Comparison of the response of NmF2 and NmE to variations in Sunspot number at different latitudes

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ABSTRACT
The comparison of the response of NmF2 and NmE to Sunspot Variation at Ibadan (7.4°N, 3.9°E, 6°S dip), Singapore (1.30°N, 103.80°E dip 18°s) and slough (51.5°N 359.4°E, dip 66.5°N) is studied. The results obtained from statistical analysis of data collected and from the graphs plotted show the following: NmF2 was found to respond better then NmE at the three stations. In the three stations the response of NmE is greatest around noon. NmF2 was found to respond better than NmE at the three stations. This does not that FOE responds better to sunspot number than f0f2. NmF2 responds better to solar activity at Singapore and Slough than at Ibadan. This is probably due to the more variable F-region electron dynamics at equatorial station of Ibadan. NmE responds better at Ibadan and Singapore than at Slough. This may be due to slight decrease of NmE at temperate Latitude and a slight enhancement of NmE at equatorial Latitude by Sq current.

Keywords: NmF2, NmE, temperature and variation

INTRODUCTION
The ionosphere - a region of highly ionized particles above the stratosphere [1]. The ionosphere is a shell of electrons and electrically charged atoms and molecules that surrounds the Earth, stretching from a height of about 50km to more than 1000km. It owes its existence primarily to x-rays and ultraviolet radiation from the sun. The shorter wave ultraviolet solar radiation extending into the X-ray region, acts on the molecules and atoms of the upper atmosphere by detaching one of their electrons, leaving behind a molecular or atomic (positive) ion. Some of the electrons will attach themselves to an atom or molecule of oxygen to form a negative ion. These actions lead to several others particularly charge transfer and three body or radiative recombination. The region in which there are free electrons in significant number is called the ionosphere. It extends below the mesopause (80km), but the electron density is greatest above 100km, it rises to a maximum of the order of $10^{11}$ m$^{-3}$ at the peak of E-layer to $10^{12}$ m$^{-3}$ at the peak of F-layer [2].

The existence of the ionosphere as an electrically conducting region was first suggested by, Balfour Stewart in 1883. He inferred it from a study of the small daily geomagnetic variation observed at the earth's surface. Chapman in his theory considered the earth's atmosphere as one that consists of a single gas of molecular weight M which is at a uniform temperature under the action of gravity over a flat earth (chapman layer formation) [3].

In the opening years of 20th century after Marconi had transmitted radio waves across the Atlantic, the presence of an ionized region of the upper atmosphere was given as the explanation, by Kenelly and Heaviside. This region can prevent the passage of radio waves of wavelength below a certain limit into outer space; instead, it reflects or bends them round the curved surface of the earth. Since 1920 the ionosphere has been widely explored by radio scientist among whom are: Appleton, Breit and Tuve.

Electron density is of the order of $10^{11}$ m$^{-3}$ at the peak of E-layer to $10^{12}$ m$^{-3}$ at the peak of F-layer [2].
PURPOSE OF STUDY

Sunspots are caused by very high magnetic activities taking place in the core of the sun, which hinders convection and as a result forms areas of decreased surface temperature. Whenever sunspots appear on the solar surface, the number of sunspots is a measure of the solar activity. If small number of sunspots is observed, the sun is said to be in its quite state and to have a low solar activity. When large numbers of sunspots are observed, the sun is said to be in a highly disturbed state, and to have a high solar activity. Scientists have observed that the ionization that takes place in all the regions of the ionosphere are closely associated with variations in sunspot number. The ionization are said to increase or decrease as the sunspot number increase or decreases in course of a solar cycle. All the variations of $f_0 F_2$ and $f_0 E$ are tied to the solar activity [4]. The response of $\text{Nm} F_2$ (the peak electron density of the F layer) and $\text{Nm} E$ (the peak electron density of the E-layer) to variation in sunspot number is a function of location, latitude, time of the day and year. In this study, we intend to investigate, the extent to which the response of Nm$ F_2$ to variation in sunspot number compares with the response of Nm$ E$ to variation in sunspot number at different latitudes. Our study is the comparison of the response of Nm$ F_2$ and Nm$ E$ to sunspot variation at Ibadan (7.43°N, 3.90°E, dip 6°S), Singapore (1.30°N, 103.80°E, dip 18°S and Slough (51.5°N, 359.4°E dip 66.5°N).

METHOD

SOURCES AND COLLECTION OF DATA

Available values of $f_0 F_2$ and $f_0 E$, were obtained from the records of the ionosonde the ionosonde Radio Mark II, recorder, type developed at the Radio Research Station in Slough. A common method of obtaining photographic record called the ionosonde, which was developed by [5]. The transmitter and receiver of the ionosonde are separate units kept in tune by a frequency sensitive servo gear system. Pulses are transmitted over a range of 0.7MHz to 25 MHz in a sweep time of 5 minutes duration. The interval between the transmitted pulse and the corresponding echoes are recorded photographically. The variation of apparent height $h$ with frequency $f$ of radio waves is shown on the records, referred to as ionograms. In these records, hourly mean values of the parameters of $f_0 f_2$ and $f_0 E$ which are tabulated, obtained from the monthly publication of university of Ibadan bulletins of Ionospheric data have been used in this research work. It is assumed that the values of the peak electron density of the F2 layer. $\text{Nm} F_2 = 1.24 \times 10^{10} f_0 F_2^2$ (where $f_0 F_2$ is the critical frequency of F2 layer). Also, it is assumed that the values of the peak electron density of the E - layer $\text{Nm} E = 1.24 \times 10^{10} f_0 E^2$ (where $f_0 E$ is the critical frequency of E - layer). For the periods under study, $\text{Nm} F_2$ and $\text{Nm} E$ variability of January to December of 1958 and 1973 data for Ibadan Station were used. This represents the variability for high and low solar activities respectively. Again, the Nm$ F_2$ and the Nm$ E$ variability of July 1900 to 1974 available data for Ibadan, Singapore and Slough were also used for the purpose of latitudinal comparison.

ANALYSIS OF DATA

With the use of an electronic Calculator the hourly mean values of the critical frequencies of $f_2$ and $E$ regions were obtained. The results obtained for (a) Ibadan 1958 (b) Ibadan 1973 (c) Ibadan July 1960 to 1970 (d) Slough July 1963 to 1971 (e) Singapore July 1900 to 1971 are displayed on the tables 1 to 9. From the relationship $\text{Nm} F_2 = f_0 F_2^2 \times 1.24 \times 10^{10}$, and $\text{Nm} E = f_0 E^2 \times 1.24 \times 10^{10}$ The values of $f_0 F_2$ and $f_0 E$ were converted to Nm$ F_2$ and Nm$ E$, as shown in tables 10 - 18. In the analysis of the data, the following statistical theories were used:

(a) A mathematical relationship between Hz (sunspot number) and
Nmf₂ (peak electron density of F₂ layer), and between Rz and NmE (peak electron density of the E-layer), employing Regression Analysis.

(b) The correlation coefficients of Rz and Nmf₂, and Rz and NmE were calculated for a period between 06 hours and 18 hours.

(c) The Trend line for Nmf₂, NmE and Rz were calculated and drawn at 12 hours for Ibadan, Slough and Singapore.

(d) The graphs of Nmf₂, NmE and Rz were plotted against different months of the year for Ibadan 1958 an 1973. While graphs of Nmf₂, NmE and Rz were plotted against different years for Slough and Singapore.

THE COMPARISON OF NMF₂ AND NME WITH VARIATIONS IN RZ VALUES

(a) To compare Nmf₂ and NmE with variation in Rz values at Ibadan, Slough and Singapore, we calculate the correlation coefficient of Nmf₂ with Rz and NmE with Rz.

(b) A mathematical relationship is established between Rz and Nmf₂, and between Rz and NmE using regression analysis.

(c) A graph of Nmf₂, NmE' and Rz is plotted against the months of the year for Ibadan 1958 and 1973. A graph of Nmf₂, NmE and Rz is plotted against different years for Slough and Singapore.

(d) The equation of Trend lines for Rz. Nmf₂ and NmE are calculated and drawn-out in a graph.

RESULTS AND DISCUSSION

Seasonal variation in the response of Nmf₂ and NmE to solar activity at Ibadan.

The seasonal variation in the response of Nmf₂ and NmE at Ibadan to solar activity in 1958 are illustrated in figures 1-13. The peak values for NmE occur in June solstice (in August in the first half of the day [figures 1-7] and in July in the second half of the day (figures 8-13).

Data from table 15 to 18 were used to plot the graphs figure 1 to figure 26 representing the plot of Nmf₂, NmE and RZ against the months of the year for Ibadan 1958 (Figures 1 to figure 13 and figures 14 to figure 26 represents that of Ibadan 1973).

With the data on tables 11 and 12 the graphs - figures 27 to figure 39 were plotted for Slough covering the period 06 hours to 18 hours. Also with the data on table 13 and table 14 the graphs - figure 40 to 52 were plotted for Singapore covering the period 06 hours to 18 hours.

In plotting the graphs, for the purpose of comparison, the values of Nmf₂ and NmE are plotted on a side of the Y- axis against different years (1963 to 1971) for Slough) on the same graph, the sunspot number Rz are plotted on the second Y -axis against different years. For Singapore, the years considered are 1960-1971.

STATISTICAL ANALYSIS OF DATA

The data collected were analyzed using statistical theories as a basis for:

(a) Calculating and determining the level and extent of the response of Nmf₂ to variation in sunspot number Rz.

(b) Calculating and determining the level and extent of response of NmE to variation in Rz.

(c) Accurate comparison of the response of Nmf₂ and NmE to variation in Rz:

The statistical theories employed for this purpose are;

i. Correlation analysis

ii. Regression analysis

iii. The equation of a Trend line.
between 08h and 16h, and in June solstice at 17h and 18h. (See figures 14 - 26).

The peak values of NmE occur in September Equinox and in June solstice generally.
Figure 27 in which the diurnal variation of the correlation coefficient between NmE and sunspot number, Rz and between NmE and Rz for Ibadan during 1958 is illustrated.

It shows that NmF2 increases with sunspot number Rz between 06h and 10h. NmE is observed to increase or decrease alternately with Rz. The mean correlation coefficient r for NmE is 0.29 while that of NmF2 is -0.0278. NmE therefore is found to respond better to Variation in sunspot number Rz than NmF2, since a positive relationship exists between Rz and NmE while a negative relationship exists between Rz and NmF2.
During 1973, the diurnal variation of the correlation coefficient of NmE and NmF2 with Rz (see figure 28) shows that NmF2 increase or decreases alternately with Rz. NmE is also found to increase or decrease alternately with Rz. The mean correlation coefficient \( r \) between NmE and Rz is 0.385 while that of NmF2 is 0.508.
NmF2 therefore responds better to variation in sunspot number Rz than NmE, though a positive relationship exists between both NmF2 and NmE, with Rz.

Diurnal variation of NmF2 and NmE of July 1958, 1970 and 1973 at Ibadan

From figure 29, the values of NmF2 are found to be high during years of high solar activity and low during years of low solar activity.

The peak value of NmF2 are between 09h and 10h.
FIG 30 shows the diurnal NmE variation for July 1958, 1970, and 1973. From the graph, the following results were obtained:

(a) The values of NmE are high during years of high solar activity and low solar activity.

(b) It therefore shows that both NmF2 and NmE vary with change in sunspot number Rz.

(c) In the years under consideration, the peak values of NmE were obtained between 11h and 15h.

GENERAL DISCUSSION

1. Nmf2 was found to respond better than NmE at the three stations. This does not contradict [6] who said that FoE responds better to sunspot number than foF2.

2. NmF2 to solar activity responds better at Singapore and Slough than at Ibadan. This is probably due to the more variable F-region electron dynamics at the equatorial station of Ibadan.

3. NmE responds better at Ibadan and Singapore than Slough. This may be due to slight decrease of NmE at temperate latitude and a slight enhancement of NmE at equatorial latitude by Sq current [7].

Enhancement in equatorial NmE is due to vertical drift of electrons as a result of E-W electric field present in the E region [8]. The Sq current is known to increase with solar cycle.
CONCLUSION

1. For Slough, Ibadan and Singapore, NmF2 response is greater at noon and sunset than in the morning than at other hours.
2. In the three stations the response of NmE is greatest around noon.
3. NmF2 was found to respond better than NmE at the three stations. This does not contradict [8] who said that FoE responds better to sunspot number than foF2.
4. NmF2 to solar activity responds better at Singapore and Slough than at Ibadan. This is probably due to the more variable F-region electron dynamics at equatorial station of Ibadan.
5. NmE responds better at Ibadan and Singapore than Slough. This may be due to slight decrease of NmE at temperate Latitude and a slight enhancement of NmE at equatorial Latitude by Sq current [9].

Enhancement in equatorial NmE is due to vertical drift of electrons as a result of E-W electric field present in the E region [10]. The Sq current is known to increase with solar cycle.
6. NmF2 and NmE values depend on the sunspot number Rz. The values of both show a positive correlation with sunspot number Rz at the three Stations. The mean values of both NmF2 and NmE were found to be higher during years of high solar activity and lower during years of moderate and low solar activity.

REFERENCES