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Variability of the Critical Frequency of the F_2 Layer, foF_2 in West Africa using Ionosonde Stations at Ouagadougou and Dakar

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Abstract: The critical frequency of the F_2 layer of the ionosphere, foF_2 is responsible for various effects on radio communication such as refraction, scintillation, absorption, error in Global Positioning System (GPS), jitter and phase delay. The variations of the critical frequency of the F_2 layer at two different locations over West Africa were studied using ionosonde data for a solar cycle (1979 to 1989) at low, moderate and high solar activity, 1986, 1983 and 1989, respectively. The ionosonde stations are Dakar in Senegal (15°N, 17°W) and Ouagadougou in Burkina Faso (12°N, 1.8°W). The investigation of critical frequency of the F_2 layer, foF_2 using Relative Standard Deviation (RSD) revealed the spread and the occurrence of foF_2. The results obtained in this study are proposed as equatorial input values for the development of a Variability Model for the International Reference Ionosphere.

Key words: Ionosphere, variability of foF_2, critical frequency, equatorial input, West Africa

INTRODUCTION

The state of ionosphere may be described by different parameters. The most widely used description of its state is the critical frequency. The critical frequency of an ionospheric layer is the highest frequency of a given layer when standard daily stratification is present (Mosna *et al*., 2008). The critical frequency of the F_2 layer of an ionosphere is the frequency at which the F_2 layer reflects electromagnetic waves. It is related to the maximum ionospheric electron density, Ne, according to the equation (Mosna *et al*., 2008):

$$(f_N)^2 = \frac{Ne^2}{\varepsilon_0 m 4\pi} \qquad (1)$$

Where:

f_N = Plasma frequency
N = Electron concentration
e, ε_0 and m = Elementary charge, vacuum permittivity and mass of electron, respectively

The measure of the state of the ionosphere is determined by the foF_2 values. The critical frequency of the F_2 layer of an ionosphere is influenced by the solar activity as well as the geomagnetic activity and the neutral atmosphere effects. It is highly variable with short periods (minutes), medium periods (1day, 27 days solar cycle) and long periods (1 year, one solar cycle). Due to these dynamic characteristics of the critical frequency of the F_2 layer of an ionosphere, foF_2, it is necessary to use proper methods to understand its variation in the ionosphere as it highly attenuates the propagation of radio wave.

In this study, Relative Standard Deviation (RSD) was used to study the variations of critical frequencies of the F_2 layer using the ionosonde stations at Dakar in Senegal (15°N, 17°W) and Ouagadougou in Burkina Faso (12°N, 1.8°W). Relative Standard Deviation (RSD) is often times more convenient because it is expressed in percent thus make it easier to compare the values of the critical frequencies of the F_2 layer using different stations. The Relative Standard Deviation is given as:

$$RSD = \frac{s}{\mu} \times 100 \qquad (2)$$

Where:

σ = The standard deviation
μ = Mean

There are many recent studies on the variability of the ionosphere. These studies vary in terms of the specific ionospheric parameter whose variability is being investigated. Jayachandran *et al.* (1995), Forbes *et al.* (2000), Rishbeth and Mendillo (2001) and Kouris and Fotiadis (2002) used monthly median, upper and lower quartile to investigate the variations of foF_2. However, it was observed that the parameters do not cover all the

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data points. It covers 50% of all the data points and ignores the other 50% of the data. Thus, the reason to consider a method which fully utilizes all the data point so as to be justified in given reports on the variation of critical frequency of the F_2 layer, foF_2.

MATERIALS AND METHODS

Data collection: The data used for this study were collected from two ionosonde stations in West Africa, namely Dakar in Senegal (15°N, 17°W) and Ouagadougou in Burkina Faso (12°N, 1.8°W) through NSSDC/SPDF both stations are near the magnetic equator and contained highest data of the critical frequency of F_2 layer in the West Africa region. The choice of choosing the two stations is to investigate the degree of variability of the critical frequency of F_2 layer in the West Africa region. The data were collected hourly and covers the years of low, moderate and high solar activity of 1986, 1983 and 1989, respectively; within the solar cycle 1979 and 1989.

Seasonal variations of the critical frequency of the F_2 layer were investigated by using a 3 months data for each season: March Equinox (February, March and April), June Solstice (May, June and July), September Equinox (August, September, October). The diurnal investigation was carried out using the equinox and solstice seasons. The months of March Equinox used for the study corresponds with the months of Winter, the June solstice corresponds with the Spring and September Equinox corresponds with the Summer. The calculations of the monthly sunspot number (Smoothed Sunspot Number, SSN) was carried out using average annual sunspot number (R_Z) relation (Table 1):

$$R_Z = \sum \frac{SSN}{12} \qquad (4)$$

where the SSN represents the monthly Smoothed Sunspot Numbers:

$$SSN = \frac{\frac{n_1}{2} + n_2 + n_3 + --- + n_7 + --- + n_{11} + n_{12} + \frac{n_{13}}{2}}{12}$$

Where:

n_1 to n_6	=	Represents 6 months before the month that researchers want to calculate
n_7	=	The month researchers obtained
n_8-n_{13}	=	The 6 months backward

Data analysis: The solar cycle selected for the analysis of the critical frequency, foF_2 of the F_2 layer, over Dakar and Ouagadougou consisted of 11 years data from 1979-1989. The hourly values of foF_2 over the years of low, 1986, moderate, 1983 and high, 1989 solar activity were used in the study. This was done by grouping the hourly values on equal interval ranges between 0 and 23 h for each month and season and then the 3 months running mean μ and standard deviation σ of each season were calculated. The Relative Standard Deviation, RSD was used to investigate the variability of the critical frequency, foF_2 over Dakar and Ouagadougou of the seasonal variation covering March Equinox (February, March and April), June Solstice (May, June and July) and September Equinox (August, September and October).

Table 1: The years of data used in this study and their average sunspot number

Solar activity	Low	Moderate	High
Dakar	1986 (Rz = 13.4)	1983 (Rz = 66.6)	1989 (Rz = 157.6)
Ouagadougou	1986 (Rz = 13.4)	1983 (Rz = 66.6)	1989 (Rz = 157.6)

The standard methods that have been mostly used to investigate the variability of the ionosphere are the median and mean model. For example, Kouris and Fotiadis (2002) and Fotiadis have used the median (q_{50}), upper/lower quartiles (q_{25}, q_{75}) and deciles (q_{10} q_{90}) to represent the data scatter during the month. The advantage of these parameters (median, upper/lower quartile and deciles) is that they are easily interpreted in terms of probability e.g., the upper/lower quartile (q_{25}, q_{75}) covers 50% of all data points. The disadvantage is that the quartiles ignore the other 50% of the data. But the Relative Standard Deviation (RSD) on the other hand is a good measure for describing the average deviation from the monthly mean.

The Relative Standard Deviation (RSD) of a set of data was calculated using the standard deviation. The use of relative standard deviation in investigating the variation of foF_2 will be more justified in given report of the true behavior of the foF_2 because the relative standard deviation uses all the data points in a set of values as compared to mean and median which only give the average of a set of data representing the whole set.

RESULTS AND DISCUSSION

Diurnal variations of the critical frequency of the F_2 layer of the ionosphere: Figure 1-3 show the plot of the diurnal variations of the critical frequency of the F_2 layer for two stations for 1986, 1983 and 1989. A gradual morning rise and evening decrease of foF_2 was observed. Maximum foF_2 occurred around (10-16 h LT) between (10-15 MHz). There were irregularities in the trend of the result obtained; this could be attributed to spread F layer of the ionosphere. These were caused by strong undulations and irregular plasma structuring in the F region electron density.

Figure 4-6 showed the comparison between the predicted fo F_2 by IRI and measured foF_2 values. The

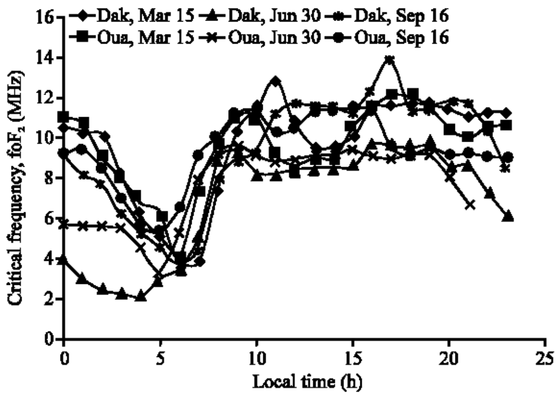

Fig. 1: Diurnal variations of foF_2 in Dakar and Ouagadougou for year of low solar activity in 1983

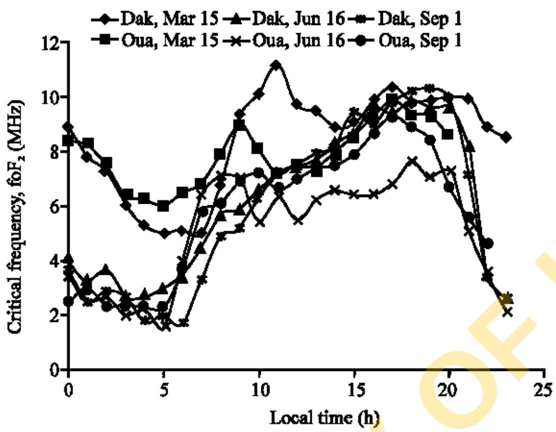

Fig. 2: Diurnal variations of foF_2 in Dakar and Ouagadougou for year of moderate solar activity in 1986

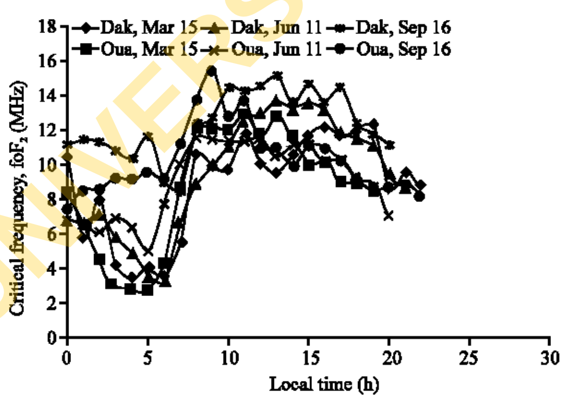

Fig. 3: Diurnal variations of in Dakar and Ouagadougou for year of high solar activity in 1989

irregular variations observed from the measured values of foF_2 were not observed with the Predicted IRI values.

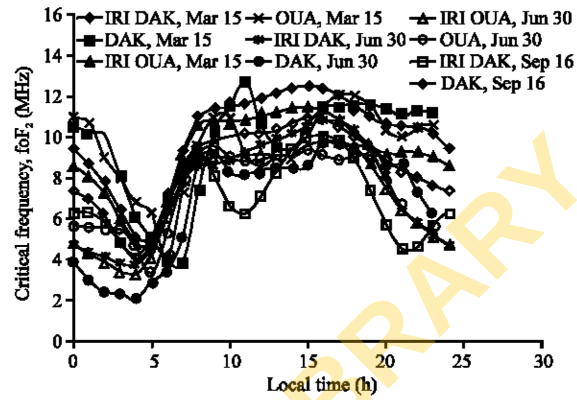

Fig. 4: Diurnal variations of the measured values of the foF_2 and the IRI value of the foF_2 for Dakar and Ouagadougou. Year of low solar activity in 1983

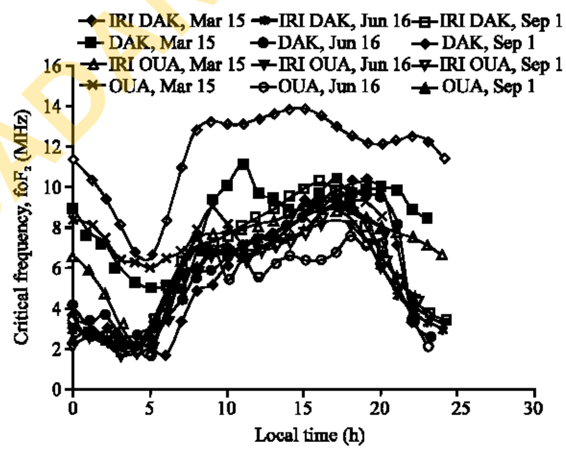

Fig. 5: Diurnal variations of foF_2 in Dakar and Ouagadougou. Year of moderate solar activity in 1986

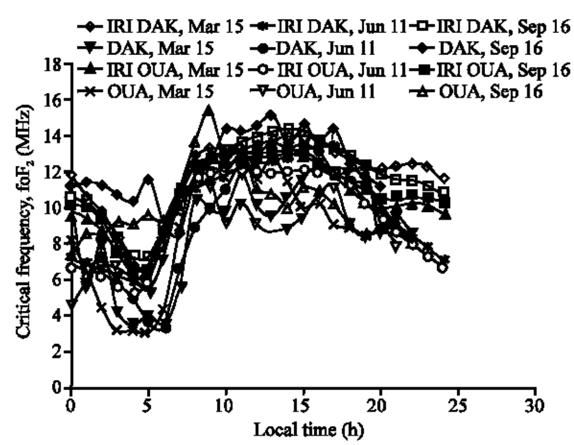

Fig. 6: Diurnal variations of foF_2 in Dakar and Ouagadougou. Year of high solar activity in 1989

The prediction is similar for all the days considered in the past research carried out (Oyeyemi, 2006) on the confirmation of IRI Model.

Seasonal variations of the critical frequency of the F_2 layer of the ionosphere: The Relative Standard Deviation (RSD) Model was used to analyze the seasonal variations of the critical frequency of the F_2 layer of the ionosphere based on March Equinoxes, June solstice and September Equinox for the low, moderate and high solar activity (1986, 1983 and 1989) in the solar cycle (1979-1989) over Dakar and Ouagadougou. Figure 7 is the diurnal plot of Relative Standard Deviation (RSD) for the Ouagadougou station at low solar activity. The plot showed the variation of the critical frequency of the F_2 layer with local time for all the seasons. The highest variations of foF_2 are seen in the March and September equinoxes compared to June solstice. For all the seasons, the variability of the critical frequency of the F_2 layer was lowest during day time (8-18%) and increased during night time (21-78%). The only consistent variations of foF_2 are seen in the afternoon, it rose at sunset (11-45%). The night differences were at least in part a result of lower mean, μ value during the night time and this result in higher percentage variability during the nighttime. Similar observations were seen in the research of Bilitza (2004) on the variability of foF_2 in the equatorial ionosphere. Tong *et al.* (2008) observed that the standard deviations decreased significantly mostly during day time in each season and night time in summer at Chongqing station, China.

In Fig. 8, the diurnal plot of Relative Standard Deviation (RSD) for the Dakar station at low solar activity have greater variations in the March and September equinoxes than June solstice. Although, lower variations of foF_2 were observed as compared to Ouagadougou, it was highest during night time (20-40%), at day time it reducee (6-15%) then rose at sunset (15-36%). Comparing the variations of the foF_2 derived from Ouagadougou at low solar activity with the foF_2 variations at moderate solar activity as shown in Fig. 9, the Ouagadougou's foF_2 variations were lower despite being at moderate solar activity. Comparing this observation with the research of Tong *et al.* (2008), it was observed that the variations of fo F_2 was nonlinearly dependent on solar activity, at Chongqing station, China. Sethi *et al.* (2002) observed that at mid-latitudes, foF_2 showed nearly a linear relationship with R12 (the 12 months running average of the sunspot number) but the relation was nonlinear for low-latitudes.

The variability of the critical frequency of the F_2 layer was lowest during day time (9-12%) and increased durig

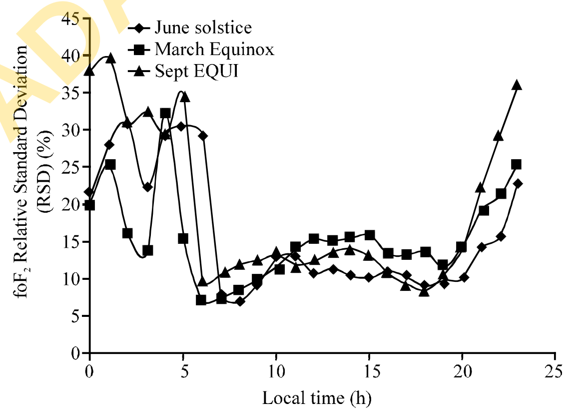

Fig. 8: Diurnal variation of the relative standard deviation for all seasons at low solar activity for Dakar in 1986

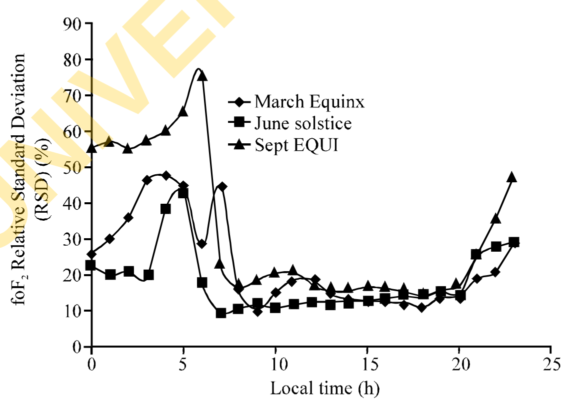

Fig. 7: Diurnal variation of the relative standard deviation for all seasons at low solar activity for Ouagadougou in 1986

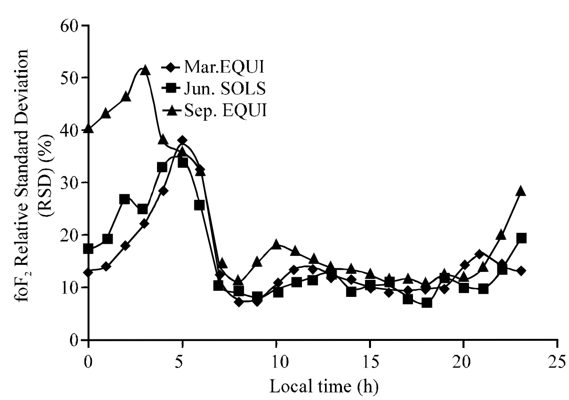

Fig. 9: Diurnal variation of the relative standard deviation for all seasons at moderate solar activity for Ouagadougou in 1983

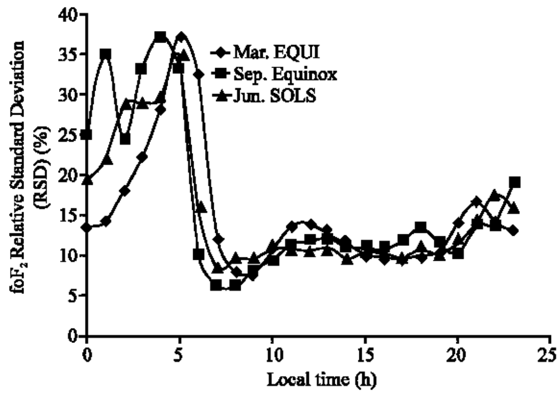

Fig. 10: Diurnal variation of the relative standard deviation for all seasons at moderate solar activity for Dakar in 1983

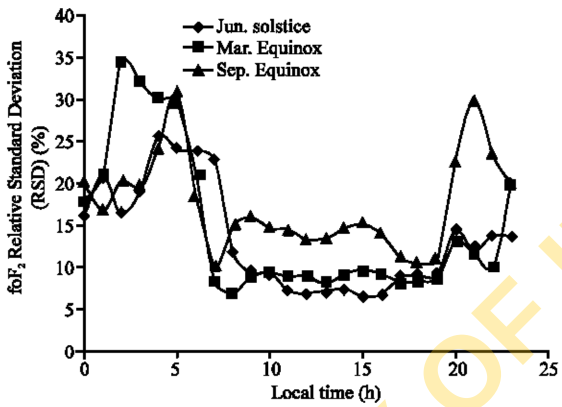

Fig. 11: Diurnal variation of the relative standard deviation for all seasons at high solar activity for Ouagadougou in 1989

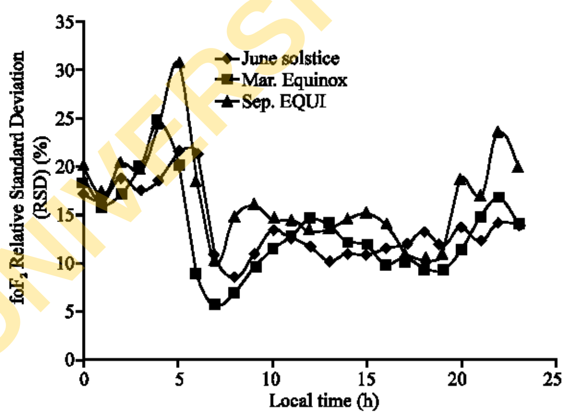

Fig. 12: Diurnal variation of the relative standard deviation for all seasons at high solar activity for Dakar in 1989

night time (12-51%) and at sunset it increased again (12-28%). The only consistent variations of foF_2 were seen in the afternoon (5-10%). The highest variations of foF_2 were seen in the March and September ascribed to the equatorial or seasonal anomaly. In Fig. 10, the diurnal plot of relative standard deviation for the Dakar station at moderate solar activity also showed low variations of foF_2. At night time (13-36%), day time (6-11%) and at sunset (11-17%) with the equinoxes having greater variations compared to the solstice. These findings may be due to the latitudinal variation of the ionosphere. The variations of the ionosphere decreased with increasing latitude. The foF_2 latitudinal dependence derived in this study is in consonance with the result of Danilov and Mikhailov (1999).

The observation in the low and moderate solar activity of the foF_2 was confirmed with the plots in Fig. 11 and 12 at high solar activity. The night time variations of foF_2 are (16-35%), daytime (6-15%) and at sunset (9-29%) with the equinoxes having greater variations compared to the solstice for Ouagadougo. For Dakar at night time (16-36%), day time (5-14%) and at sunset (12-24%) with the equinoxes having greater variations compared to the solstice as shown in Fig. 12. Generally, the observations noted in Fig. 7-12 was in consonance with the observations made in the research of Bilitza (2004). However, further studies are needed using more data measurement at different locations within West Africa in order to make a definite statement.

Plotting the RSD of foF_2 for hourly values of variability of critical frequency of the F_2 layer calculated on a yearly basis for Ouagadougou and Dakar at all the three levels of solar activity (Fig. 13 and 14). The strongest variations of foF_2 with solar activity were seen during night time with a clear increase in variability but decrease in solar activity.

During the daytime, smaller variations of foF_2 were seen. This can be associated with the change in absolute value of the critical frequency of the F_2 layer. And with increase in solar activity, critical frequency of the F_2 layer increased. As a result of this, the percentage variability decreased. This result confirmed the conclusions of the research of Bilitza (2004) on the variability of foF_2 in the equatorial ionosphere.

Comparing the percentage variability of foF_2 for the two stations, variability at Dakar was a few percent smaller than the variability at Ouagadougou. This was expected since Dakar lied in the less variable trough region of the equator anomaly whereas the variability of critical frequency of the F_2 layer in Ouagadougou was influenced by the steep gradients in the rising part of the anomaly crests (Danilov and Mikhailov, 1999).

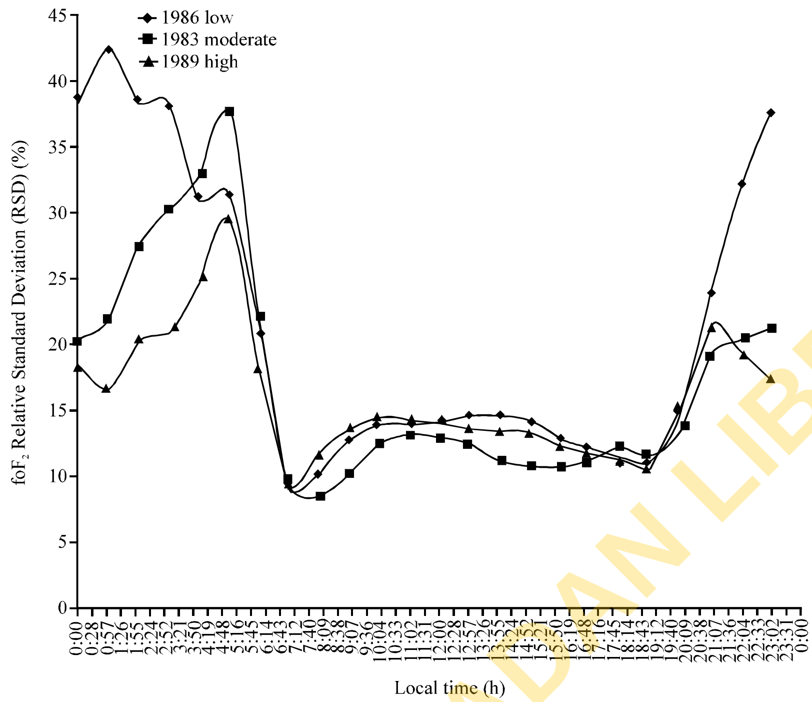

Fig. 13: Variations of the critical frequency of the F_2 layer using Relative Standard Deviation (RSD) averaged over the whole year for low, moderate and high solar activity for Ouagadougou

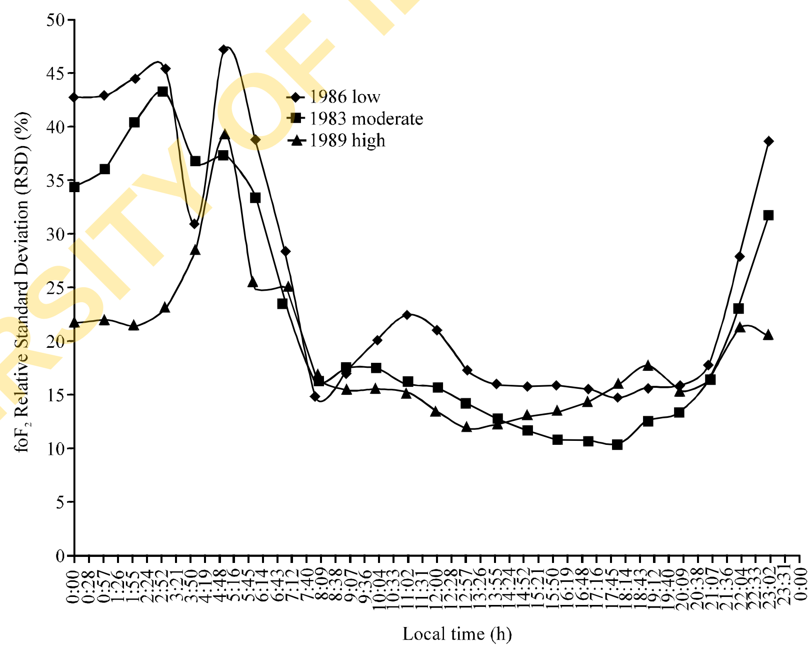

Fig. 14: Variations of the critical frequency of the F_2 layer using Relative Standard Deviation (RSD) averaged over the whole year for low, moderate and high solar activity for Dakar

CONCLUSION

There is a notable agreement between the observations made in this study and that of earlier researches. However, further studies are needed using more data measurement made at different locations within the West Africa region in order to make a definite statement. The Relative Standard Deviation (RSD), variations values of the critical frequency of the F_2 layer, foF_2 obtained in this study will serve as representative values for the equatorial ionosphere in building a variability model for the International Reference Ionosphere.

REFERENCES

Bilitza, D., 2004. 35 years of international reference ionosphere-karl rawer's legacy. Adv. Space Res., 2: 283-287.

Danilov, A.D. and A.V. Mikhailov, 1999. Spatial and seasonal variations of the foF_2 long-term trends. Annal. Geopyisicae, 17: 1239-1243.

Forbes, J.M., S.E. Palo and X. Zhang, 2000. Variability of the ionosphere. J. Atm. Sol. Ter. Phys., 62: 685-693.

Jayachandran, B., N.R. Balachnadran, N. Balan and P.B. Rao, 1995. Short term variability of the ionospheric electron content and peak electron density during solar cycles for a low latitude station. J. Atmo. Solar Terrestrial Phy., 52: 1599-1609.

Kouris, S.S. and D.N. Fotiadis, 2002. Ionospheric variability: A comparative statistical study. Adv. Space Res., 29: 977-985.

Mosna, Z., P. Sauli and O. Santolik, 2008. Analysis of critical frequencies in the ionosphere. Proceedings of the 17th Annual Conference of Doctoral Students-WDS 2008, (Part II), June 3-6, 2008, Matfyzpress, Prague, pp: 172-177.

Oyeyemi, E.O., 2006. A Global Ionospheric f2 Region Peak Electron density model using Neural Networks and extended geophysical relevant inputs. Ph.D. Thesis, Rhodes University, Grahamstown.

Rishbeth, H. and M. Mendillo, 2001. Patterns of F2-layer variability. J. Atmos. Solar Terrs. Phys., 63: 1661-1680.

Sethi, N.K., M.K. Goel and K.K. Mahajan, 2002. Solar cycle variations of foF_2 from IGY to 1990. Annal. Geopyisicae, 20: 1677-1685.

Tong, X., Z. Wu, J. Wu, G. Wei and J. Feng, 2008. A Single-Station Spectral Model of the Monthly Median foF_2 over Chongqing. Vol., 4 Annals of Geophysics, China.