

foF2 Diurnal Variability at African Equatorial Stations: Dip Equator Secular Displacement Effect

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ABSTRACT

The paper goal is to analyze the variability of foF2 at African equatorial stations and the effect of dip angle on this variability. The gap between the dip angle of Dakar and Ouagadougou is superior to that between Djibouti and Ouagadougou. The trend of the dip angle at Ouagadougou and Dakar decreases while that of Djibouti increases. The relative position of the station with respect to the equator and the trend sign explains the difference observed in foF2 variability at Dakar station and at the two other stations. At Djibouti and Ouagadougou, foF2 exhibits noon bite out profile during all solar cycle phases while at Dakar observed profile is dome or plateau during the maximum and the predominance afternoon peak for the other solar cycle phases.

Keywords: Dip Angle; foF2; Diurnal Variability; Solar Cycle Phase

1. Introduction

Equatorial ionosphere particularly that of African stations has been intensively investigated during the last decade (e.g. [1] Rishbeth and Mendillo; [2] Pancheva *et al.*; [3] Lei *et al.*; [4] Ataç *et al.*; [5] Ouattara *et al.*; [6] Obrou *et al.*; [7] Özgüç *et al.*; [8] Pham *et al.*; [9] Ouattara and Zerbo; [10] Ouattara and Amory Mazaudier; [11] Gnabahou *et al.*; [12] Ouattara). The investigation goals are: 1) to see the effect of geomagnetic storm (e.g. [13] Jones; [14] Jones and Risbeth; [15] Lal; [16] Araujo-Pradere; [17] Lal; [18] Obrou *et al.*; [19] Le Huy *et al.*; [20] Zhang *et al.*; [21] Ouattara and Fleury); 2) to analyze ionosphere variability ([22] Huang and Cheng; [23] Bilitza; [24] Özgüç *et al.*; [25] Ouattara *et al.*; [26] Thiam *et al.*); [27] Gnabahou and Ouattara; [28] Ksouri *et al.*; [29] Sambou *et al.*); 3) to model ionosphere parameters (e.g. [30] Adeniyi and Adimula, [31] Souza *et al.*; [32] Zou *et al.*; [33] Batista *et al.*; [34] Bilitza *et al.*; [35] Fotiadis *et al.*; [36] Batista and Abdu; [37] Ouattara *et al.*).

foF2 variability at Ouagadougou and Dakar ([37] Ouattara *et al.*) shows the difference between these two stations foF2 diurnal variations. The difference has been

attributed to the longitudinal variation of foF2. The analysis of foF2 diurnal variation at Djibouti station ([27] Gnabahou and Ouattara) and that at Ouagadougou station ([10] Ouattara and Amory Mazaudier) show some similitude, and this induces that the foF2 variations at this African sector are not only due to longitude effect. As these African equatorial stations (Ouagadougou, Dakar and Djibouti), do not have the same dip angle, the topic of the present study is to analyze the effect of the dip equator secular displacement on foF2 variability at these African equatorial stations. This study appears as the first one which investigates such effect at this sector in foF2 variability. It can be noted that the dip equator secular displacement effect in foF2 long term variations of this sector has been investigated recently by [11] Gnabahou *et al.* [37] Ouattara *et al.* study also points out that foF2 shows the phase-to-phase variability of the solar-activity due to solar ultraviolet radiation variability. For this reason the present work takes into account the effect of solar cycle phases.

After Section 2 where we present the data used in the present study and our methodology, we present and discuss our results in Section 3. Section 4 concerns the conclusion of the paper.

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2. Material and Methods

The data concern African equatorial ionosonde stations of Ouagadougou (lat: 12.4°N; long: 358.5°E, dip: 1.43 for 2013), Dakar (lat: 14.8°N; long: 342.6°E, dip: 8.44 for 2013) and Djibouti (lat: 11.5°N; long: 42.8°E, dip: 9.32 for 2013). These stations operated from 1966 to 1998, from 1964 to 1980 and from 1957 to 1981, respectively. Ouagadougou station data are provided by France Télécom, Dakar and Djibouti data are obtained from <http://www.ips.gov.au/IPSHosted/INAG/web-73/index.html>.

The data of Ouagadougou covered three solar cycles (20, 21 and 22), the data of Dakar three solar cycles (19, 20 and 21) and these of Djibouti two solar cycles (20 and 21).

The solar cycle phases are determined by using sunspot number (Rz) provided by SPIDR data base. The dip angle of the stations is given by IGRF (<http://www.gdc.noaa.gov/seg/geomag>).

For analyzing foF2 variability of these equatorial stations, we considered the two solar cycles which are the intersection of their operated periods. Therefore, the data of solar cycles 20 and 21 will be analyzed. Solar cycle phases are determined by using the following criteria given by [37] Ouattara *et al.*, improved by [25] Ouattara and applied after by [9] Zerbo *et al.*, [25] Ouattara *et al.*, [27] Gnabahou and Ouattara, [12] Ouattara and [38] Nanéma *et al.* 1) minimum phase: $Rz < 20$, where Rz is the yearly average Zürich Sunspot number; 2) ascending phase: $20 \leq Rz \leq 100$ and Rz greater than the previous year's value; 3) maximum phase: $Rz > 100$ [for small solar cycles (solar cycles with sunspot number maximum (Rz max) less than 100) the maximum phase is obtained by considering $Rz > 0.8 * Rz \text{ max}$]; and 4) descending phase: $100 \geq Rz \geq 20$ and Rz less than the previous year's value.

3. Results and Discussion

In **Figures 1** and **2** broken red curves concern Dakar station, triangle green graphs are devoted to Djibouti station and these of blue line to Ouagadougou station. Panel (a) is for minimum phase, panel (b) for increasing phase, panel (c) for maximum phase and panel (d) for decreasing phase. Because of lack of data, the graph of Ouagadougou and that of Djibouti during the minimum phase of cycle 20 and during the decreasing phase of cycle 21 are absent, respectively.

In all graphs of **Figures 1** and **2**, during solar minimum, increasing and decreasing phases at Ouagadougou and Djibouti stations, the afternoon peak is always greater than that of the morning. The asymmetry is more perceptible in the graphs of Djibouti than in those of Ouagadougou. In these graphs, afternoon peak appears around

1600 LT while the morning one is seen at 1000 LT and 0900 LT at Ouagadougou and Djibouti, respectively.

For all solar cycles (**Figure 2**) foF2 curves of Ouagadougou and Djibouti stations highlight the same variability. This variability is different from that of Dakar station. For all solar cycle phases, we observe the noon bite out profile characterized by the presence of the strength electrojet (see [39] Fayot and Vila). At solar maximum and for cycle 20 (panel (c) of **Figure 1**), we observe at Ouagadougou station, the same amplitude for the morning and afternoon peaks (11.7 MHz). For the cycle 21 at the solar maximum, the amplitudes of the morning and afternoon peaks are respectively 12.8 MHz and 12.1 MHz (panel (c) of **Figure 2**). The trough is observed around 1200 LT. At Djibouti station and for solar maximum, the afternoon peak amplitude (11.4 MHz for cycle 20: panel (c) of **Figure 1**; 12.6 MHz for cycle 21: panel (c) of **Figure 2**) is greater than that of morning peak (11.1 MHz for cycle 20: panel (c) of **Figure 1**; 12 MHz for cycle 21: panel (c) of **Figure 2**). Trough is seen around 1100 LT.

In the panel (c) of **Figure 2**, Ouagadougou and Dakar curves exhibit night peak which is the signature of the pre-reversal Electric field ([40] Rishbeth; [41] Fejer; [42] Fejer *et al.*; [43] Farley *et al.*).

It is important to note that the profiles observed at Dakar station are different from these observed at Ouagadougou and Djibouti stations. Dakar profiles are: 1) afternoon peak profile for solar minimum, increasing and decreasing phases for both solar cycles (panel (a), (b) and (d) of **Figures 1** and **2**). This type of profile is due to the strength counter electrojet (see [39] Fayot and Vila); 2) dome profile during the maximum of the solar cycle 20 (panel (c) of **Figure 1**) and 3) plateau profile during the maximum of the solar cycle 21 (panel (c) of the **Figure 2**). These last two profiles characterized the absence of electrojet (after [39] Fayot and Vila).

The explanation of the difference observed between Dakar and the two other stations is maybe due to their relative position with respect to magnetic equator. In fact, this assertion emerges from the analysis of **Figure 3**.

The **Figure 3** shows the trend of the variation of the dip angle from 1950 to 2010 where the interval 1960-1984 coincides with our study period covered by solar cycles 20 and 21. In this figure, green graph is devoted to Dakar, the blue curve to Ouagadougou and the red one to Djibouti.

It can be seen in **Figure 3** that Ouagadougou and Djibouti are closed to the magnetic equator than Dakar even though the magnetic equator approaches Ouagadougou and Dakar stations and rolls away from Djibouti station. This relative position should explain the particular variability of foF2 at Dakar.

In **Figure 4**; we have three panels corresponding to 1) the year which the dip angle of Ouagadougou and Dji-

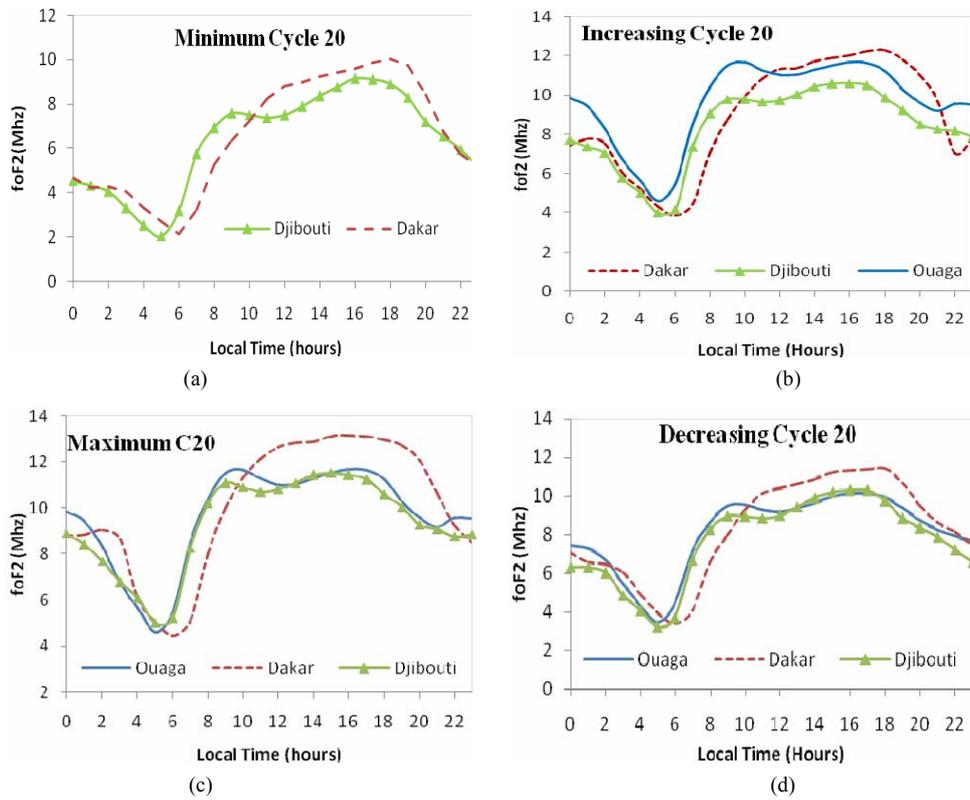


Figure 1. foF2 diurnal variation for solar cycle 20. (a) for minimum phase; (b) for increasing phase; (c) for maximum phase and (d) for decreasing phase.

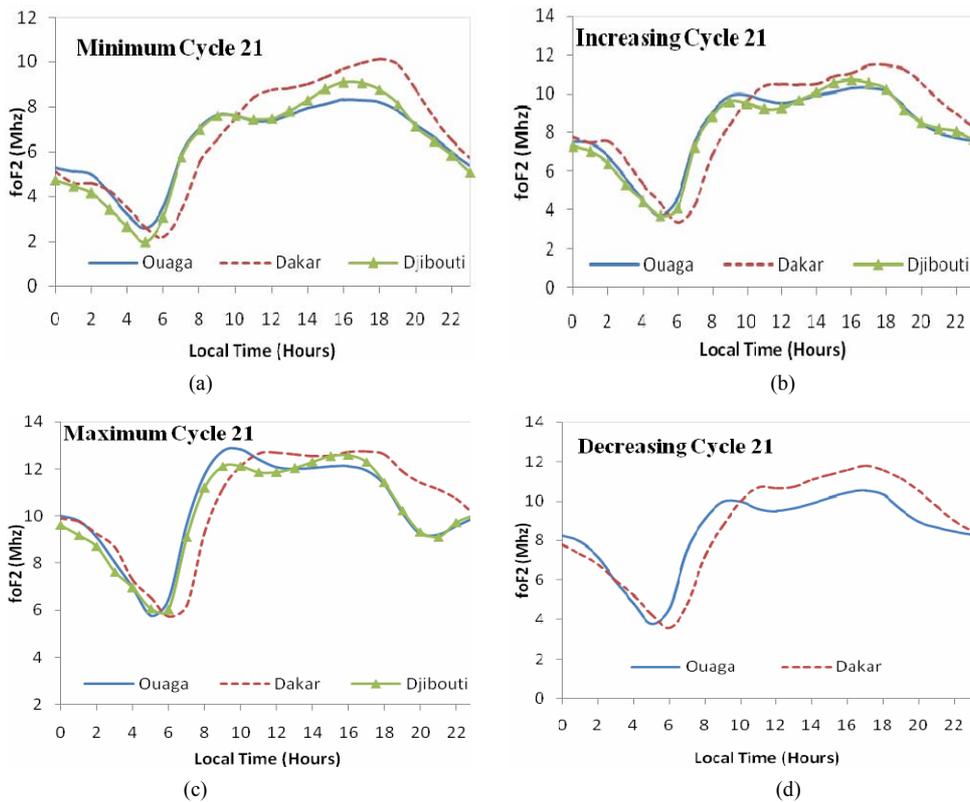


Figure 2. The same as Figure 1 but for solar cycle 21.

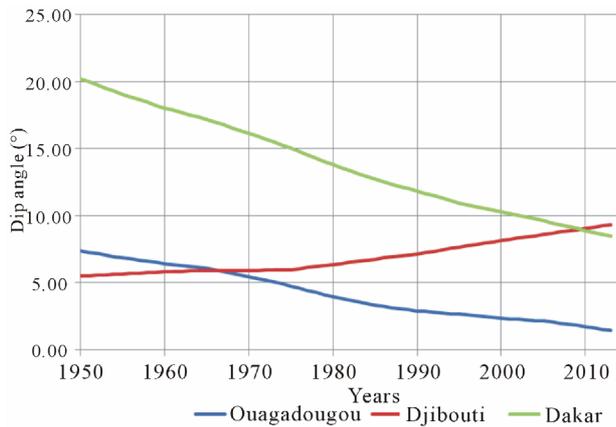


Figure 3. The trend of dip angle from 1950 to 2010.

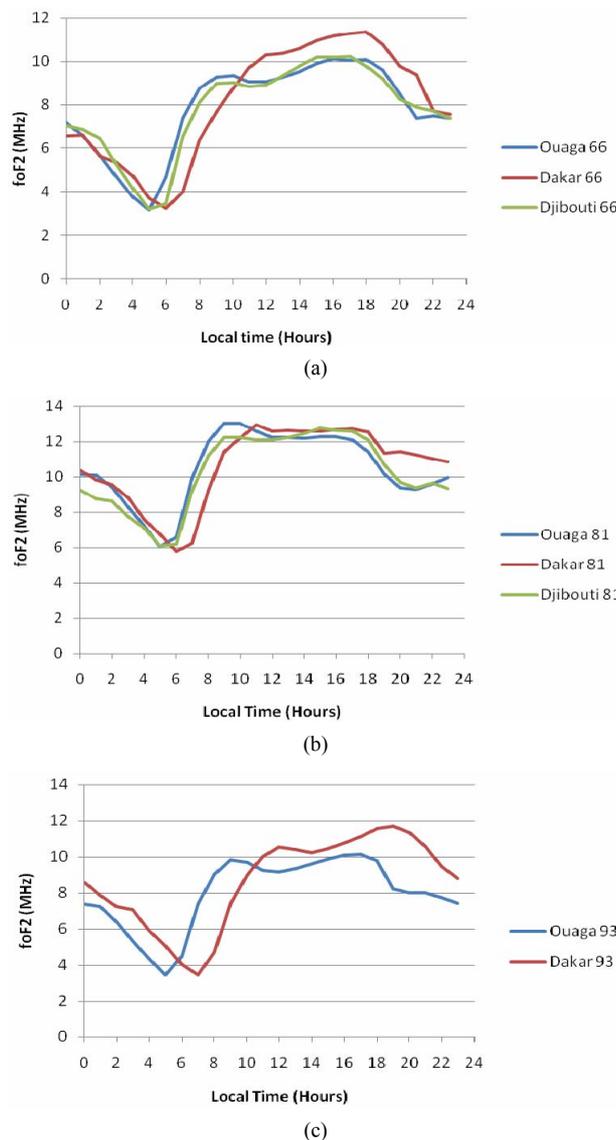


Figure 4. foF2 diurnal variation for year 1966, year 1981 and year 1993, located on panel (a), panel (b) and panel (c), respectively.

bouti are the same (1966), 2) the year corresponding to the end of the available data year interval of Djibouti (1981) and one year between this year and the year of the end of the available data year interval of Ouagadougou (1998). We chose here, 1993 as this year.

The panel (a) of **Figure 4** concerns the year 1966 where Djibouti and Dakar have the same dip angle, the panel (b) expresses foF2 variability for the year 1981 and the panel (c) foF2 variability for the year 1993.

The graphs of the panel (a) not only show the same variability of foF2 at Ouagadougou and Djibouti but also the almost confused graphs. We have here the noon bite out with predominance afternoon peak due to the presence of the strength electrojet while at Dakar we have the afternoon peak profile characterized by the presence of the strength counter electrojet. The gap between this profile and the other two profiles is non-negligible.

Panel (b) shows morning peak for Ouagadougou station and fairly morning peak for Dakar station and fairly afternoon peak for Djibouti. It can be retained that as Djibouti rolls away from the equator, the gap between its foF2 profile and that of Ouagadougou profile increases and the profile type looks like that of Dakar during the year 1966 where at this period this station is not close to the equator as the other stations are. The profile of Dakar station comes closed to that of Ouagadougou as these two stations approach the equator.

Panel (c) shows the similar foF2 profiles at Ouagadougou and Dakar stations for these stations are close to the equator. The graphs are not confused because their dip angles are different.

4. Conclusion

The present work shows foF2 variability for African equatorial stations. At Ouagadougou and Djibouti stations foF2 profiles are a noon bite out profile with more and less asymmetry in the peak amplitudes during solar maximum phase. At Dakar station foF2 profiles are afternoon peak during minimum, increasing and decreasing phases. During solar maximum the profile is dome or plateau. The difference between Dakar foF2 profile and the two other station profiles depends on the relative position of the station with respect to magnetic equator. Dakar and Ouagadougou approach the equator while Djibouti rolls away of it. The gap between Dakar and Ouagadougou stations is greater than that between Djibouti and Ouagadougou stations.

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