A COMPARATIVE STUDY OF SEASONAL AND QUIETTIME foF2 DIURNAL VARIATION AT DAKAR AND OUAGADOUGOU STATIONS DURING SOLAR MINIMUM AND MAXIMUM FOR SOLAR CYCLES 21-22

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Abstract

A statistical study of quiet time foF2 diurnal variation of two West Africa stations (Dakar and Ouagadougou) is examined through seasons and during solar minimum and maximum phases. It is shown that during solar minimum and for all seasons both stations foF2 exhibit the same variability with more and less deep trough between 1200 LT and 1400 LT. foF2 profiles are afternoon predominance profiles except during winter and for Dakar station where the profile is morning predominance peak. During solar maximum, foF2 profiles show different behavior only for spring and summer where Dakar foF2 profiles are plateau profile and dome profile, respectively. For these seasons Ouagadougou profiles are morning predominance profile and noon bite out profile, respectively. At daytime there is more ionosphere at Dakar station than Ouagadougou at all seasons and for the solar cycle phases involved.

Keywords: F2 layer critical frequency, quiet time, seasonal variation, comparative statistical study, solar cycle minimum and maximum phases

Introduction:

To contribute to space weather study and to investigate existing prediction models, the analysis of the statistical variability of ionosphere parameters is a good means. The present paper focuses on space weather study through foF2 statistical variability. It is performed after foF2 statistical study conducted for an African Equatorial Ionization Anomaly (EIA) by Ouattara and Amory Mazaudier (2012) at Ouagadougou station (Lat: 12.4°N; Long: 358.5°E; dip: +1.43°) and that driven by Ali et al. (2015) at Dakar station (Lat: 14.8°N; Long: 342.6°E, dip: + 8.44°) situates between the crest and the trough of the EIA region of African sector at the trough of ionization. The previous works took into account different geomagnetic conditions but based on the particularity of Dakar station (see Gnabahou et al., 2013a, and Gnabahou et al., 2013b) and the geographic location of stations, we only consider quiet time conditions. This study is also performed under solar minimum and maximum conditions. In future work, the other solar cycle phases and the other geomagnetic classes of activity will be considered. For the present work, section 2 presents the materials and methods, section 3 our results and the paper ends with the discussion and conclusion section.

2. Materials and Methods

The data used in this study concern Dakar station (Lat: 14.8°N; Long: 342.6°E, dip: + 8.44°) in Sénégal and Ouagadougou station (Lat: 12.4°N; Long: 358.5°E; dip: +1.43°) provided by Télécom Bretagne. We analyze foF2 statistical diurnal variation for solar cycles 21-22 that contain part of the operating periods of Ouagadougou and Dakar stations which are 1966-1998 and 1971-1996, respectively. We especially consider the years 1971-1996.

Solar cycle phases are determined by using sunspot number Rz. Solar minimum year is given by Rz<20 and solar maximum year is obtained by taking Rz>100. Keep in mind that for small solar cycles (solar cycles with sunspot number maximum (Rz max) less than 100) the maximum phase is obtained by considering Rz>0.8*Rz max.

By using pixel diagrams that are built by means of (1) Mayaud (1971; 1972) geomagnetic index aa daily mean value Aa, (2) the date of Sudden Storm Commencement (SSC) and (3) color code (white and blue colors for quiet time and the other colors (green, yellow, orange, red and olive red) for disturbed time) we identify the four classes of geomagnetic activity. In pixel diagram, quiet time condition is given by $Aa \leq 20\, nT$ and disturbed conditions by $Aa > 20\, nT$.

Seasons are classified as follows: winter (December, January and February), spring (March, April, May), summer (June, July, August) and autumn (September, October and November). In this classification, equinoctial properties are highlighted by spring and autumn seasons. The properties of solstice are shown by winter and summer seasons.

Statistical hourly foF2 values are evaluated by means of the following equations (for more detail see Ouattara and Amory Mazaudier, 2012; Ali et al., 2015):

Solar cycle phase impact: $foF2_{Cycle}^{Hourly} = \frac{\sum_{j=1}^{Ny} foF2_{Year}^{Hourly}}{Ny}$ (1).

Where $foF2_{Year}^{Hourly} = \frac{\sum_{k=1}^{Nm} foF2_{Month}^{Hourly}}{Nm}$ corresponds to the mean hourly foF2 value of the considered year and Ny the number of year involved in the considered solar cycle phase. It can be noted that $foF2_{Month}^{Hourly}$ is the monthly hourly mean value of foF2 and Nm the number of available months involved in the considered year.

Seasonal study impact: $foF2_{Month}^{Hourly} = \frac{\sum_{l=1}^{Nd} foF2_{Day}^{Hourly}}{Nd}$ (2).

In the precedent equation, $foF2_{Day}^{Hourly}$ is an hourly foF2 value for quiet day and Nd the number of quiet day involved in the considered month.

In order to appreciate the difference of foF2 time variation observed in both stations, we use (1) error bars shown in foF2 profile of Ouagadougou station. These are obtained by applying $\sigma = \sqrt{V}$ where V is the variance defined by $V = \frac{\sum_{i=1}^{N}(foF2_i - \overline{foF2})^2}{N}$ and with $\overline{foF2}$ mean value and N the total number of data and (2) percentage difference obtained by utilizing $percentage = 100x\frac{\text{foF2Dakar} - \text{foF2Ouaga}}{\text{foF2Dakar}}$ where $foF2_{Dakar}$ and $foF2_{Ouaga}$ are F2 layer critical frequency values of Dakar and Ouagadougou stations, respectively.

3. Results

Figure 1 concerns data for solar minimum and figure 3 that for solar maximum. Red graph is for Ouagadougou data and blue for Dakar data. Error bar shown in Ouagadougou graph allows to appreciate the gap. Panels a, b, c and d are devoted to winter, spring summer and autumn, respectively.

Figure 2 and figure 4 show the percentage difference variability for solar minimum and solar maximum, respectively.

In figure 1a graphs present trough around midday at Ouagadougou and around 0100 LT at Dakar station. At daytime Dakar foF2 is higher than that of Ouagadougou. Dakar graph shows morning peak while that of

Ouagadougou presents fairly afternoon peak. In spring (panel b) both graphs show afternoon peak with only trough shown in Ouagadougou curve around midday. Between 0900 LT-1900 LT there is more ionosphere at Dakar station than at Ouagadougou station. Panel c graphs exhibit afternoon peak with trough only in Ouagadougou curve around midday. From 0800 LT to 1100 LT and after 2000 LT there is more ionosphere at Ouagadougou station than at Dakar station. Between 1100 LT-1800 LT it is the reverse. Figure 1d shows that from 0800 LT-2000 LT there is more ionosphere at Dakar station than at Ouagadougou station. Curves show double peaks with predominance afternoon peak. Trough is exhibited in Ouagadougou graph at 1200LT and at 1400 LT in that of Dakar.

In figure 1, it can be seen that graphs variability shows equinoctial asymmetry at both stations. One can see that there is more ionosphere in winter than in summer. Spring foF2 is higher than that of autumn. This latter situation is more pronounced in Dakar graph.

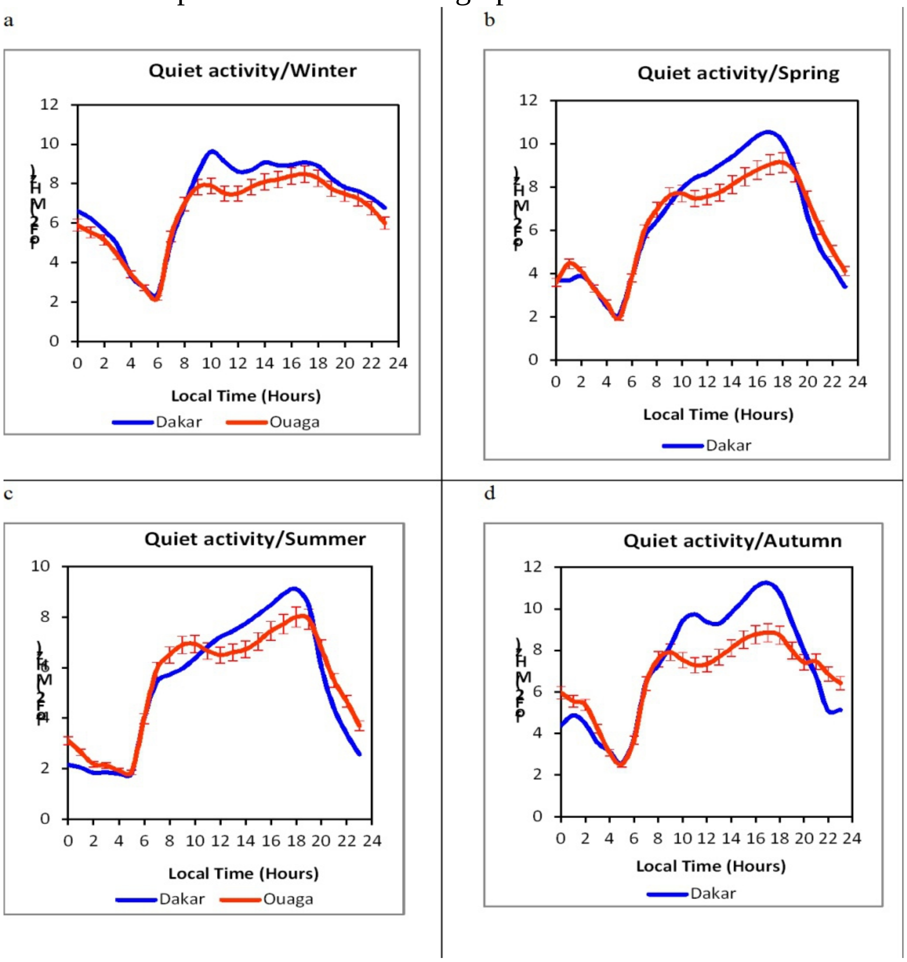

Figure 1: Quiet foF2 time variation during solar minimum phase

Figure 2 shows that during daytime we have $foF2_{Dakar}$> $foF2_{Ouaga}$. At night time $foF2_{Dakar}$<$foF2_{Ouaga}$ except for winter season. For this season, at all times $foF2_{Dakar}$ > $foF2_{Ouaga,}$ except at 0400 LT and 0700 LT where it is the reverse. The maximum percentage difference is observed at 1100 LT for winter and autumn and at 1700 LT for spring and summer. The variability of the percentage difference during spring and autumn shows equinoctial asymmetry.

In figure 3a both graphs present the same variability with Dakar foF2 higher than that of Ouagadougou from 1000 LT to night. The graph gap also increases from day to night. Night time trough is more pronounced at Ouagadougou station than at Dakar station. For the night time peak it is the reverse. Curves show morning peak profile. Panel b exhibits plateau profile at Dakar station while morning peak in foF2 is seen at Ouagadougou station. foF2 at Dakar station is higher than that of Ouagadougou station except between 0700 LT-1100 LT. Panel c shows fairly dome profile at Dakar station and noon bite out profile (double peak with trough located around midday). foF2 of Ouagadougou station is higher than that of Dakar between 0700 LT and 1100 LT and during night time. During autumn (panel d), graphs present double peak with morning predominance peak profile at Ouagadougou station and fairly noon bite out profile. foF2 of Ouagadougou station is higher than that of Dakar between 0700 LT and 1100 LT.

During equinoctial months, the difference in the form of foF2 profile and foF2 maximum value reached can be observed. Therefore, we can assert that figure 2 shows equinoctial asymmetry. It can also be seen that there is

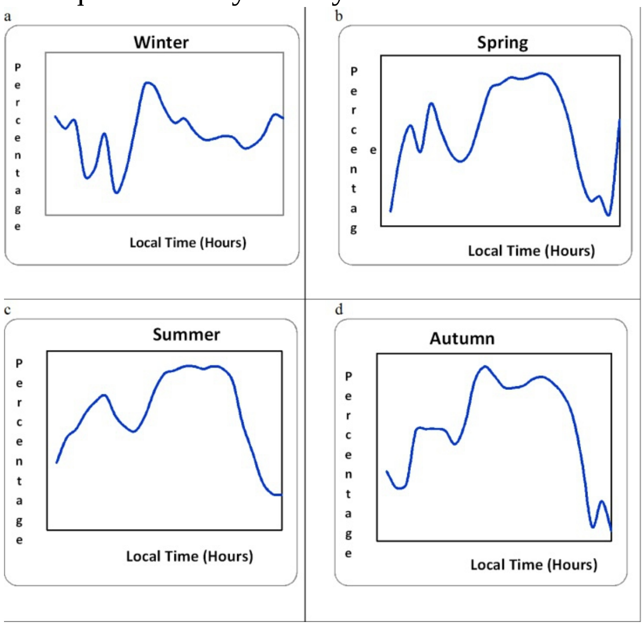

Figure 2: Quiet time percentage difference during solar minimum phase

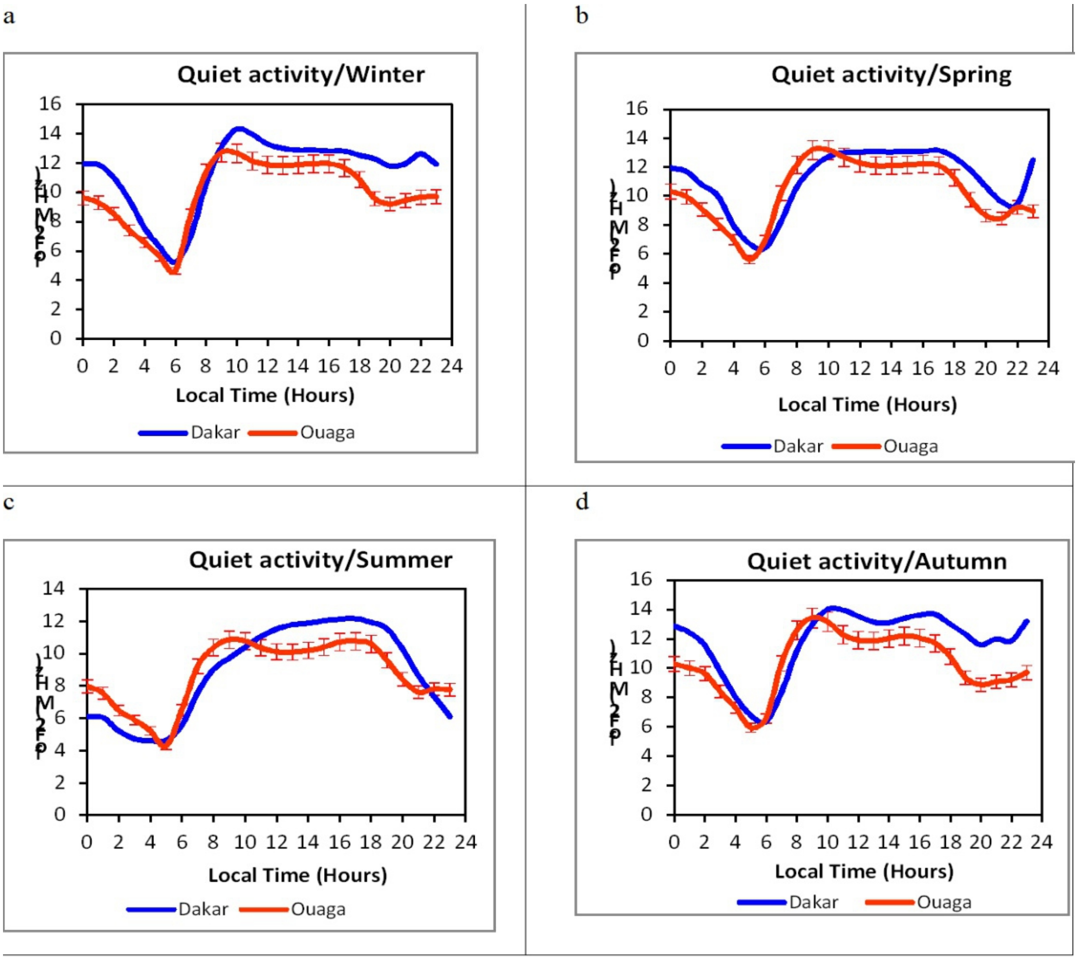

Figure 3: Quiet foF2 time variation during solar maximum phase

One can see in figure 4 that for all seasons and between 0600 LT-0900 LT $foF2_{Dakar} < foF2_{Ouaga}$. For the other times and in all seasons $foF2_{Dakar} > foF2_{Ouaga}$, except during summer where from 2200 LT to 0400 LT $foF2_{Dakar} < foF2_{Ouaga}$

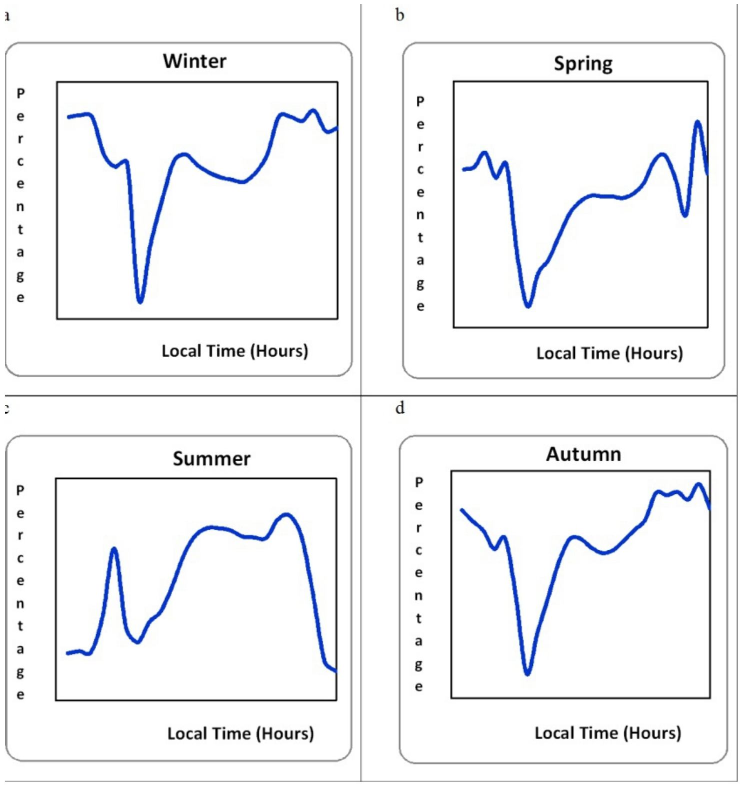

Figure 4: Quiet time percentage difference during solar maximum phase

4. Discussion and conclusion

During solar minimum, graphs show the same variability with more pronounced trough around midday at Ouagadougou station. Trough is noticed at Dakar station two hours later than that of Ouagadougou station. As trough round midday is the ExB effect, it can be retained that this appears two hours before Ouagadougou station. This allows us to assert that ExB effect seems to move from south to north because Ouagadougou is located in the EIA trough region and Dakar between the trough and the north crest. At daytime there is more ionosphere at Dakar station than at Ouagadougou station because Dakar is situated between the trough and the crest while Ouagadougou is located in the trough.

During solar maximum, curves highlight the same variability in winter (figure 2a) and in autumn (figure 2 d) with more and less pronounced trough between 1200 LT-1400LT. foF2 time profile variability is different for the two other seasons where trough is absent in Dakar foF2 time profile. The absence of trough in foF2 profile at Dakar station for these two seasons expresses that there is no vertical drift ExB effect. In fact, in the point of view of electrodynamics trough in foF2 profile for EIA region shows the signature of the vertical drift ExB (Fejer et al., 1981; Farley et al., 1986).

Moreover, it can be noticed that at all season Ouagadougou station foF2 profile shows the signature of the vertical drift ExB; that signature effect depends on season. The seasonal dependence of this signature effect is well known and has been investigated in several works (Richmond, 1995; Oyekola and Oluwafemi, 2007; Adebesin et al., 2013; Yizengaw et al., 2014).

The main difference between foF2 time variation profiles of both stations is due on the one hand to the highest ionization at Dakar station (that maybe due to its location) and on the other hand to a different profile behavior during spring and summer (Plateau and Dome profiles at Dakar station and fairly morning peak and noon bite out profiles at Ouagadougou, respectively). With a possibility to link ionosphere variability to the nature, the force or the absence of E region electric currents (Dunford, 1967; Vassal, 1982a; Vassal, 1982b; Acharya et al., 2010; and Acharya et al., 2011), it appears that Dome profile or plateau profile expresses the absence of electrojet while morning profile shows the presence of mean intensity electrojet and noon bite out profile the presence of strength electrojet (see Vassal, 1982b). These differences not only show a seasonal dependence of ExB effect but also its longitudinal and especially equatorial electrojet seasonal and longitudinal dependence. In fact, Yizengaw et al. (2014) clearly pointed out the equatorial electrojet and ExB seasonal differences in magnitude.

It can be retained from this study that: (1) ionization is higher at Dakar station than at Ouagadougou station; (2) the profile at Ouagadougou station always shows noon bite out profile with more or less predominance morning or afternoon peak; (3) the profiles at Dakar station during minimum phase principally are reverse profile except in winter. During solar maximum profiles change from one season to another.

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