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Longitudinal Influence of NmF2 Variability on the Equatorial Ionosphere During High Solar Activity

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Abstract

This paper presents the effect of longitude on the relative variability (VR) of the maximum electron density of the F2 region (NmF2) during High Solar Activity (HSA). Data from six equatorial stations located from west to east of the Greenwich Meridian (GM) are used for this study. Ionospheric stations in the neighbourhood of GM are found to have lowest post-midnight NmF2 VR, while the stations west of GM are found to have the lowest pre-midnight NmF2 VR. Large daytime NmF2 VR is found in stations close to GM. Longitudinal influence is observed in the hour of occurrence of post-midnight peak of NmF2. While post-midnight NmF2 VR in stations close to GM occurred between 05 – 07 hour, post-midnight NmF2 VR of stations east of GM occur earlier that is between 02 – 04 hour. In all six stations considered, the variability of NmF2 is generally greater at Huancayo (78%) and Vanimo (70%) than other stations in the neighbourhood and east of GM due to their longitudinal differences.

Keywords

NmF2 Variability, Equatorial Ionosphere, Longitudinal Influence, Peak Electron Density

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1. Introduction

The ionospheric behaviour of the earth's upper atmosphere during quiet time is of vital importance in trans-ionospheric communication. This is owing to the fact that the local time, seasons, solar cycle and longitude play a significant role in varying the ionosphere as a result of changes in the components of solar radiation and other dynamic and chemical processes (Richard, 2001; Sardar et al., 2012). The seasonal behaviour of the ionosphere has been explored with measurements of critical frequency, peak electron density of the F2 layer and total electron content (Mc Namara and Smith, 1982; Sardar et al., 2012). Also, the variability of critical frequency, electron density among other parameters were looked into in the IRI Task Force Activity meetings held during 2000 and 2001 (Bilitza, 2001; Ezquer et al., 2004). Several other models have also been developed after then to predict the behavior of the ionosphere.

The variable nature of the ionosphere affects modern technologies such as civilian and military communications, navigation systems, Avionics and surveillance systems, etc. For many communication and navigation systems, these arise because the systems use signals transmitted to and from satellites, which must therefore pass through the ionosphere. For the most reliable communication and navigation it is necessary to correct the signals for effects imposed by the ionosphere. To do that, the properties of the ionosphere such as its variability with respect to magnetospheric disturbance, diurnal, seasonal, longitudinal and solar cycle variability must be well understood. The results of longitudinal influence on ionospheric variability have also been mentioned by Somoye et al., (2013). They found significant dependence of foF2 VR on longitude. Fotiadis et al. (2004) also obtained a significant dependence of MUF VR on longitude.

Ionospheric variability or deviation from climatological

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means is a pronounced and permanent feature of the ionosphere (Zhang and Holt, 2008). It can occur on hourly, daily, seasonal, and solar cycle scales. Under extreme geophysical conditions, ionospheric variability may signify serious threats to communication and navigation systems (Basu et al., 2002).

Furthermore, since the ionosphere exhibits both temporal and spatial (latitudinal) variations. The regular variations like the daily, seasonal and solar cycle variations are fairly well understood. However in addition to these regular variations there are largely day to day variations both on geomagnetic quiet as well as on geomagnetic active days. Long series of ionospheric data obtained from regular radio soundings of ionosphere all over the globe provide valuable database for studying the climatology of ionosphere during different geophysical conditions. While the features like daily, seasonal, solar cycle and latitudinal variations are understood but the day-to-day variability, both on geomagnetic quiet and disturbed days, is yet to be completely understood. Space weather effects and pre-seismic ionospheric anomalies are some of the topics of recent interest. (Chandra et al. 2010)

In this research work, we attempt to investigate the response of the quiet time F2 layer peak electron density (NmF2) to local time, season and longitude in the equatorial ionosphere.

2. Method of Analysis

The data used in this study are hourly foF2 values obtained from six equatorial stations located from west to east of Greenwich Meridian (GM) namely Huancayo (west of GM), Ouagadougou and Dakar (Neighbourhood of GM), Djibouti, Vanimo and Manila (east of GM). Table 1 show the geographic coordinates and the dip angles of these stations.

Table 1. Stations and Coordinates.

STATIONS	COORDINATES		
	Geographic		Dip angle
	Latitude	Longitude	
Huancayo	12°S	75.3°W	2.4°S
Ouagadougou	12.4°N	1.5°W	17.0°N
Dakar	14.8°N	17.4°W	12.1°N
Djibouti	11.5°N	42.8°E	0.8°S
Vanimo	2.7°S	141.3°E	4.3°S
Manila	14.7°N	121.1°E	0.7°N

These data were used to obtain NmF2 using equation 1,

$$NmF2 = 1.24 \times 10^{10}(foF2)^2 \quad (1)$$

The data which were obtained from Space Interactive Data Resource website (http://spidr.ngdc.noaa.gov/) have been automatically scaled to minimize errors. They cover year of high solar activity (HSA: 1982). The values of NmF2 obtained from equation 1 were further processed using equation 2 below to obtain their variability (i.e. NmF2 VR). These values were then plotted against each hour of the day on seasonal scales to evaluate diurnal and seasonal effects on NmF2 VR.

The data were grouped into four seasons of March equinox comprising February, March and April; June Solstice comprising May, June and July; September Equinox comprising August, September and October; December Solstice comprising November, December and January (Bilitza et al., 2004). Variability (VR) is obtained by using the monthly mean NmF2 values, $\bar{X}$ and the standard deviation, σ at each hour. Using the method adopted by Forbes et al. (2000) and Bilitza et al. (2004), Variability (VR) is define as:

$$VR\ (\%) = \left(\frac{\sigma}{\bar{X}}\right) * 100 \quad (2)$$

where

$$\bar{X} = \frac{1}{N}\sum_{r=1}^{N} X_r \quad (3)$$

and

$$\sigma = \sqrt{\frac{\sum(X - \bar{X})^2}{N}} \quad (4)$$

N is the number of counts for each of the hour.

2.1. Methods of Determining Variability (VR)

Three Statistical formulae methods of determining VR used by some researchers are described below;

(i) VR (%) = (σ/μ) × 100

Where σ and μ are the monthly hourly standard deviation and mean respectively, of values of ionospheric characteristics. This formula has been used by Forbes et al (2000); Rishbeth and Mendillo (2001); Bilitza et al. (2004); Somoye (2009a), Somoye and Akala (2010, 2011); Akala et al. (2010). The advantage of this formula is that the deviation of all the daily values from the mean is considered indicating that the whole data is used. It is however not easy to interprete in terms of probability (Bilitza et al. (2004).

(ii) VR (%) = (Interquartile range/ median) × 100

This formula which has been used by Zhang et al. (2004) for foF2 (F2 peak critical frequency), hmF2 (F2 peak height), Bo (buttomside thickness) and B1 (shape parameters); Ezquer et al. (2004) for foF2, M(3000)F2 (propagation factor); Amarante et al. (2004) for foF2, hmF2, Bo and B1 is easy to interprete in terms of probability since the interquartile range, which is the difference between the upper quartile (q_{75}) and the lower quartile (q_{25}), cover 50% of the data. Also, the median (q_{50}) and the upper and lower quartiles are readily available in ionospheric bulletins. However, this formula has the disadvantage of ignoring 50% of the data.

(iii) VR (%) = (Interdecile range/ median) × 100

Fotiadis et al. (2004) used this formula to determine the variability of MUF and ionospheric VR at fixed heights respectively. This formula covers 80% of the data points and ignores only 20% of the data. Hence the demerit of this formula is that 20% of the data are ignored.

(iv) VR (%) = (Range / median) x100

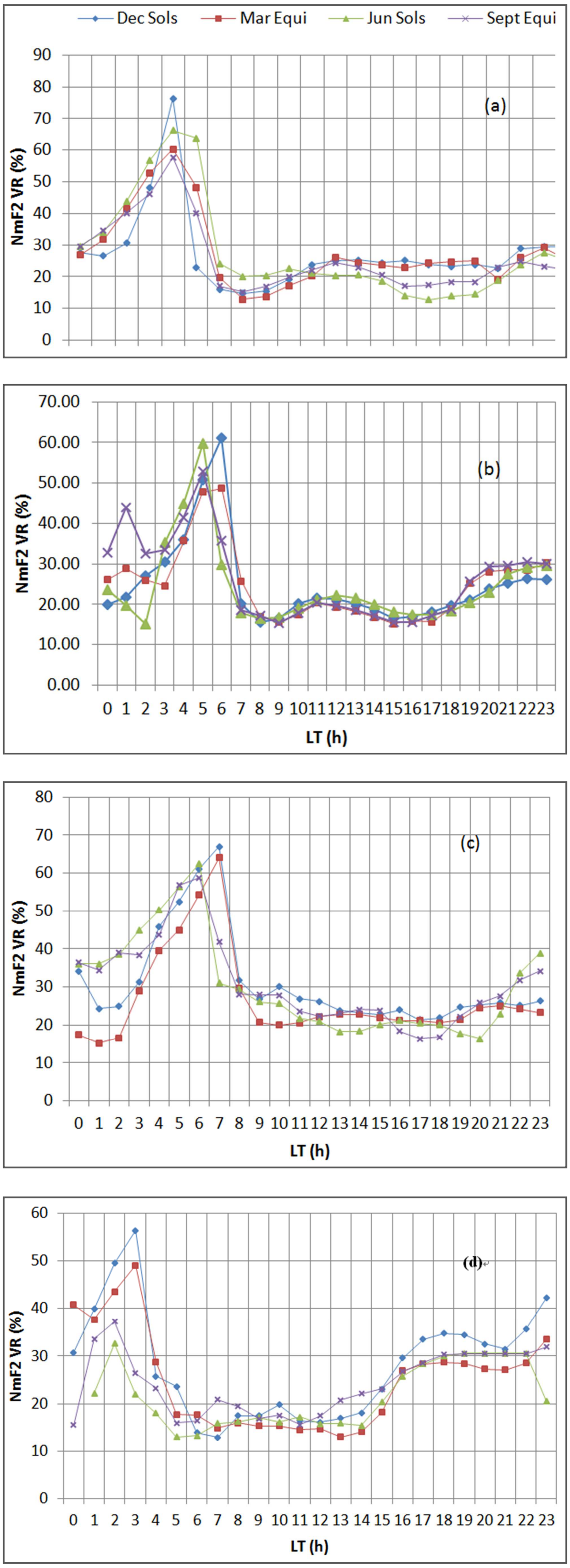
This is another formula not commonly used in literature by most workers because the range being the difference between the highest and lowest values of the data set do not used the whole data and is too simple to calculate as a measure of dispersion.

2.2. Importance of Ionospheric Variability (VR)

Regardless of our improved knowledge of the ionospheric dynamics, the *day-to-day variability:* from one day to the next at a given hour, *hour-to-hour variability:* from one hour to the next at the same day, and *within-the-hour variability:* that occurs within a single hour, still lies within the framework of statistical estimations and the underlying physical mechanisms are far from being fully understood. Thus the analysis of the variability of the ionosphere parameters is a very important means of studying the variation of the equatorial ionosphere. Practical implications of space weather studies include knowledge of impact of ionospheric variability on trans-ionospheric radio propagation (Zhang et al., 2004) and on space based communication and navigation system as well as for modelling the ionosphere has contributed to space weather study and investigation of existing prediction models of the ionosphere.

3. Results

Figures 1 (a) – (f) show the diurnal plots of NmF2 VR from west to east of GM namely Huancayo (west of GM), Ouagadougou and Dakar (neighbourhood of GM), Djibouti, Vanimo and Manila (east of GM



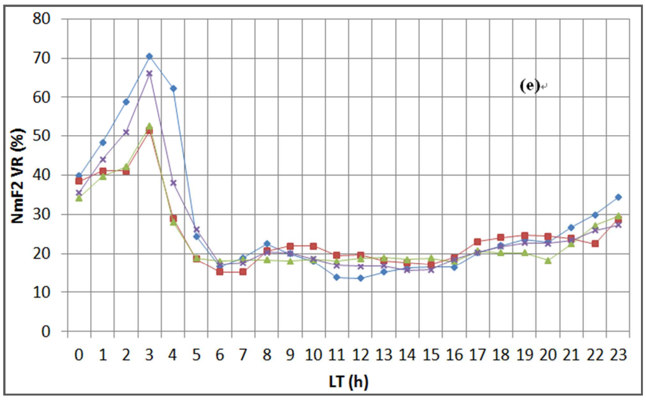


Figure 1 (a)–(f). Diurnal plots of NmF2 variability for (a) Huancayo (b) Ouagadougou (c) Dakar (d) Djibouti (e) Vanimo and (f) Manila during high solar activity.

4. Discussion

On a general consideration, all the plots have similar diurnal characteristics, that is comparatively high variability during the night-time and low variability during the day time. During the night time NmF2 variability attains its highest values that range from 30% - 78% which reduces to about 8% - 30% during the day. Also all the plots have two characteristics peaks that occurred between 05 - 07 hour (post midnight peak) and 20 – 23 hour (pre-midnight peak) for stations west and neighbourhood of GM. While that of stations east of the GM occurred between 02 – 04 hour (post midnight peak) and 22- 23 hour (pre- midnight peak). The pre-midnight peaks for stations east of the GM are more enhance than those in stations west and neighbourhood of GM. This may be due to their longitudinal influences.

The highest peaks are observed to occur during post midnight hours 49% - 78% for stations west and neighbourhood of the Greenwich Meridian (GM) and 42% - 70% for stations east of the Greenwich Meridian (GM). These peaks of variability can be as a result of sharp electron density concentration caused by the presence and absence of solar ionization (Bilitza et al, 2004, Chou and Lee, 2008) and the F region irregularities (spread F) on the background electron density (Woodman and La Hoz, 1976).

On seasonal basis, from figure 1(a) – (f) all the plots show similar trends with high values of variability occurring during the solstice period than at the equinoxes. NmF2 VR was highest during December solstice (58% - 78%) for all the stations except Manila where the highest value was recorded during the June solstice (68%)

Evaluation of station to station NmF2 VR reveals that the highest value (78%) occurred at Huancayo west of GM and (70%) at Vanimo east of GM during the December solstice. jThis may likely be due to their longitudinal difference since both stations are farther away from Greenwich Meridian compared to the other stations. Akala et al (2011) reported similar observation with foF2 VR being greatest for Huancayo west of GM followed by Vanimo east of GM. They found out that foF2 VR of ionospheric stations east and west of GM are greater than those of stations in the neighbourhood of GM. This again maybe due to longitudinal influence.

5. Conclusion

This paper presents longitudinal influence of NmF2 variability on the equatorial ionosphere during high solar activity. A total of six stations were considered.

In all the stations considered, NmF2 variability was highest during night time and low during the day since VR increases as ionization decreases.

Diurnal analysis from this study reveals that ionospheric stations west and neighbourhood of the GM are found to have lowest pre-midnight NmF2 variability while those East of the GM have high pre-midnight NmF2 variability. Stations in the neighbourhood of the GM have lowest post midnight NmF2 variability. Seasonal analysis shows that NmF2 variability is highest during the solstice than at the equinoxes. This is because the peak values of NmF2 VR occurred mosrtly during the solstice.

The variability of NmF2 is generally greater at Huancayo (78%) and Vanimo (70%) than other stations in the neighbourhood and east of GM due to their longitudinal differences. The above results are comparable with that of other workers mentioned.

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