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RESEARCH PAPER

VARIABILITY OF SPORADIC-E (E_s) LAYER AT TWO EQUATORIAL STATIONS: FORTALEZA (3^oS, 38^oW) AND ILORIN (8.5^oN, 4.5^oE)

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ABSTRACT
The day time variability of sporadic-E (E_s) layer at Fortaleza (3^oS, 38^oW) and Ilorin (8.5^oN, 4.5^oE) during the solstice and equinox periods have been investigated using hourly daily Digisonde ionograms. The result show that during the equinox period, the critical frequency (f_oE_s) of the E_s-layer at Fortaleza dropped to minimum values before rising to its first peack values by 0900 hrs LT and 1000 hrs LT in March and September respectively. On the other hand, a continuous rise in the value of f_oE_s from sunrise till the first peack values of 6.0MHz by 0800 hrs LT and 5.5MHz by 0700 hrs LT was observed during the June and December solstices respectively. At Ilorin, the f_oE_s reached its first peack values of 5.5MHz by 1200 hrs LT and 6.0MHz by 1000 hrs LT during the March and September equinoxes respectively. A double peack of about 5.4MHz by 0800 hrs LT and 6.5MHz by 1300 hrs LT was observed during the June Solstice as compared to the single peack of about 7.00MHz during the December solstice. The height (h_mE_s) of E_s was lower at Fortaleza than at Ilorin for all the seasons (with a difference of between 2 and 4 km, depending on the month). For all the seasons and months investigated, the E-layer was never observed earlier than 0900 hrs LT at Fortaleza. At Ilorin, the E-layer was formed right from sun rise with frequencies lower than at Fortaleza. These results comfirm the latitudinal variation of the sporadic-E layer at the equatorial region. It also showed that the E-layer is formed earlier in Ilorin than at Fortaleza with a time lag of about 3 hours.

Keywords: *Sporadic-E (E_s) layer, Critical frequency (f_oE_s), virtual height (h_mE), Equinox, Solstice*

INTRODUCTION

The ionosphere is an electrified region of the upper atmosphere where there is fairly large concentrations of ions and electrons. It starts from a height of about 60 km above the earth's surface and extends upward to the top of the atmosphere (Ahrems, 2009). The ionosphere contains sufficient ions and electrons to influence the propagation of radio frequency and electromagnetic waves within and through it. It has been vertically classified into bottomside, topside and plasmasphere. The bottomside is further classsified as D, E, and F-regions according to their chemical composition, sources of ionisation, level of variability and dynamic structure.

The E-region of the ionosphere exists predominantly during the daytime and begins to disappear at dusk due to recombination (Prasad *et al.,* 2012). The E-layer is close to the earth's surface lying in the altitude region of 90-150 km. Because of its closeness to the earth's surface, the E-layer is subject to various physical influences e.g acoustic, electromagnetic radiation, etc, coming from the earth's surface (Barns, 1994; Liperovskaya *et al.,* 2003). The vertical mobilities of electrons are much higher in the E-region than those of positive ions. The primary East-West field causes a vertical polarization of electric field that greatly increases the electric conductivity of the medium (Woodman *et al*., 1977) which enable the flow of a strong eastward electric current in the E-layer during the daytime hours. This, in the equatorial region, is called equatorial electrojet (Woodman *et al.,* 1977). The E-layer exhibits irregular patches of high ionization usually confined to small regions known as Sporadic-E (E_s) layer (Barns, 1994; Flores and Foppiano, 2008; Prasad *et al.,* 2012; Tiwari *et al*., 2012). Sporadic-E layers are plasma clouds of metallic ions having small vertical and large horizontal dimensions. The vertical dimension is usually from few hundred meters to few kilometers while the horizontal dimension is between 50-200 km (Liperovskaya *et al*., 2003; Tiwari *et al*., 2012). The E_s layers sometimes can be embeded in the regular E-layer with maximum densities not more than the ambient density. The virtual heights of such E_s layers differ only very little from the virtual height of the regular E-layer (Paul, 1990). Mathews (1998) defined the sporadic-E layer as an altitude–thin E-region at an unpredictable altitude and /or unexpected intensity. The term "Sporadic-E" was derived from ionosonde observations that describes a variety of E-region echoes from a variety of high frequency sounding instruments (Ritchie and Honary, 2009; Tiwari *et al*., 2012). The term "Sporadic" has continued to pose semantic problems because the different classifications of E_s display various levels of periodicity and thus predictability. The most current definition of E_s is simply "an ionisation layer lying anywhere in the E-region" (Ritchie and Honary, 2009).

Sporadic – E_s is formed when plasma clouds of metallic ions of intense ionisation occassionally form in the E-region of the ionosphere (Liperovskaya *et al*., 2003; Ritchie and Honary, 2009). At high latitudes, Es-layers are generally believed to be caused by the precipitation of charge particles (Narinder *et al.,* 1980; Ritchie and Honary, 2009; Prasad *et al.,* 2012). At mid latitudes, charge metal ions that swept into narrow layer of about 1-5 km thick in vertical scale are called sporadic-E_s layer (Flores and Foppiano, 2008). They are formed by vertical shear in the east-west component of horizontal winds in the height range of 100 – 150 km in the E-region (Prasad *et al*., 2012). In the equatorial zone, E_s are due to strong eastward electric field (equatorial electrojet) during the day. Other factors that play a significant role in the formation of E_s in this zone are thunderstorms, meteors, ionospheric current systems, etc (Prasad *et al*., 2012). Sporadic E (E_s) layer is a daytime phenomenon in the equatorial zone and show little seasonal variations. At the auroral zone, the E_s layer is predominantly a night-time phenomenon. It show very little seasonal variation (Prasad *et al*., 2012).

The common theoretical explanation of the formation of E_s-layers is the wind shear theory. Wind shears come from three wave sources namely atmospheric gravity waves, tides and planetary waves (Flores and Foppiano, 2008). These winds originate at altitudes where the direction of the local zonal wind changes from west to the east i.e in the direction of wind shear. According to the wind shear theory, charged particles (ions) accummulate into thin, patchy sheets by the action of high altitude winds in the E-layer of the ionosphere (Liperovskaya *et al*., 2003; Ritchie and Honary, 2009). In this region, the wind velocity divergence vanishes and a sporadic layer is formed. This theory (the wind shear theory) is now widely believed to be the possible mechanism responsible for the formation of sporadic – E_s (Lipperovskaya *et al*., 2003; Ritchie and Honary, 2009; Prasad *et al*., 2012; Tiwari *et al.,* 2012).

Another cause of the formation of E_s is the electric field when it is pointing in a proper direction. The east-west electric field, which arise from the world wide dynamo current system, produces abnormally large effects in the equatorial ionosphere. In the E region, where the vertical mobilities of electrons are much higher than those of positive ions, vertical polarization electric field caused by the primary east-west field increases the electric conductivity of the medium (Woodman *et al*., 1977). This enables the flow of a strong eastward current in the E region during the daytime hours called equatorial electrojet. Parkinson *et al*. (1998) showed that this theory is particularly effective at high altitudes where strong electric fields are encountered (Ritchie and Honary, 2009). This was further corroborated by Damatie *et al*. (2002) who presented further evidence for the presence of vertical shears in the meridional E – region neutral wind and the right conditions for the electric field theory.

This work is aimed at investigating the variability of sporadic E_s layer at the equatorial region during the equinox and solstice period using two stations: Fortaleza (3^oS, 38^oW) in Brazil and Ilorin (8.5^oN, 4.5^oE) in Nigeria (Fig. 1) as case studies. The parameters used in this investiagtion are the critical frequency (f_oE_s)

Fig. 1: Map showing stations where the Digisonde is operational. The two stations used for this study are indicated in deep black dots.
(Source: ulca.uml.edu/stationmap.html)

and the height (h_mE_s) of the sporadic-E_s layer.

DATA AND ANALYSIS

The data utilized in this study were obtained from hourly records of ionograms recorded by Digisonde portable sounder at two tropical stations (Fortaleza, 3°S,38°W and Ilorin 8.5°N, 4.5°E) and posted to the website of the University of Massachussets at Lowell, USA. At Fortaleza, the ionosonde that have been in operation since 1975 was replaced in 1993 by a Canadian Advance Digital Ionosonde (CADI). A Digisonde is a mordern digital device used to determine ionospheric characteristics above the vicinity of the instrument. It comprises of radio wave transmitter, receiver, and associated transmit and receive antennas. Generally, a Digisonde operates within the 1to 20 MHz band with a physically large transmit antenna and four smaller, spaced receive antennas deployed in an equilateral triangle. A detail description of a Digisonde and how it works can be obtained from the website of High Frequency Active Auroral Research Program (HAARP). The Digisonde used for recording the ionogrammes at Ilorin came into operation in 2010. It is one of the five African stations where this equipment is currently being used. Simultaneous hourly data from the two stations covering the March and September equinoxes and June and December Solstices were extracted from the hourly ionograms and analysed and compared with results from other stations. For each day and month, hourly values of the parameters from hourly ionograms between the hours of 0600 hrs and 1800 hrs LT were extracted. The parameters extracted from the ionograms are the frequency of the E-layer (f_oE), the critical frequency (f_oE_s) of the sporadic-E (E_s) layer and the virtual height (h_mE_s) of the sporadic-E_s layer. The analysis was based on 12-hour daytime data starting from 0600hrs to 1800 hrs local time for the respective seasons in 2010.

RESULTS AND DISCUSSION

Variability of h_mE_s during equinoxes

Figs 2 (A and B) show the variability of the height of sporadic-E_s (h_mE_s) at Fortaleza and Ilorin respectively during the equinox period. It was observed from this figure that h_mE_s at sunrise is lower at Fortaleza than at Ilorin for all the seasons (a difference of between 2 and 4 km, depending on the month) signifying the latitudinal variation of h_mE_s. At Ilorin, the height of the sporadic-E_s layer continued to decrease right after sunrise during the March and September equinoxes. It decreased by about 10 km from a height of 114 km at 0600 hrs LT to 104 km by 1600 hrs LT. The observed fall in h_mE_s at Ilorin confirmed the results of Prasad *et al*., (2012) who observed a fall in h_mE_s after sunrise in India. The peak height of E_s depends on the latitude i.e as latitude increases, the height of the E_s layer increases. The frequency of the occurrence of the Es layer increases from the equator to higher latitudes. As noted earlier, the formation of the E_s-layer for equatorial latitudes differ from those for middle and high latitudes. The mechanism responsible for the formation of the E_s-layer at the equatorial region is the well-known gradient drift (i.e E x B drift) mechanism which occurs inside the Equatorial ElectroJet (EEJ). The EEJ is known to be affected by the solar cycle (Woodman *et al*., 1977; Balsey 1970) causing a reversal of the electric field.

A study of the seasonal variation of the reversal time of the EEJ over India and Peru (Rastogi and Chandra, 1974) revealled differences in the evening reversal times believed to be responsible for the major longitudinal differences in the occurence of Es, spread F and the general F region itself (Woodman *et al*., 1977). The occurence of the evening reversal time of the EEJ takes place one hour earlier during low sunspot years than during high-sunspot years. Although the spordic-Es occurence have been associated with solar activity, studies have shown that no definite correlation could be established between the two (Tiwari *et al*., 2012). For the American zone, estimates of the reversal time of the electrojet fields showed that for the June

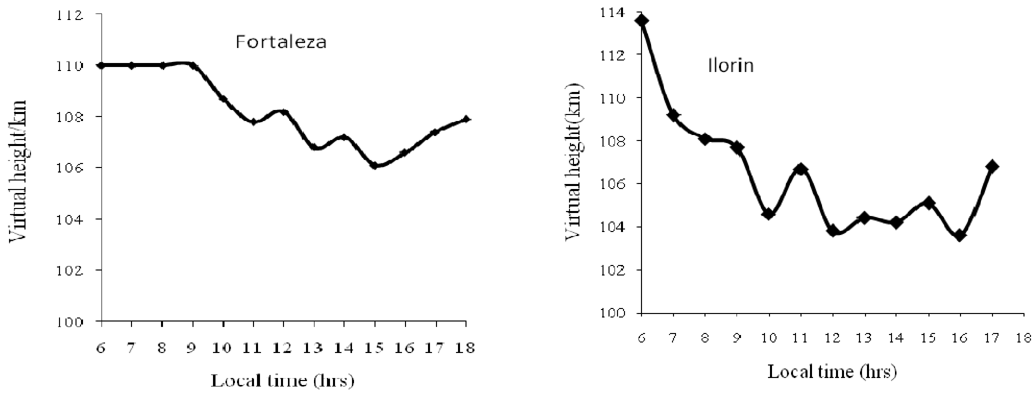

Fig. 2a: Day-to-day variability of h_mE_s at Fortaleza and Ilorin stations for March equinox

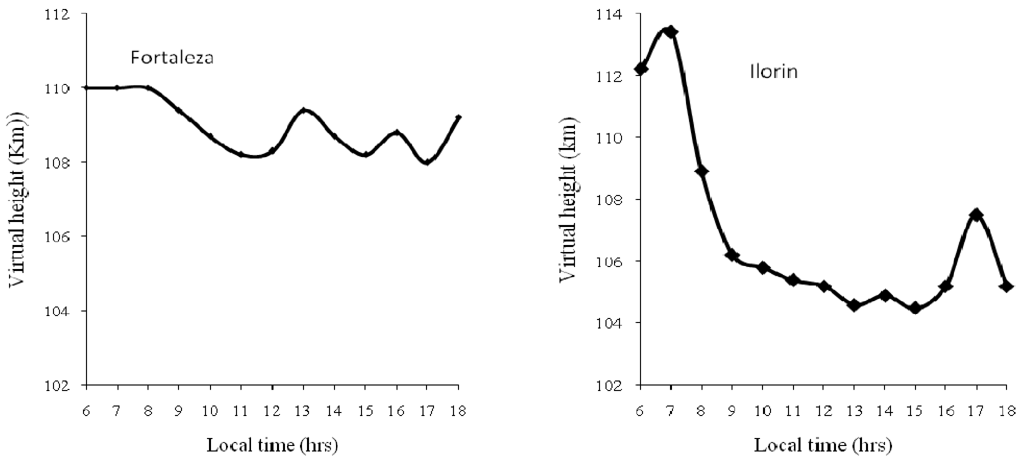

Fig. 2b: Day-to-day variability of h_mE_s at Fortaleza and Ilorin stations for September equinox.

solstical season, the reversals occur about two and half hours after sunset (Woodman *et al.*, 1977). At Fortaleza, the formation of E_s is known to be influenced by the roles of the electric fields of EEJ and neutral winds (Abdu and Batista, 1977, Tiwari *et al.*, 2012). The average virtual height of E_s-layer during the equinox period at Ilorin ranged between 104 km and 114 km while that at Fortaleza is between 106 km and 110 km. Also, there was a sudden increase in h_mE_s at Ilorin in September between 0600 and 0700 hrs LT before the continuous decrease. On the other hand, the variability of h_mE_s at Fortaleza started 3 hrs after sunrise though the variability was not significant.

Variability of f_oE_s during equinoxes

Figs 3 (A and B) show the variability of f_oE_s at the two stations during the March and September equinoxes. It was observed that the critical frequency of the E_s-layer varied greatly at the two stations. At Ilorin, the f_oE_s reached a maximum value of 6 MHz by 1000 hrs LT during the September equinox as compared to 5.5 MHz by mid-day LT during the March equinox. There was a suden increase in f_oE_s during the March equinox to another maximum of 6.5 MHz by 1400 hrs LT before decreasing to its night time value. During the September equinox, there was a second peack of smaller magnitude of 4.5 MHz by 1400 hrs LT after which it continued its normal decrease to the evening minimum.

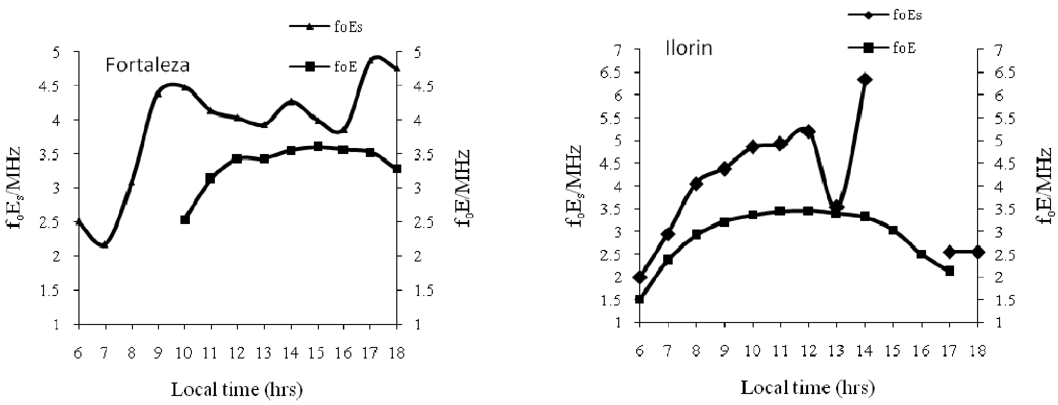

Fig.3a: Day to day variability of f_oE_s at Fortaleza and Ilorin stations for March equinox

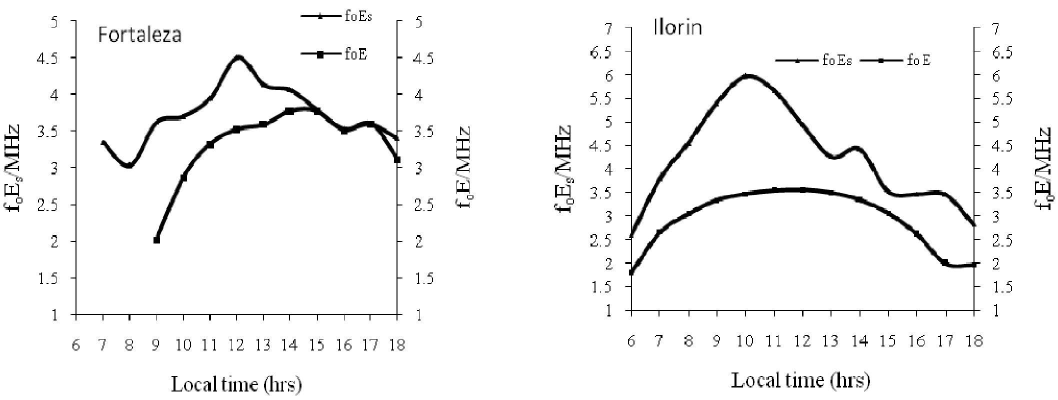

Fig. 3b: Day to day variability of f_oE_s at Fortaleza and Ilorin stations for September equinox

At Fortaleza, unlike the continuous increase in f_oE_s at Ilorin right from sunrise until it reached its first maximum in both March and September equinoxes, there was a small drop in f_oE_s in both months with a time lag of about 1 hr LT. During the March equinox, f_oE_s dropped to about 2.1 MHz by 0700 hr LT from 2.5 MHz before reaching its first peack of 4.5 MHz by 1000 hrs LT. It then decreased slightly before reaching two other peacks of 4.3 MHz by 1400 hrs LT and 5.0 MHz by 1700 hrs LT respectively. During the September equinox, the f_oE_s dropped from about 3.4 MHz to 3.0 MHz by 0800 hrs LT before reaching its peack of 4.5 MHz by mid-day. It then continued to decrease thereafter into the night-time value. It was observed from Fig. 3 that the f_oE_s at sunrise at Ilorin was lower than that at Fortaleza.There was a frequency difference of between 0.5 MHz and 0.9 MHz in March and September equinoxes respectively for the two stations. This observed decrease of f_oE_s with increase in latitude which is only observed during the equinox period is further supported by Prasad *et al.* (2012).

Variability of h_mE_s during solstices

Figs 4 (A and B) show the variation of h_mE_s at Ilorin and Fortaleza during the June and December solstices period. During this period, the virtual height (h_mE_s) of the E_s-layer remained constant for about 2 to 3 hrs LT at Fortaleza before the variability started. The h_mE_s started to drop by 0900 hrs LT during the June solstice, reaching a minimum height of about 104 km by 1400 hrs LT in the afternoon and thereafter it continued to increase steadily. In December, the h_mE_s started declining around 0800 hrs LT reaching a minimum value of about 107 km by 1000 hrs LT, after which it continued showing little variability. At Ilorin, the virtual height of the E-layer continued to decrease right from sunrise from a value of 112 km to a minimum value of about 104 km by 1100 hrs LT during the June solstice. It then remained steady for the next four hours after which it started to increase, reaching a peack of about 107 km by 1700 hrs LT and thereafter it continued to decrease. During the December soltice at Ilorin, the h_mE_s reached a height of about 114 km by 0700 hrs LT before dropping to a minimum value of 105 km by 1000 hrs LT. The variability of h_mE_s wasn't much thereafter. The average virtual height of the Es-layer at Fortaleza during the solstice period ranged between 104 km and 110 km while that at Ilorin was between 104 km and 113.8 km.

Variability of f_oE_s during solstices

The variability of f_oE_s during the solstice period is shown in Fig. 5. It was observed that the critical frequency of the sporadic-E_s layer varied greatly at both stations during this period. At Fortaleza, the f_oE_s continued its steady increase from sunrise and reached a maximum value of about 6.0 MHz by 0800 hrs LT in the morning during the June solstice. It then dropped sharply reaching a minimum value of 3.0 MHz before rising steadily. The same thing happened during the December solstice. It jumped to a peack of 5.5 MHz by 0700 hrs LT before dropping to a minimum value of 2.5 MHz two hours later. It then assumed its steady rise, reaching another peack of 5.0 MHz by 1500 hrs LT before decreasing to the night time value.

On the other hand, the critical frequency of the sporadic-E (E_s) at Ilorin increased steadily during the December solstice reaching a peack of 7.0 MHz by 1600 hrs LT in the afternoon. It then continued to drop thereafter to its night time value. Two peaks were observed for the June solstice at Ilorin. The first peack of 5.5 MHz occured by 0800 hrs LT before dropping to about 4.0 MHz one hour later. It then started increasing steadily and reached the second peack of 7.0 MHz by 1400 hrs LT in the afternoon. Another observation that could be made from Fig. 5 is that the value of f_oE_s at sunrise differed between the two stations. At sunrise, the critical frequency is about 3.0 MHz during the June and December solstices at Ilorin. At Fortaleza, there was a difference of 0.5 MHz between the June and December solstices at sunrise. There was also a difference

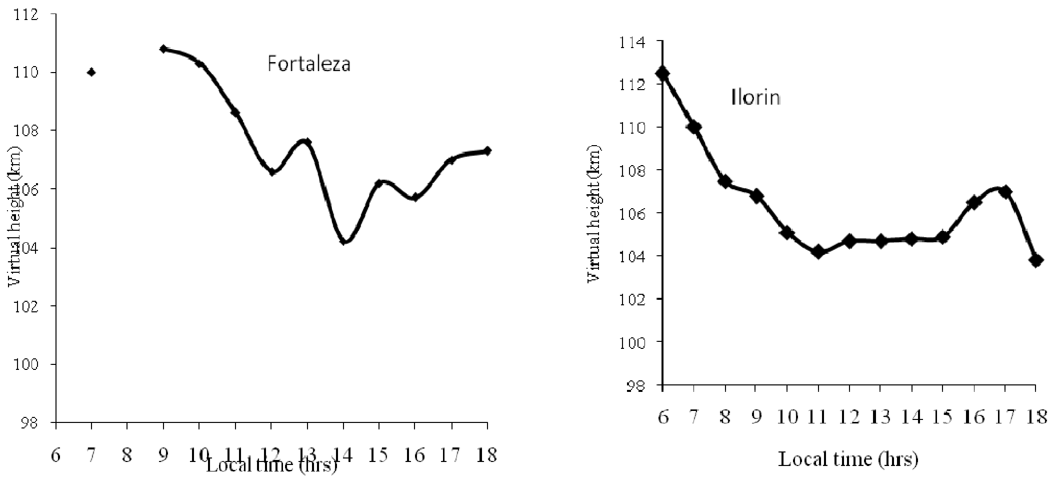

Fig.4a: Day-to-day variability of h_mE_s at Fortaleza and Ilorin stations for June solstice

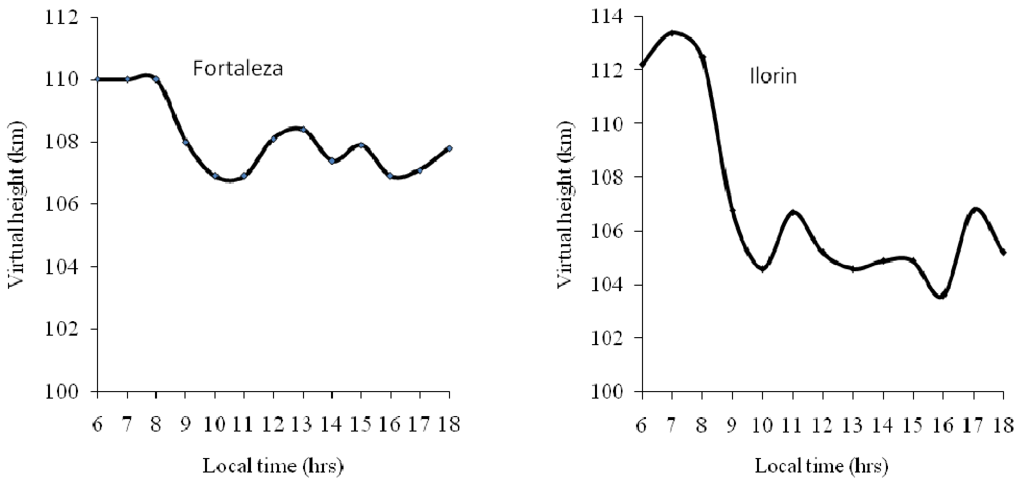

Fig. 4b: Day-to-day variability of h_mE_s at Fortaleza and Ilorin during December solstice

of 1 MHz at sunrise between Ilorin and Fortaleza during the June solstice and a difference of 0.5 MHz at sunrise between both stations during the December solstice. For both the equinox and solstice periods, the critical frequency for the E-layer at Fortaleza was not observed earlier than 0900 hrs LT.

The development of the critical frequency of the E-layer (f_oE) from the two stations during the equinox and solstice periods is also worth noting. Throughtout the two seasons, the f_oE

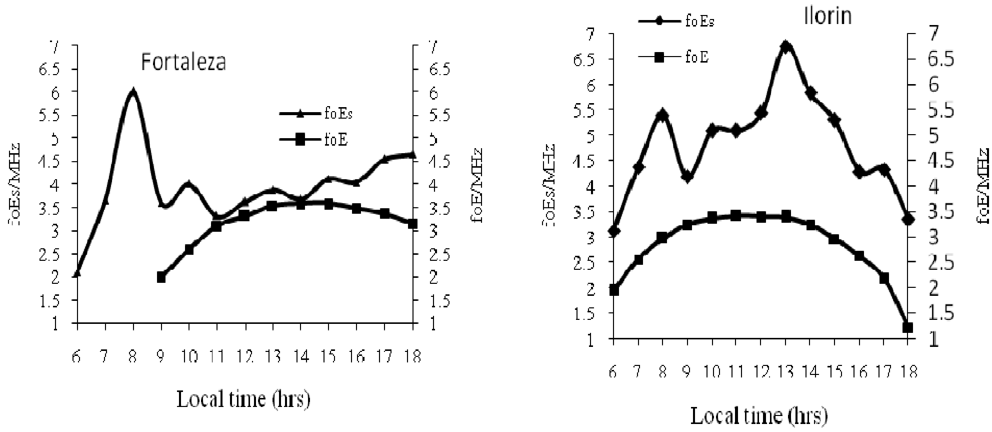

Fig. 5a: Day to day variability of f_oE_s at Fortaleza and Ilorin stations during June solstice

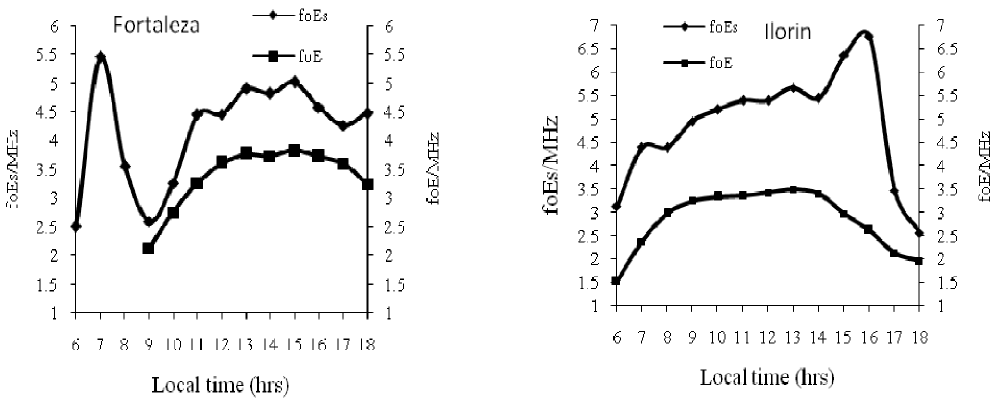

Fig. 5b: Day-to-day variability of f_oE_s at Fortaleza and Ilorin sstations during December

was not observed before 0900 hrs LT at Fortaleza.This result is consistent with Prasad et al. (2012)who could not observe the f_oE for an equatorial station (Trivandrum) in India before 0800 hr LT. However, it developed and was observed before sunset at Ilorin. The frequency at which they were first observed also vary depending on the month but generally lower at Ilorin than at Fortaleza. The f_oE for Fortaleza was higher at sunrise compared to that at Ilorin for both the equinox and solstice periods. The f_oE varied between 2 MHz and 3.7 MHz during the equinox period and 1.8 MHz and 3.6 MHz during the solstice period at Fortaleza respectively. For the same period, the f_oE varied between 1.5 MHz and 3.2 MHz .

during equinox and 1.5 MHz and 3.0 MHz during the solstice period respectively at Ilorin.

The variability of the observed number of days at Fortaleza and Ilorin are shown in Figs 6 and 7 respectively. It was noted that the number of observed days at Ilorin is lower, below 5, throughout March as compared to June, September and December (Fig.7). Also, the observed days at Fortaleza were more compared to Ilorin (Fig. 6).

CONCLUSION

Its well known that the E_s have different char-

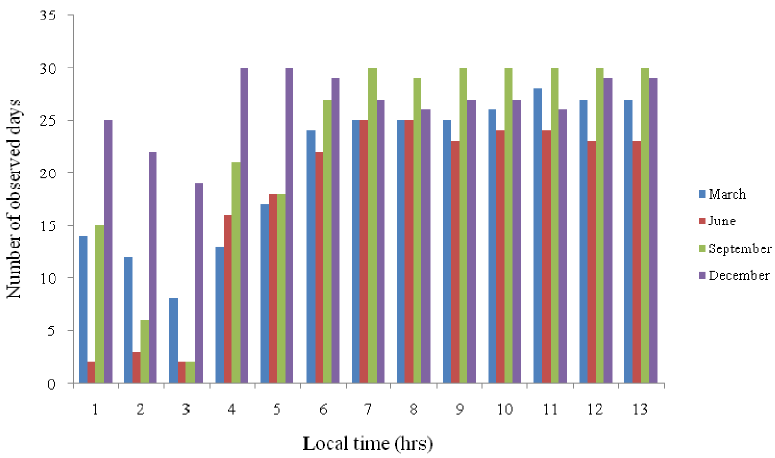

Fig. 6: Variability of the observed days for Fortaleza station

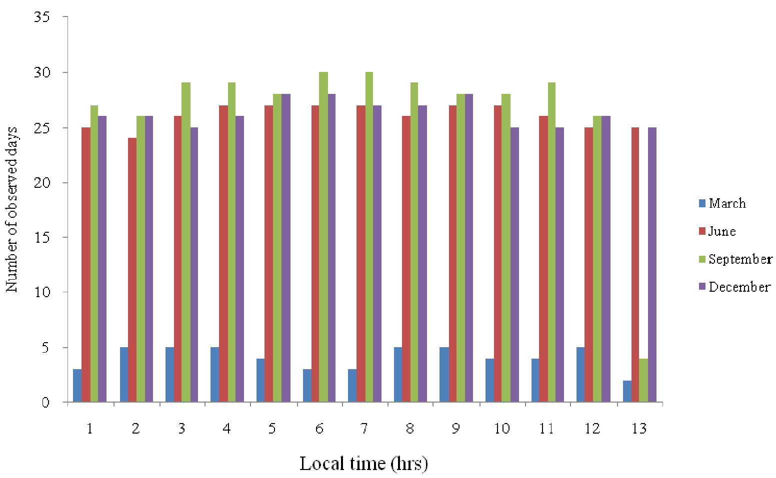

Fig. 7: Variability of the observed days for Ilorin station

acteristics in different latitudinal zones and hence several mechanisms governing behaviour. For high latitude E_s – layers, particle precipitation are generally considered to be the governing mechanism as confirmed by Narinder *et al.* (1980). These authors also found that the modified wind shear mechanism which takes into account the effect of the electric fields, is important under low electron precipitation conditions only. In the equatorial region the equatorial electrojet, thunderstorms, ionospheric current systems, etc, are known to be responsible for the formation of E_s-layer.

Although the E_s - layer at the equatorial region show little seasonal variation, our results show that the E_s-layer show more variability during the solstice period than equinox. The virtual height of the sporadic-E_s layer is lower at Fortaleza for all the seasons than at Ilorin (a difference of between 2 - 4 km, depending on the month and season). This confirms the latitudinal variation of the E_s - layer at the equatorial region as observed by Prasad *et al*. (2012) and Twari *et al*. (2012). The absence of the f_oE-layer before 0900 hrs LT at Fortaleza was also observed whereas at Ilorin this layer was developed before sunrise.

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