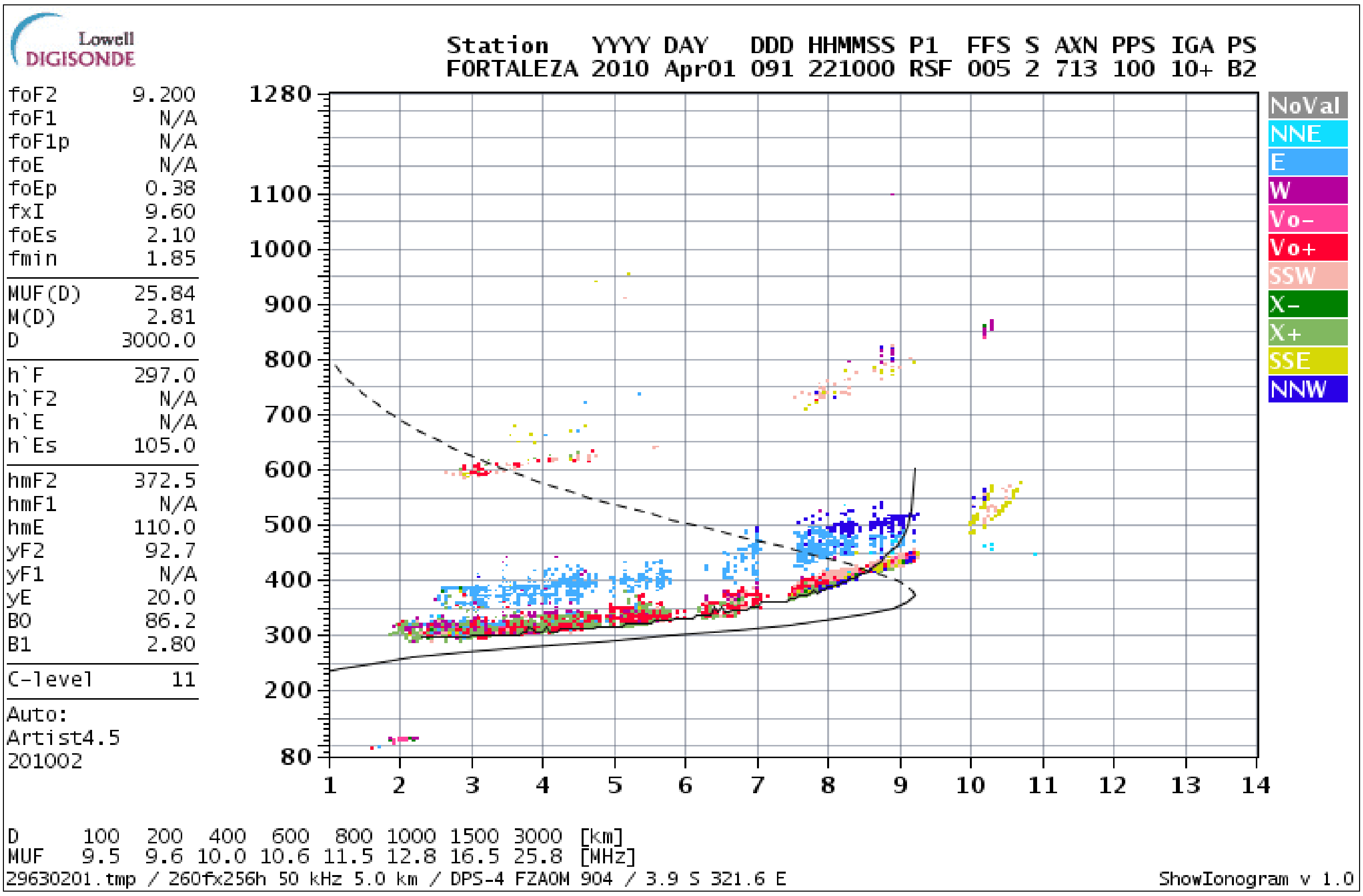

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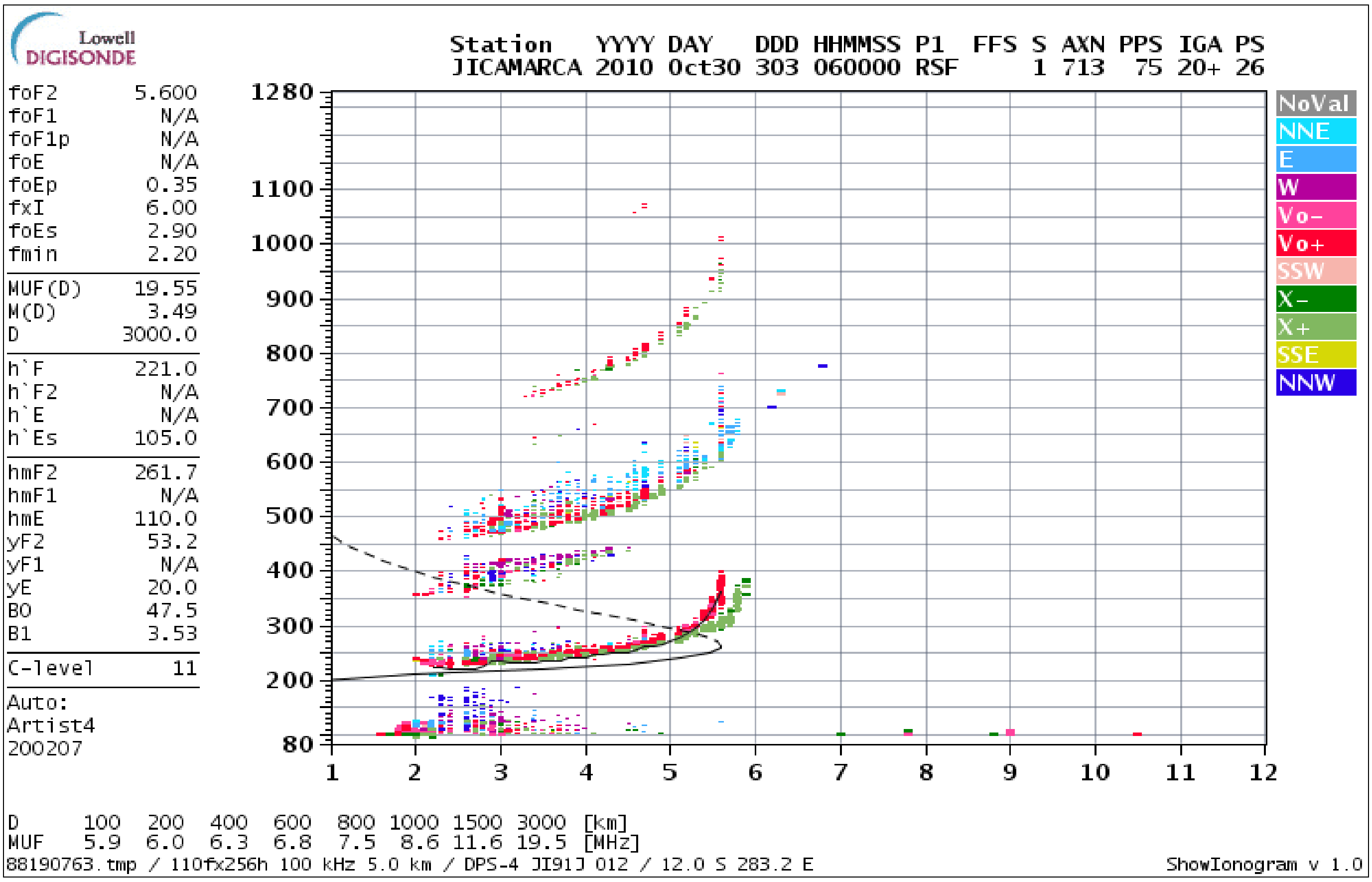

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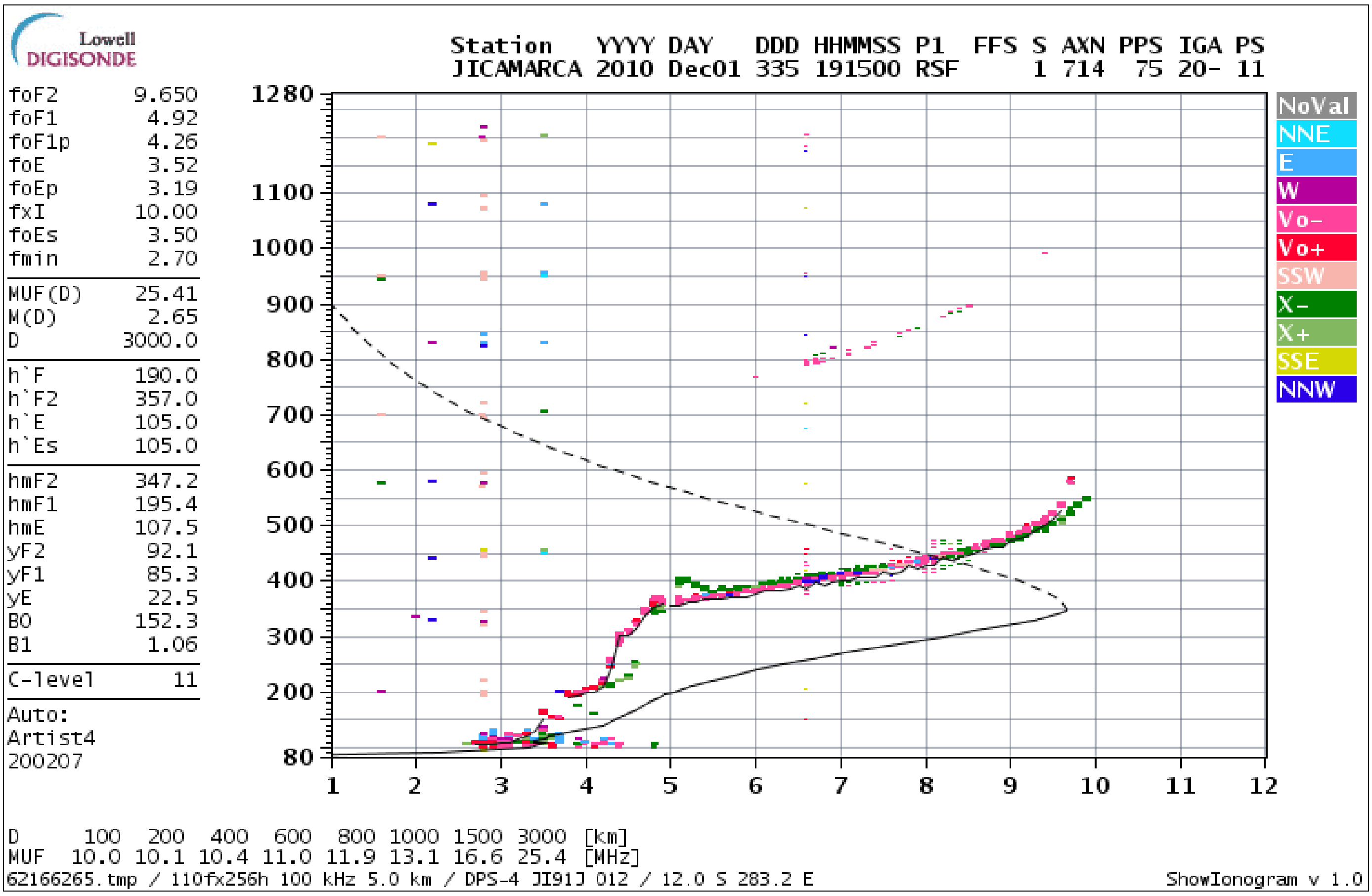


(f)

Fig 2: Typical Observed Sporadic-E during the day and night hours from (a-b) Ilorin, Nigeria (c-d) Fortaleza, Brazil (e-f) Jicamarca, Peru

III. RESULTS AND DISCUSSION

Typical day and night raw ionogram from the DPS-4 from Ilorin is shown in fig. 2 (a & b) and those of Fortaleza and Jicamarca is presented in fig. 3 (c & d, e & f) respectively. The two types of E_s layer: transparent (f_t Es) and (f_b E_s) were observed at each of the station studied. Generally, Es- layer was observed between 0000-1600 LT in all the stations under investigation. The plot of the representative months is as presented with various ionospheric parameters in fig. 4-6, the variations of the parameters used is as presented. During the March equinox for the quiet days the foE and the foEs was observed to rise steadily from 0600 LT until around 1300 LT with a sudden peak until 1400-1600 LT. The critical frequency at this point is closed to that of the F-layer of the ionosphere and was observed to be obstructed the lf communication.

At Ilorin it was observed between 0600-1100 LT and 1600-1800 LT, Jicamarca: 0100-0300 and 1400-1900 LT, Fortaleza: 0700-1000 LT. At the September; Ilorin, Es was observed at 0600-0900 and 1400-1800 LT, Jicamarca: 1200-2100 LT and Fortaleza: 0700-1100 and 2100 LT. At the June solstice, Ilorin: 0500-0800 and 1600-1800 LT; Jicamarca: 1600-2200 LT; Fortaleza: 0700-1100 and 2000-2300. During the December solstice, Ilorin: 0500-0800 and 1600-1800 LT; Jicamarca: 1100-2200 LT and 1100-1800 LT at Fortaleza The result obtained shows that sporadic E is usually observed at the region during the daytime and early evening (0600-1700 local time) and is more prevalent during solstice months. 12% of f_t E_s was observed at March equinox and 9% of f_b E_s was observed during this period; September equinox shows 15% f_t E_s and 7% f_b E_s. June solstice has 21% f_t E_s and 7% f_b E_s, while during December solstices 14% f_t E_s and 7% f_b E_s was observed. During the March equinox, f_b E_s was observed around 0200 hour local time, and that of f_t E_s at about 1000 hour local time. Observation during the September equinox shows that it occurs around 1100 hour and 0200 hour respectively. Percentage occurrence of each type of the observed Es is presented in fig. 4. When f_t E_s is present, it was observed that refraction in the F2 layer occurred and partial transmission of signal and fading is observed at the sight of blanketing sporadic-E.

Es is more prevalent during the solar minimum epoch and occurs at the solstice months than the equinox months.

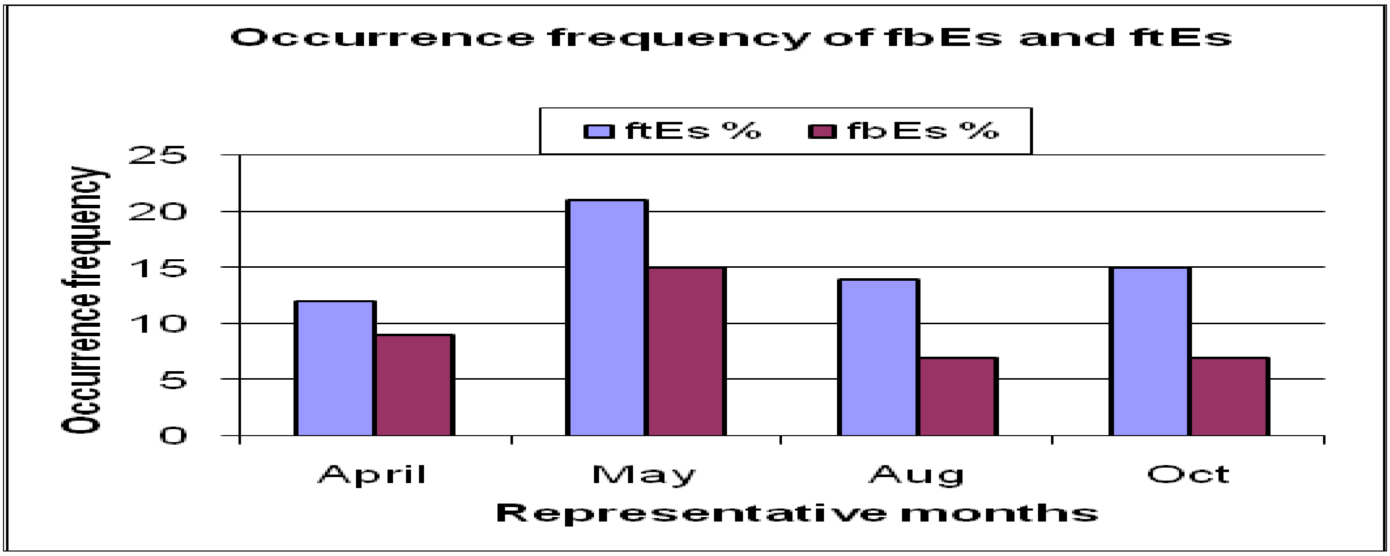
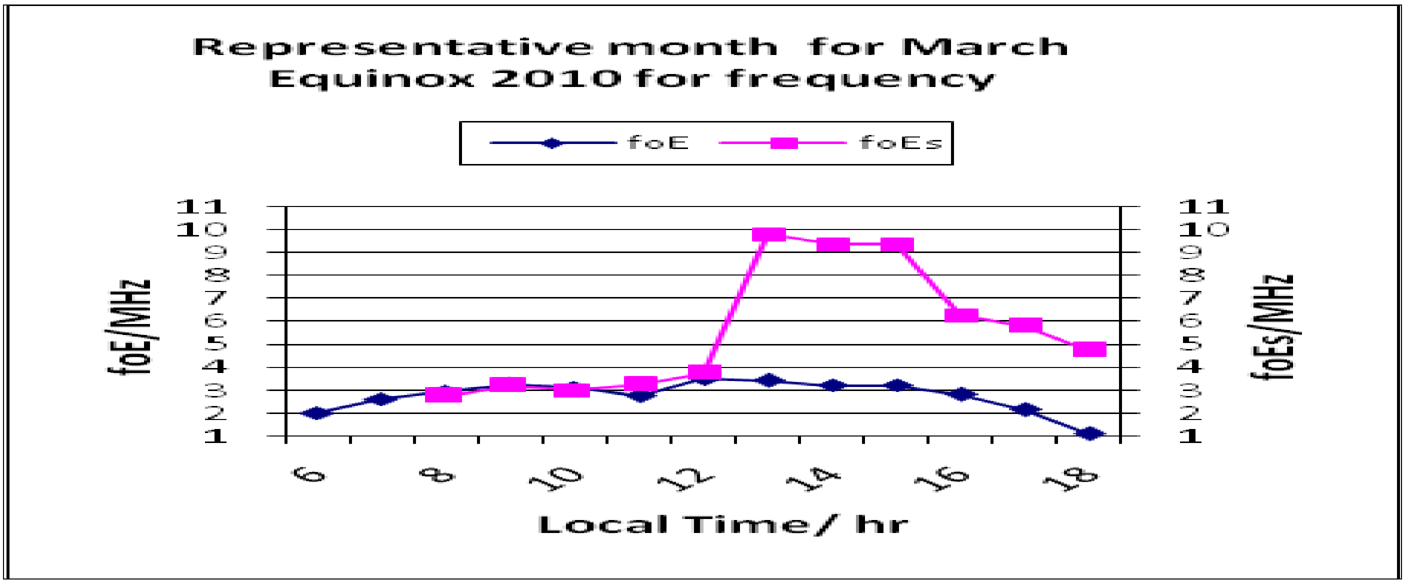


Fig 3: Plot of f_bE_s and f_tE_s from the Observed Months in the Equatorial Region



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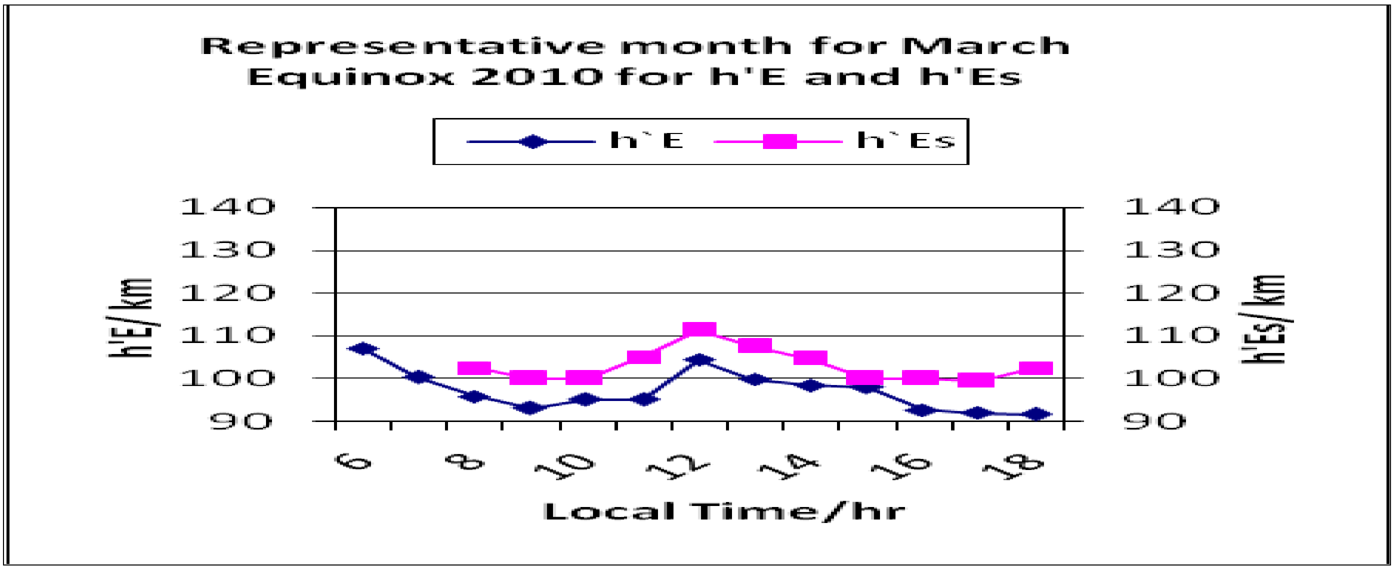
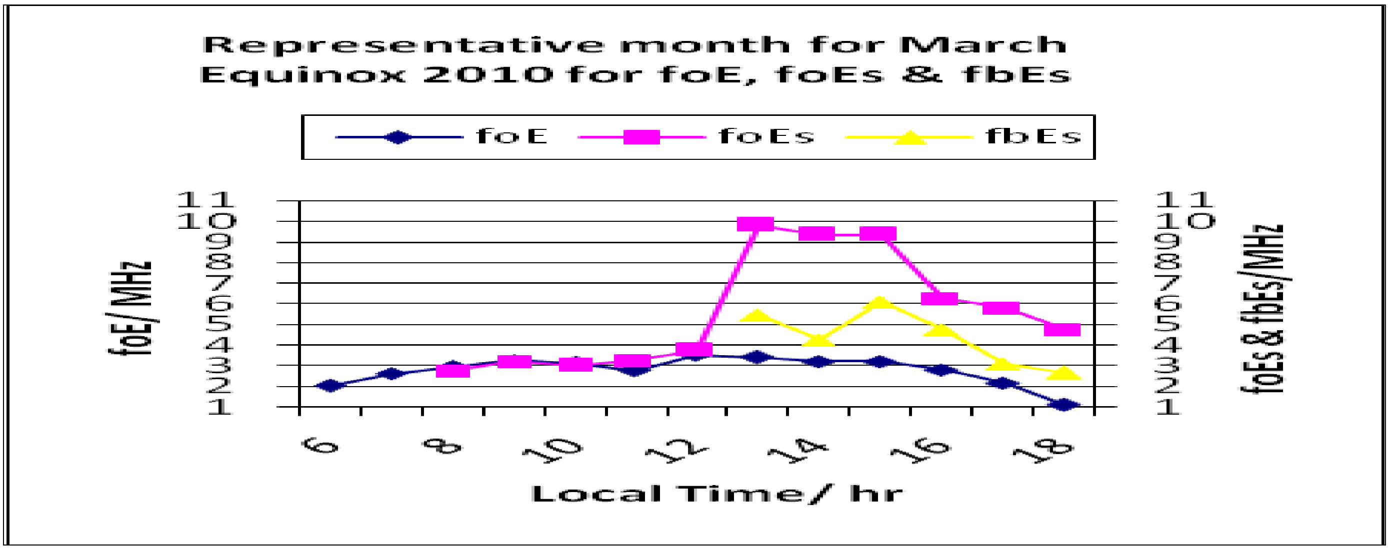
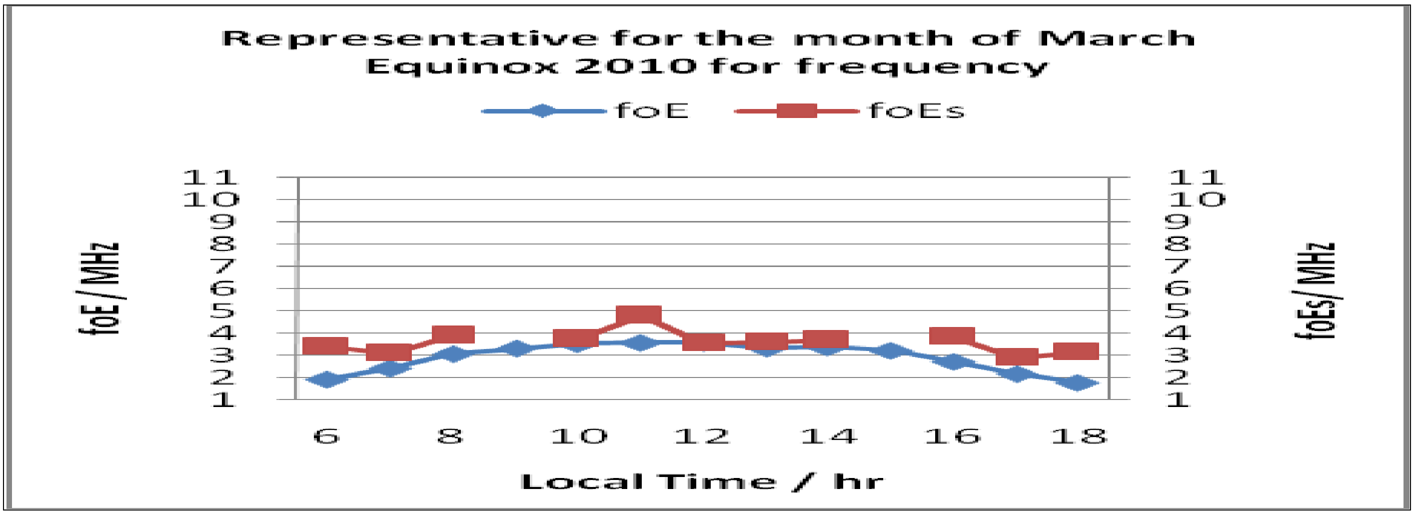


(b)



(c)

Fig 4: Representative Plots for the Quiet Days During the March Equinox



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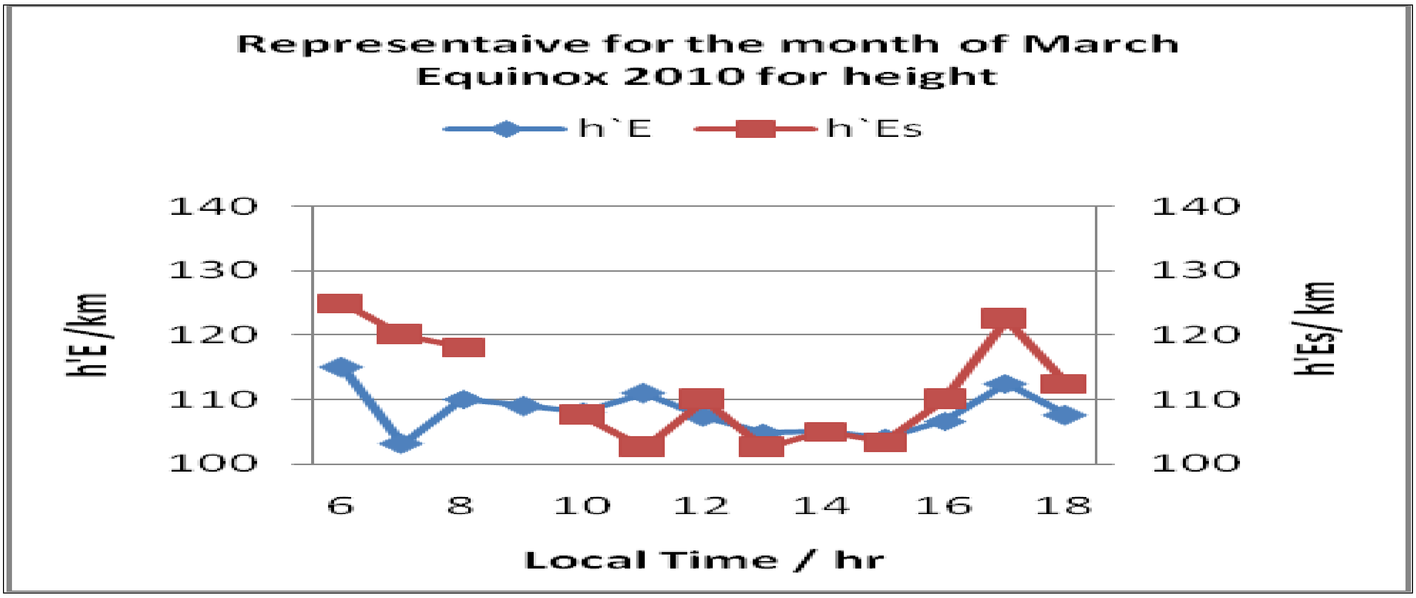

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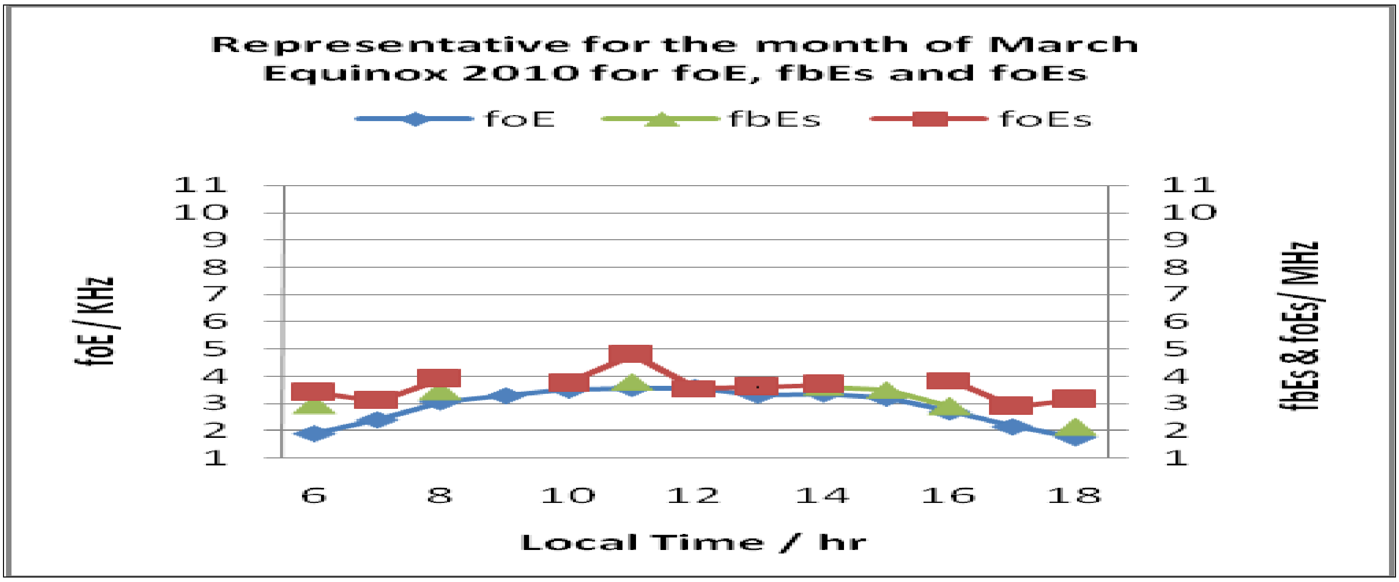
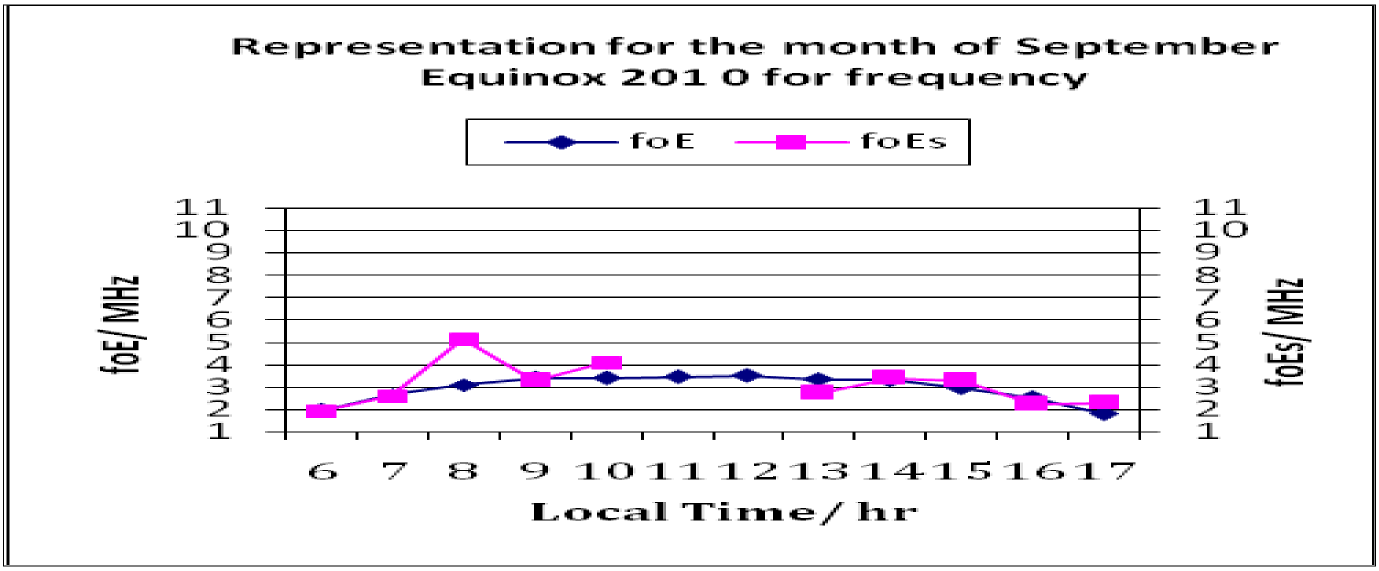
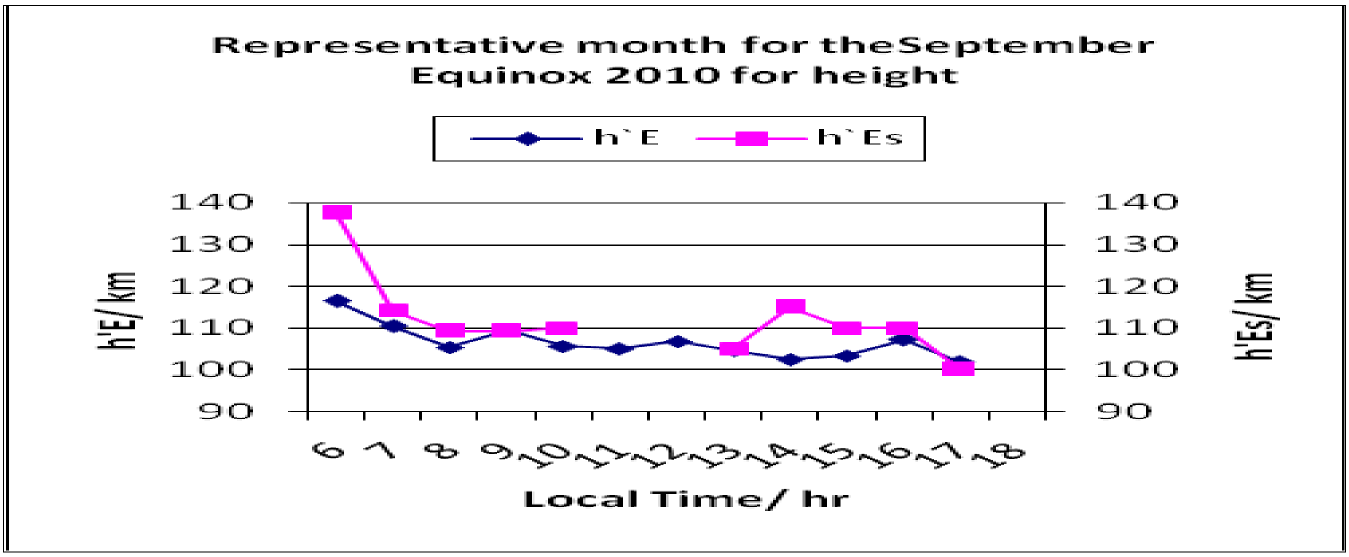


(c)

Fig 5: Representative plots for the Disturbed days during the March Equinox



(a)



(b)

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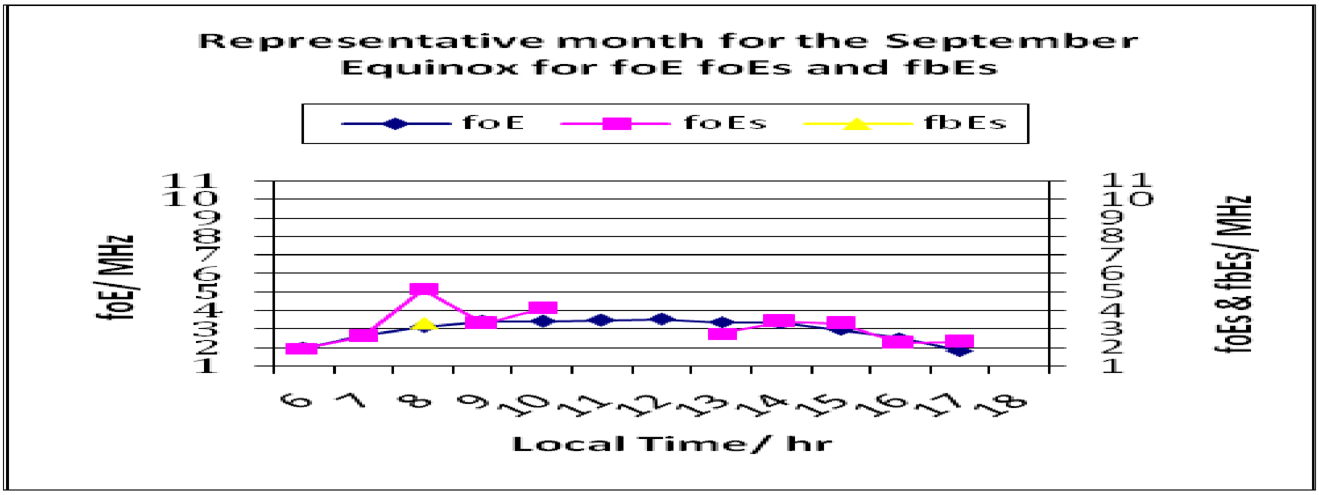

(c)

Fig 6: Representative Plots for the Quiet Days during the September Equinox

IV. CONCLUSION

The main result of the signature of Sporadic E of an equatorial ionosphere of the low latitude region is presented:

- Sporadic E is usually observed at the region during the daytime and early evening (0600-1700 local time) and is more prevalent during solstice months.
- Two types of sporadic E were observed in the region: blanket and transparent sporadic E.
- 12% of the transparent sporadic E was observed at March equinox and 9% of blanket sporadic E was observed during this period;
- September equinox shows 15% transparent and 7% blanket sporadic E. June solstice has 21% transparent and 7% blanket sporadic E, while during
- December solstices 14% transparent and 7% blanket sporadic E was observed.
- During the March equinox, the blanket sporadic E was observed around 0200 hour local time, and that of the transparent sporadic E at about 1000 hour local time.
- Observation during the September equinox shows that it occurs around 1100 hour and 0200 hour respectively.
- Generally Es-layer was observed between 0000-1600 local time (LT) for each of the stations under investigation. During the March equinox; at Ilorin: 0600-1100 LT and 1600-1800 LT, Jicamarca: 0100-0300 and 1400-1900 LT, Fortaleza: 0700-1000 LT. At the September; Ilorin: 0600-0900 and 1400-1800 LT, Jicamarca: 1200-2100 LT and Fortaleza: 0700-1100 and 2100 LT. At the June solstice, Ilorin: 0500-0800 and 1600-1800 LT; Jicamarca: 1600-2200 LT; Fortaleza: 0700-1100 and 2000-2300. During the December solstice, Ilorin: 0500-0800 and 1600-1800 UT; Jicamarca: 1100-2200 UT and 1100-1800 UT at Fortaleza.
- When transparent sporadic-E is present, it was observed that refraction in the F2 layer occurred and partial transmission of signal and fading is observed at the sight of blanketing sporadic-E.
- Es is more prevalent during the solar minimum epoch and occurs at the solstice months than the equinox months.
- No correlation between Es and geomagnetic storm was observed

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