DAY -TO- DAY - VARIABILITY IN SOME IONOSPHERIC PARAMETERS IN THE QUIET EQUATORIAL IONOSPHERE (CASE STUDY: f«F₂)

J. C. Morka and D. N. Nwachukwu

Abstract

The F_2 region of the Ionosphere is a complex one. There are large irregular changes of foF_2 from day - to - day. This paper discusses the diurnal and seasonal variations of f_0F_2. While the diurnal variation of foF_2 has a maximum value at a time far from mid-day, the seasonal variation curve has two maximum points in the months of March and November respectively, with a minimum in July. Thus, indicating that the seasonal variation of foF_2 is a semi - annual one. It was also shown that for short time variations, the day-to-day variability in f_0F_2 is neither due to season nor relative sunspot number, Rz. The test of significance between the standard errors of foF_2 before and after correction for season and Rz show no significant difference at 95% level of significance.

The Ionosphere consists of a number of ionized regions above the earth's surface at a height of 60km to 100km containing ions which play an important role in the propagation of radio waves. It is made up of three layers namely; the D, E and F regions. The region in which this study is based is the F region- ionized region above E region which is further divided into fi and F2 layer in day- time. It is the critical frequency of Fj region that is used for this study.

The predominant ions are No^+ and O^+2 in the F region produced by electromagnetic radiation. In particular, the phenomenology of F2 region is very complex in that the F2 region is very thick with electron density of about $10^6/cm^3$. The F2 region is highly anomalous. Some of these anomalies include geographic, diurnal, seasonal and eclipse.
The diurnal variation of foFa has been observed to vary from time to time and occur with a valley near noon, often called the neon bite out effect. It has also been remarked that there is a well marked semi-annual variation in both maximum electron density and the total columnar ionization of the F2 layer and hence foF_2 of the F2 region (Bates, 1960). There is the world wide result summarized by (Retcliffe, 1960) in the expression
$(f_0F_2)a\ (1 + 0.02Rz)$

Where Rz is the mean Zurich sunspot number. This shows that ft»F2 varies with sunspot number, hence establishing a kind of solar cycle variation (variation of 1 1 year periodicity) The purpose of this study therefore is to investigate all the above using Ibadan data,

Data Collection

The data used in this study were collected from the readings of an lonosonde, which were recorded, into booklets. The lonosonde is the ionospheric sounder used in Ibadan . Ibadan has geographical coordinates 07° 24^7N, 03°$54^/$. The period covered by data is January to December 1998. it was a year of sunspot maximum and when ionospheric recordings were adequately made.

Criteria Used For Quiet Day and Terminologies Used.

The selection of quiet days was based on data readily available and the Ap indices (geomagnetic amplitudes) which are more influenced by short term transient variations for which a satisfactory estimate of Ap less than or equal to 10 (Ap <10) was taken as indicating a magnetically quiet day (arbitrary) and the results, therefore describe the behaviour of the undisturbed F region.

Terminologies Used

Time: Time refers to as local mean time.

Daytime: Hours between 0600 and ISOOhrs.

Nighttime: Hours between 1900 and OSOOhrs.

Seasons: Following the division of the year into seasons by Danilov, and Mikhailov (2004), the different seasons are given by March and April representing March equinox, September and October representing September equinox, May to August representing June solstice, and November to February representing December solstice,

foFa is the ordinary wave critical frequency of the F2 layer.

Analysis

Diurnal Variation

The observed values of foF2 at each hour of the day, representing September equinox, June solstice and December solstice are shown in tables 1(A and B),2 (A and B)and 3(A and B) respectively.

September Equinox (Month of September) F_0f_2 Values (Observed) MHZ

00	01	02	03	04	05	06	07	08	09	10	11	12	13
7.3	7.1	8.7	8.4	8.5	7.9	9.3	12.2	-	14.8	14.3	12.9	12.5	12.1
8.1	7.9	8.6	8.7	8.5	8.5	9.0	12.1	-	14.8	15.2	14.5	13.3	12.7
7.8	7.6	7.4	7.6	7.2	5.3	8.5	11.8	13.4	12.8	13.0	12.1	11.9	11.8
8.6	10.0	8.6	8.4	7.0	3.7	8.3	11.9	13.5	-	14.5	14.3	14.1	13.6
-	-	-	-	-	-	-	-	14.0	14.9	-	13.9	13.2	12.0
-	-	-	-	7.3	6.3	8.3	11.8	13.6	14.8	14.9	14.2	13,2	12.8
1.1	11.2	11.4	10,8	7.7	6.2	8.5	11.8	13.5	14.0	13.6	12.5	12.9	12.1
0.8	10.9	8.5	8.2	6.2	3.6	7.9	11.2	13.1	14.0	14.6	-	14.2	14.3
0.2	10.0	9.8	7.9	5.8	3.8	8.0	11.3	12.7	12.5	11.5	11.5	11.7	11.8

Table la

14	15	16	17	18	19	20	21	22	23	Rz
12.0	11.8	11.8	11.6	11.3	8.6	8.7	8.6	8.6	8.6	245

12.1	11.1	11.1	-	9.4	7.5	6.6	7.2	6.6	7.5	268
12.2	12.5	12.5	11.7	11.2	9.8	7.5	7.2	7.2	*ILL*-	265
13.2	12.4	11.7	-	-	-	6.6	-	-	-	233
11.7	11.6	11.3	LIIL–	-	8.5	8.4	8.5	10.1	10.7	187
12.6	12.6	12.3	11.6	11.3	9.5	10.4	10.8	10.8	10.9	156
12.2	11.9	11.7	11.5	-	8.6	8.7	8.7	9.0	8.8	172
14.3	14.2	13.8	11.7	11.3	8.3	8.5	8.5	10.5	10.8	175
12.3	12.4	12.5	-	10.3	6.9	8.4	8.3	8.4	8.5	174

Table Ib
June Solstice (Month of May) F_0f_2 Values (Observed) Mhz

00	01	02	03	04	05	06	07	08	09	10	11	12
8.4	8.6	8.6	-	-	-	-	-	13.7	14.8	15.2	14.7	13.7
6.6	8.1	8.3	7.9	7.4	5.2	8.5	12.1	13.9	15.1	15.1	15.1	14.2
10.0	9.8	9.5	8.0	3.7	2.7	8.7	10.5	13.3	14.0	12.9	12.9	12.2
0.5	6.4	6.3	6.4	6.1	4.4	8.9	12.4	13.7	13.8	11.8	11.8	11.5
-	.	-	-	-	5.5	9.2	12.7	14.0	14.1	12.4	12.4	12.0
-	6.4	5.6	5.4	4.7	3.1	-	-	-	-	11.7	11.7	10.9
4.9	4.8	4.8	5.1	5.2	5.2	9.4	12.5	13.8	14.3	14.3	14.3	13.4
6.7	6.7	6.6	6.3	4.8	3.1	8.5	11.8	13.6	14.0	12.3	12.3	11.3
6.0	6.0	5.9	5.9	5.1	3.9	8.8	11.9	13.7	14.3	13.3	13.3	11.4

Table 2a

13	14	15	16	17	18	19	20	21	22	23	Rz
12.6	12.4	12.2	12.1	11.8	10.4	9.4	7.9	-	-	-	150
13.4	12.5	11.4	10.9	10.9	10.6	-	-	-	-	-	166
12.0	11.7	11.9	11.7	11.9	10.9	8.7	-	8.3	7.7	6.6	140
11.5	11.6	11.6	11.5	-	-	-	-	-	-	-	132
11.5	11.5	11.7	11.4	11.5	11.8	10.9	9.2	-	-	-	162
10.9	10.9	11.2	11.6	11.7	-	-	-	-	6.5	5.3	165
12.7	12.3	11.9	12.0	12.0	11.7	9.7	6.6	6.6	6.7	6.7	171
10.7	10.6	10.8	11.2	11.3	11.1	-	8.6	8.2	-	6.3	204
10.9	10.6	10,9	11.0	11.4	11.1	10.8	-	8.3	6.6	6.1	192

Table 2b
December Solstice (Month of December) fofz Values (Observed) MHZ

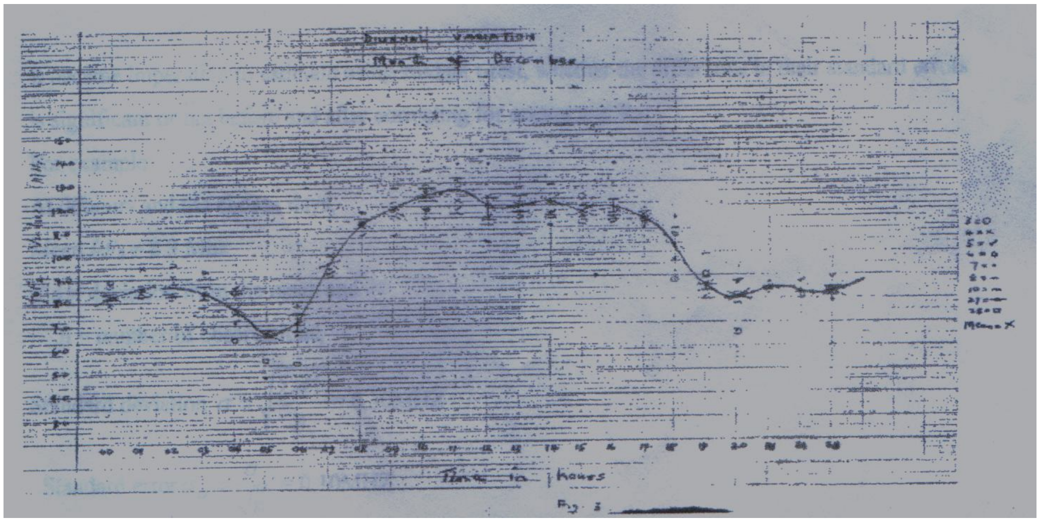
00	01	02	03	04	05	06	07	08	09	10	11	12
8.0	8.5	8.9	9.2	8.4	-	.	-	11.4	11.9	11.7	13.1	-
8.0	9.5	9.1	8.4	7.5	6.7	7.9	10.0	11.2	11.6	12.6	12.2	12.4
8.2	8.5	8.3	8.3	8.6	6.7	7.1	9.2	10.8	10.8	11.5	11.9	11.5
7.8	8.3	8.2	6.8	6.4	6.6	7.9	-	11.3	12.1	12.8	12,9	12.0
3.4	8.4	8.4	8.2	7.1	4.8	6.6	9.4	11.3	11.9	13.4	13.8	13.8
8.2	8.3	8.3	7.8	7.2	6.8	7.5	10.3	11.5	12.8	13.5	13,2	-
-	-	-	-	-	9.2	-	-	11.8	11.9	11.9	-	10.5
8.3	8.3	8.4	9.0	8.3	-	-	-	-	-	12.4	11.7	11.2
8.9	8.7	9.6	9.3	8.4	5.5	5.4	9.1	11.3	-	-	-	-

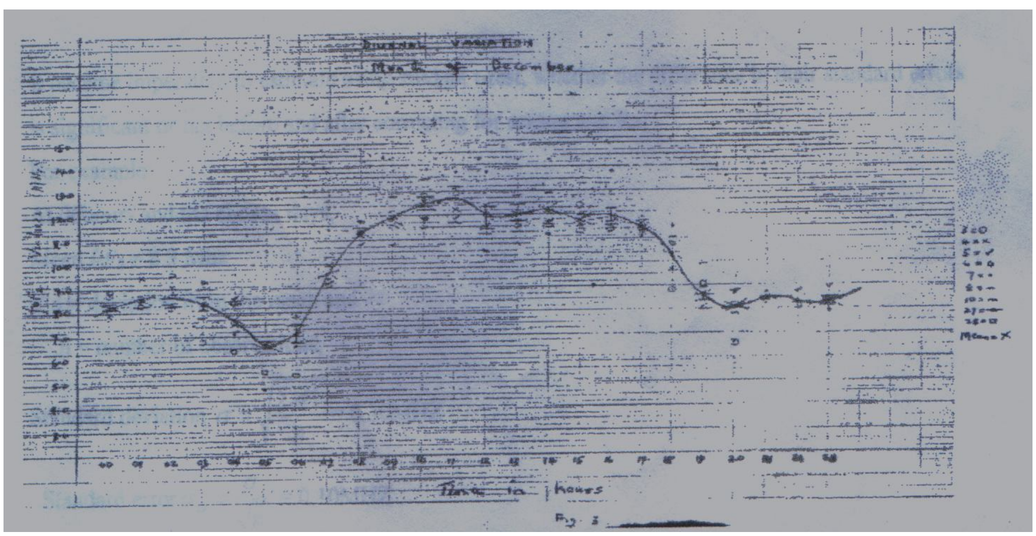
Table 3a

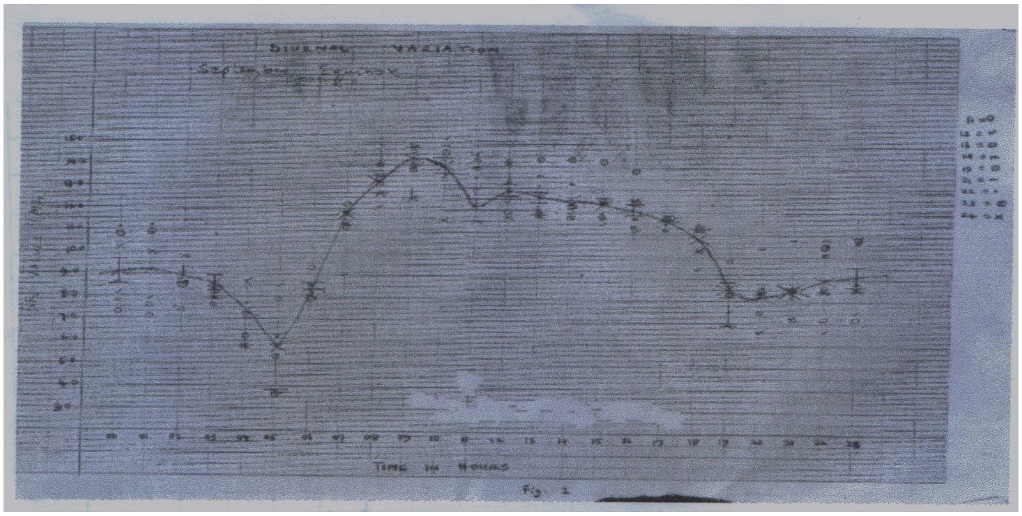
13	14	15	16	17	18	19	20	21	22	23	Rz
11.7	11.6	11.6	11.4	11.1	8.8	P	6.6	-	8.1	8.2	200
12.0	12,1	11.6	-	11.6	9.7	8.6	-	-	-	-	210
11.5	11.7	11.8	11.7	11.4	11.0	8.1	-	-	8.7	8.9	190
12.0	12,1	12.4	-	11.3	-	-	-	8.3	-	-	192
14.3	14.3	-	13.8	11.6	11.6	8.4	8.7	8.7	8.1	7.9	200
12.8	12.9	12.0	11.7	11.7	-	8.9	8.8	8.5	8.2	8.3	210
10.8	11.2	11.7	11.4	11.3	-	8.6	-	-	8.2	-	250
11.3	-	-	-	-	-	8.0	-	-	-	-	185
-	11.5	11.3	11.4	11.4	10.4	9.0	8.2	8.4	8.2	8.4	100

Table 3b

These tables 1,2 and 3 were used to plot the diurnal variation curves for the September equinox , June solstice and December solstice are shown in figs 1,2 and 3 respectively.







It became imperative to estimate using student t-test, whether the difference in their standard errors is significant or not before and after correcting for season and Rz

For example:

At 00hours and the chosen days,

Mean f_0F_2=8.3Mhz

If d=deviation from the mean and

n=number of observations,

$$\text{Standard deviation } \sigma = \sqrt{\frac{\sum d^2}{n}} = 0.30\text{MHZ}$$

$$\text{Standard error } \sigma_m = \frac{\sigma}{\sqrt{n}} = 0.10\text{MHZ}$$

Hence f_0F_2 = 8.3±0.10 MHz (see error bars on graphs)
Similar analysis was carried out at various times of the day on the variation curves.

Table 4 illustrate the result obtained.

TIME	00	03	06	10	12	13	16	19	23
September Equinox									
A	1.4	0,9	0.4	1.1	0.8	0.8	0.7	0.8	1.3
<V	0.5	0.3	0.1	0.3	0,2	0.2	0.3	0.3	0.4
$3a_m$	1.5	0.3	0.3	0.9	0.6	0.6	0.9	0.9	1.2
June Solstice									
A	1.4	1.0	0.3	0.6	l.l	0.8	0.3	0.7	0.4
Ora	0.5	0.3	0.1	0.2	0.3	0.2	0.1	0.3	0.2
$3a_m$	1.5	0.9	0.3	0.6	0.9	0.6	0.3	0.9	$\tilde{W}$
December Solstice									
<3	0.3	0.7	0.8	0.7	1.0	1.0	0.8	0.3	0.3
O_m	0.1	0.2	0.3	0.2	0.4	0.3	0.3	0.1	0.1
$3a_m$	0.3	0.6	0.9	0.6	1.2	0.9	1.0	0.3	0.3

Table 4

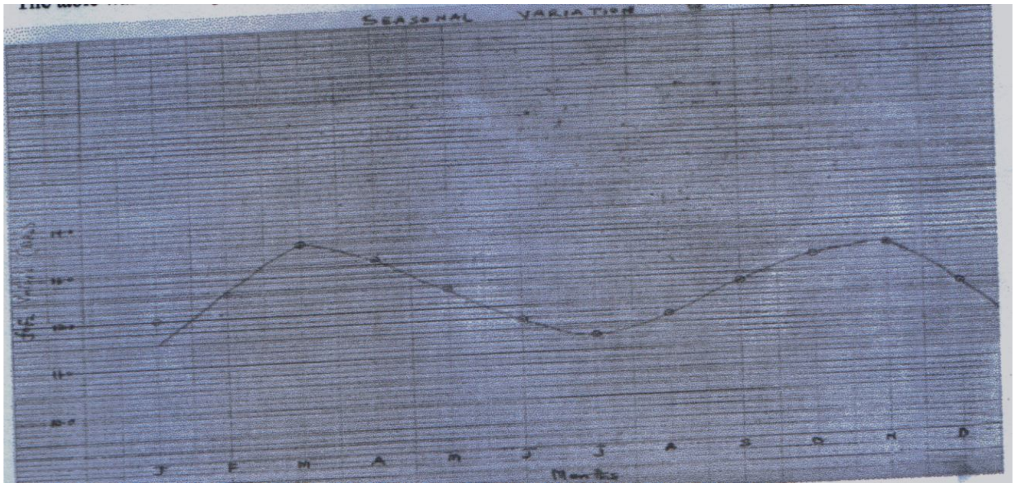
Seasonal Variation

The mean values of the observed daily values of foFzat each hour of the day for each month was computed to study the yearly behaviour of foF_2. Table 5 below shows the result obtained.

MONTHS	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
foF_2MHz	12.0	12.5	13.5	13.1	12.4	11.7	11.3	11.7	12.3	12.8	13.0	12.0

Table 5

The Table was used to plot the seasonal variation curve shown in fig 4



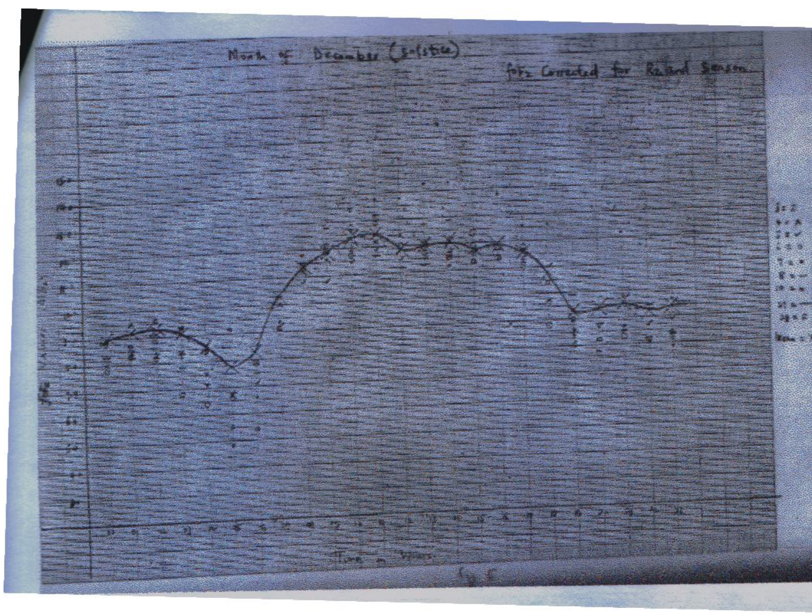
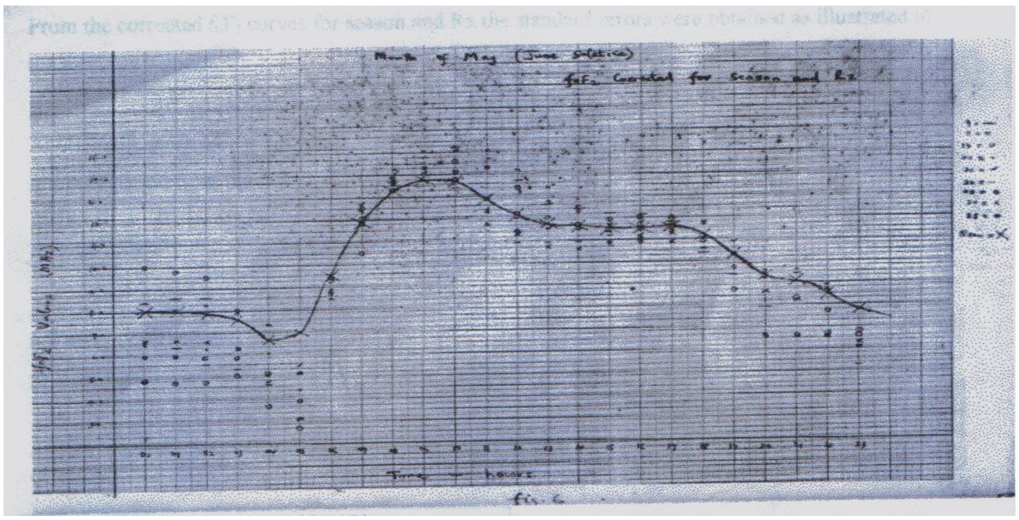
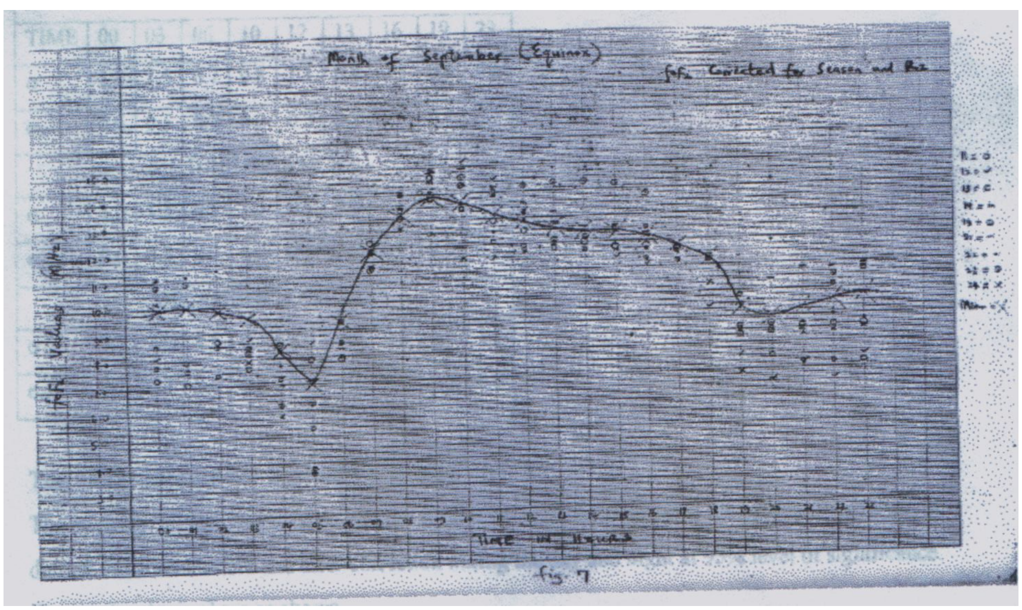


FIG 4

Corrected f_0F_2

It is important to examine the effect of seasonal variation and Rz on foF2. Fig 4 is used to correct for season. (Yokoyama,2004) showed that critical frequency of the F_2 layer is related to the relative sunspot number Rz by foF2 = A + 0.028Rz, where A = constant dependent on magnetic dip (Maruyama,1996) using Ibadan data, showed that for short time variations, the constant A is approximately equal to 6.77Mhz (magnetic dip for Ibadan = -6°). The above equation was used to correct for Rz. The corrected diurnal variation curves are as shown in figs 5,6 and 7for the solstice and equinox.





From the corrected f_0F_2 curves for season and Rz the standard errors were obtained as illustrated in the example below.

At 00 hours, means f_0F_2=8.0 MHz

If d = deviation from the mean,

$$\text{Standard deviation} = \sigma = \sqrt{\frac{\sum d^2}{n}}$$

n = no of observations.

$$\text{Standard error } \sigma m = \frac{\sigma}{\sqrt{n}} = 0.7$$

Similar analysis was carried out at various times of the day. Table 6 below shows the results obtained.

September Equinox

TIME	00	03	06	10	12	13	16	19	23
O	1.8	1.5	0.7	0.8	1.1	0.8	0.3	0.9	0.6
CFm	0.6	0.5	0.2	0.2	0.3	0.2	0.1	0,4	0.7
				June Solstice					
O	1.6	1.3	0.9	1.1	0.8	0.8	0.6	1.4	1.5
°m	0.6	0.5	0.3	0.4	0.2	0.2	0.2	0.5	0.5
				December Solstice					
O	0.7	1.0	1.5	0.7	1.0	1.0	0.8	0.8	1.1
°m	0.2	0,3	0.6	0.2	0.4	0.3	0.3	0.3	0.4

-

Test of Significance For Diurnal Variations

The students "t" test was used to test the significant difference between the standard errors of the diurnal variations before and after correction during the day and night at 95% level of significance. The results obtained are as shown. 1. Month of May (June Solstice)

Daytime (lOOOhours)

Before = 0.22

After-0.28

t=0.11

$\mathbf{t_{95\%}=2.31}$

$t_{95}\%>t$ **(t=0.11)**

Month of September (September Equinox)
Daytime (lOOOhours)
Before-0.38

After-0.40 t = 0.02
t_{95}%-2.31>t (t-0.02)

Month of December (December Solstice)
Daytime (lOOOhours)
Before - 0.24
After - 0.24
t_{95}%>t (t-0)

The above result in each case show no significance at 95% level of significance by day.
2. Month of May (June Solstice)
Night time (2300hours)
Before = 0.21
After -0.74 t-0.52
t_{95}%-2.31>t (t = 0.52)

Month of September (September Equinox)
Night time (2300hours)
Before - 0.49
After = 0.54 t-0.07
t_{95}%>t (t-0.07)

Month of December (December Solstice)
Night time (2300hours)
Before-0.18
After - 0.49 t - 0.46
t95% > t (t - 0.46)

Hence no significant difference between the two standard errors before and after correction for season and Rz at 95% level of significance, by day and by night.

Summary of Results and Discussion

From the diurnal variation curves, it is observed that they are large irregular changes of fbF2 during individual days. The amplitude of variation is greater in daytime than at night.
Essentially, foF_2 at midday (1200hrs) varies from day to day. While it's value is 2.5MHZ between day 23 and 24 at the equinox (September), it is 2.1MHZ at the solstice (June).

From the results obtained in error estimation, it is clearly shown that the errors associated with the mean values of foFi are less than 3 times the standard errors. The seasonal variation curve has two maximum points in the months of March and November respectively with a minimum in July. This indicates that the seasonal variation of foF2 is more of a semi-annual variation.

The test of significance carried out indicates that neither seasonal variation nor Rz are responsible for the day-to-day variability in the F_2 region.

Conclusion

The results obtained in this study compared favourably with some other studies. For example Bhuyan, P.K et al (2003) indicated that the general features of the diurnal variation of *$¥2* could readily be explained by a loss coefficient, which was substantially greater by day than at night. (Kuriyan, 1983)

[illegible] o be a cause of diurnal variation. He also remarked that there is a well-marked semiannual variation in both maximum electron density and foFa of the F_2 region. (Adeniyi,2004) showed that there is a seasonal variation of f_0F_2 using Ibadan data.

One would therefore hope that the data and results established by this study be proposed as equatorial input values for the development of a variability model for the international reference ionosphere.

References

Adeniyi, J.O. et al (2004): Advances in space research: Variability of in the equatorial ionosphere. of Advances in space research, *Elsevier* 34(9), 1901-1906.

Bates, D. R.(1960); *Physics of the upper atmosphere.* Academic press, New York pp.378.

P.K et al (2003):Diurnal seasonal and latitudinal variations of electron density in the topside F-region of the Indian ionosphere at solar minimum and comparison with IRI. *Journal of atmospheric and solar-terrestrial physics* 65, 3, pp.359-368.

Danilov, A. D. & Mikhailov A.V (2004) Long-term trends in F2 layer parameters at Argentine Island and Port Stanley Stations. *Annales of Geophysics*,41(4) 488-496

Kuriyan, et al (1983):Long term relationship between sunspot Ca player and the atmosphere. *J.Atmos. Terr.Phys.*5, 285-285

Maruyama, T, et al (1996). Modelling study of Equatorial ionospheric height and spread F occurance. *J. Geophys.Res*, 101,5157-5163.

Ractliffe, J. A. (1951), Some regularity in the F2 region Ionosphere, *J. Geophys.* Res; 56(4), 487-507

Yokoyama, T, et al (2004). Relationship of the on set of the equatorial F region irregularities with the sunset terminator observed with the equatorial atmosphere. Radar Geophys. Res. Lett 31, L24804, doi, 10,1029/2004 GL021529, 2004.