Variability of Ionospheric F2 region critical frequency (*foF2*) for a low latitude station

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Abstract

In this study, f_oF2 variability diurnally, seasonally and annually was investigated during a Low Solar Epoch (LSE) over Ilorin (latitude 8.31°N, longitude 4.34°E, dip latitude 2.95°), a low latitude station along the equatorial anomaly trough. The percentage variability index (V_R) was used for the analysis. The percentage variability index (V_R) is lowest during the day (2-17%); increases during night to (8-55%); and attained the highest magnitude during pre-sunrise phase (17-68%), for the period of LSE. Two major peaks were noticed in V_R: the pre-sunrise peak, which is higher, and the post-sunset peak. Annually, V_R peaks at 44% for the pre-sunrise phase, and 37% for the post-sunset phase, during the LSE. The rapid electron drift away from the equator coincides with subsequent rise in the percentage variability index immediately after sunset for all the seasons.

Keywords: *Critical frequency (f_oF2); Variability index (V_R); Pre-Sunrise; Post-sunset; Sunrise, Low Solar Epoch*

1.0 Introduction

Ionospheric F2-region has been shown to be the most efficient region for long-distance high frequency (HF) radio propagation, since it contains both the highest electron density (N_mF2) and highest height (h_mF2) including the peak critical frequency (f_oF2). A better understanding and interpretation of this region will be of utmost advantage to radio and communication experts. A good prediction of the f_oF2 variability is thus of great benefit in this respect as it holds a considerable feature of the complex subject of space weather, for both its practical applications and scientific importance. Akala, *et al.* (2011), Bilitza, *et al.* (2004), Olawepo and Adeniyi (2012) and Jayachandran, *et al.* (1995) are among the numerous researchers who have quantified and studied the f_oF2 spread at different latitudes and solar cycles. Zhang and Holt (2008) studied electron density variability and plasma temperatures at mid-latitudes.

Oladipo, *et al*. (2009) investigated the electron density distribution at fixed heights by making use of the Gaussian distribution test. Jin *et al*. (2008) and Lilensten and Blelly (2002), on the other hand, used GPS observations to study f_oF2 variability pattern at different latitudes.

This work focuses on the diurnal, seasonal, and annual f_oF2 variability for a single low latitude station of Ilorin (latitude 8.31°N, longitude 4.34°E) within the equatorial anomaly in the West Africa sector during the period of low solar epoch using the methodological analysis of percentage variability index (V_R). Note that other analytical parameters besides the mean (μ) and standard deviation (σ) have been used in some previous works to illustrate the f_oF2 variability (e.g., Kouris and Fotiadis 2002). Such works have used the upper/lower quartiles or deciles to represent the data scatter. These latter parameters have the advantage of being interpreted easily in terms of probability (in the first half of the data) but ignore the other half. However, the percentage variability index (V_R) provides a better gauge for unfolding the average deviation from the monthly mean for each hour of the day, even though it is difficult to interpret in terms of probability.

2.0 Data and method of analysis

The data for this study consists of ionospheric F2-region critical frequency (f_oF2). Hourly values of this parameter were extracted from Ilorin (latitude 8.31°N, longitude 4.34°E, dip latitude 2.95°), a low latitude ionospheric station in Nigeria, West Africa. The study is for the year 2010, a period of low solar epoch. The data sets for f_oF2 were obtained from the ionograms observed by the Ilorin digisonde. The ionograms were downloaded from the Digital ionogram DataBase (DIDBase), and the ionograms were manually edited with the SAO Explorer software package. The occurrence probability is the number of F2 region occurrence in a certain hour divided by the number of noticed ionograms in this hour for a month. The digisonde sounds at 15 minutes' interval. However, this time interval is too small to reveal the changes we want to study. Hourly interval datasets of F2 region critical frequency (f_oF2) were used for this study. This will elucidate the noticeable changes in F2 region. In practice, ionospheric variations in the Africa sector located in the Northern Hemisphere are categorised into the seasons of June Solstice, December Solstice, or Equinoctial period (e.g., Iheonu and Oyekola 2006; Chaitanya, *et al*. 2012). For this reason, data for the months of April and October represent the equinoctial period; the average across each hour of the two months is used to represent equinox season. Because Ilorin falls in the Northern Hemisphere, data for the months of July are used for the June Solstice season, while

November data falls in the December Solstice season. The datasets cover the entire 24 hours of the day for each of the stated representative months of the year 2010 used. This was done so that we can build a better statistical sample for representation of low solar epoch. Some earlier works (e.g., Radicella and Adeniyi 1999; Anderson, *et al*. 2006; Oladipo, *et al*. 2009; Ehinlafa *et al*. 2023) adopted the idea of using representative months for each of the seasons and their results are reasonable and well documented.

Following the example of Bilitza *et al*. (2004), as well as Rishbeth and Mendillo (2001), we have used the monthly mean (μ) and standard deviation (σ) to estimate the monthly variability index, while assuming that the variations represent real changes in critical frequency (f_oF2) and not just a redistribution of the existing plasma. The standard deviation (σ) is the usual way of quantifying precision, and hence is a measure of how precise the average is; that is, how well the individual dataset agrees with each other. Standard deviation is given mathematically as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\mu)^2}{n-1}} \tag{1}$$

where μ is the mean value taken as the data average, x_i is the individual data point, n is the number of data points, and quantity $(x_i - \mu)$ is the deviation of each data point from the average. The variability index is the absolute value of the coefficient of variation. It is often expressed as a percentage. A lower percentage indicates a lower variability in the dataset while a higher percentage indicates the dataset is more varied. The f_oF2 variability index, V_R used in this study is given by:

$$V_R = \frac{\sigma}{\mu} \cdot 100\ \% \tag{2}$$

For the seasonal pattern of the f_oF2 variability, the datasets are solved by finding the hourly mean values for the chosen months. In like manner, we made use of the average monthly values across each hour to interpret the annual pattern.

3.0 Results and Discussion

3.1 Variability Index in Ionospheric f_oF2

Figure 1 shows the diurnal f_oF2 variability index [V_R (%)] pattern plotted against local time (LT) over Ilorin.

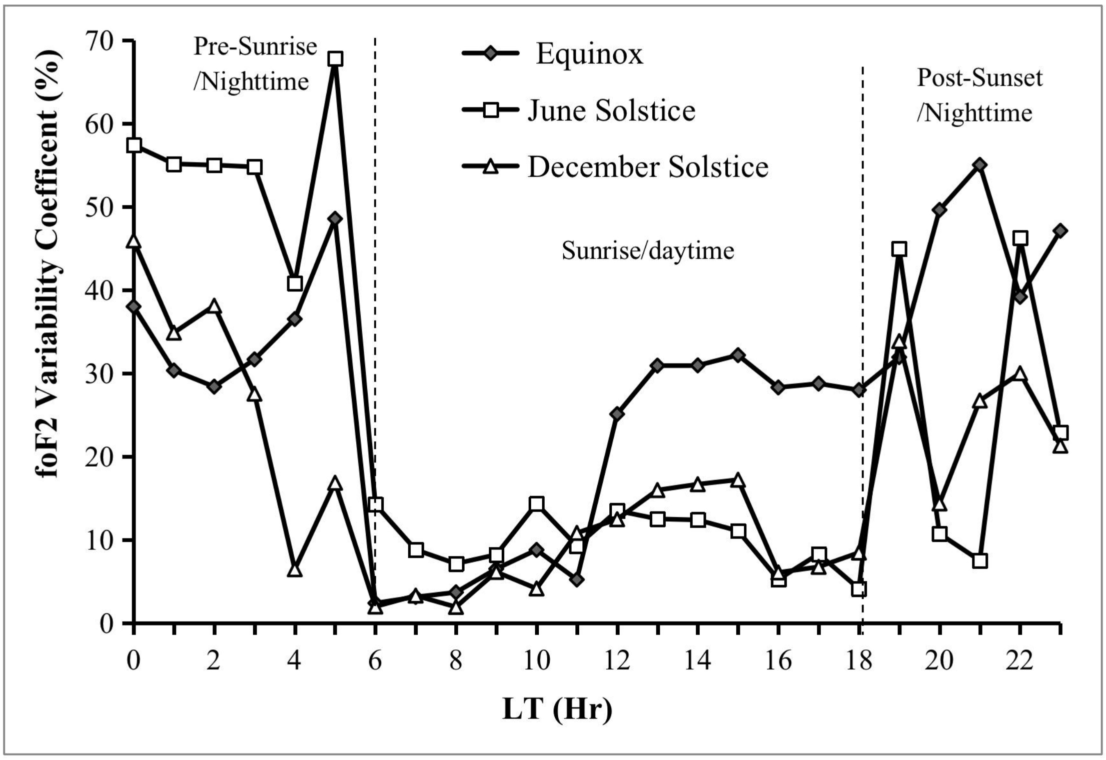

Figure 1: Diurnal Plots of f_oF2 variability index (V_R) over Ilorin for all seasons during year of low solar epoch

On the average, the diurnal variations follow the same pattern for all the seasons. The variability is noticed to be lowest during the sunrise phase (day time) (2-32%). At post-sunset phase (night time), the variability increased to (8-57%). However, the highest magnitudes were attained during the pre-sunrise phase, having a peak occurring around 0500 LT with a magnitude range of 17-68%. For this pre-sunrise peak, the highest was noticed in June Solstice (68%), then equinoctial (49%), and the least in December Solstice (17%). The second peak (the post-sunset peak) were noticed between 2100 and 2200 LT during all the seasons. For this post-sunset peak, the least was noticed in December Solstice (30%) around 2200 LT, followed by June Solstice (46%) around 2200 LT, and the highest in equinoctial season (55%) around 2100 LT. In all the seasons, the pre-sunrise peak is higher than the post-sunset peak. Moreover, the post-sunset phase variability index observations were seen to be higher than the pre-sunrise phase observations. The differences in the post-sunset and the pre-sunrise observations were explained, in part, to be due to the lower mean (μ) value during the night, which for comparable absolute variability gives rise to higher variability percentage at night time (e.g. Bilitza *et al.*, 2004).

The two f_oF2 variability peaks noticed, according to Chou and Lee (2008), Oladipo *et al*. (2008), Diabaté *et al.* (2019) and Ehinlafa *et al*. (2023), are ascribed to abrupt electron density gradients triggered by the onset and turn-off of solar ionization, as well as the superimposition of spread-F on the background electron density. The pre-sunrise peak was attained lately during December Solstice, and early in June Solstice. The highest post-sunset peak magnitude was recorded during equinoctial season. The inference from these observations is that much of the f_oF2 variations are noticed during the June Solstice suggesting that there may be some other factors present during this season causing the variability which may not necessarily be present during other seasons.

The hourly annual plot of variability index (V_R) against local time (LT) is represented in Fig. 2.

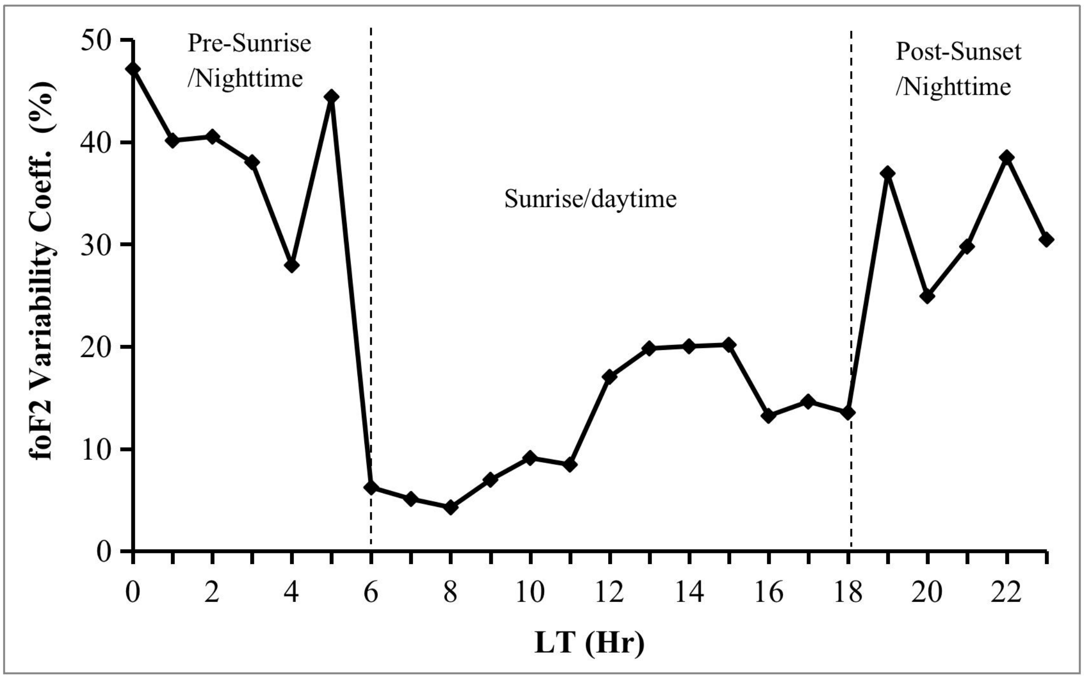

Figure 2: Annual Mean Plot of the foF2 variability index (V_R) derived over all seasons for low solar epoch.

The plot shows an average pre-sunrise peak of 44% magnitude around 0500 LT. The sunrise phase (daytime) magnitude ranges from 4-20% between the local time of 0600 - 1600, while the post-sunset peak recorded 37% magnitude around 1900 LT. Annually, night time variability is higher than the day time variation. According to Ambili *et al.* (2012), Alagbe (2012), and Bai *et al.* (2020) gravity waves and irregular wind had also been suggested to be another factor responsible for the night time ionospheric density gradient enhancement.

4.0 Summary and Conclusion

This study has investigated both the diurnal, seasonal, and annual f_oF2 variability over a West Africa sector equatorial station during a low solar epoch period. The variability index (V_R) was used for our analysis.

Variability index (V_R) is lowest during the day ranging from 2–32%, thereafter V_R increases during the night ranging from 8-57%, and the highest magnitude was attained during pre-sunrise (around 0500 LT) ranging from 17-68% for the LSE year. Two major peaks noticed were the pre-sunrise peak and the post-sunset peak. The highest pre-sunrise peak magnitudes were during the season of June Solstice, while the lowest was in December Solstice for the low solar epoch. The pre-sunrise peak magnitudes in the variability index (V_R) during the December Soltice, Equinox and June Solstice seasons were recorded as 17%, 49% and 68% respectively. At local noon, magnitudes of V_R ranges from 13– 25% for all the seasons during the LSE year. V_R peak of pre-sunrise phase is higher than the peak of post-sunset phase during the LSE.

Annually, V_R peaks were recorded as 44% and 37% magnitudes for the pre-sunrise and the post-sunset phases respectively. The reciprocal relationship of variability index (V_R) increasing for all the seasons during the LSE is also continual during the sunrise phase but with smaller absolute change. These were attributed to the sharp density gradients caused by the onset and turn-off of solar ionization on the background electron density; as the lifetime of a free electron is of the order of hours [Hines *et al*. (1965) and Olga (2021)], hence, the ionization equilibrium can be strongly affected by the movements of electrons that result from electromagnetic forces, temperature changes and diffusion.

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