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ASIAN JOURNAL OF
SCIENCE AND TECHNOLOGY

ISSN: 0976-3376

Asian Journal of Science and Technology
Vol. 13, Issue, 09, pp.12190-12192, September, 2022

RESEARCHARTICLE

COMPARATIVE STUDY OF FOF2 DIURNAL VARIATION BETWEEN THE DAKAR AND OUAGADOUGOU STATIONS DURING THE ONE-DAY, TWO-DAY AND THREE-DAY SHOCK PERIODS FOR THE SOLAR MINIMUM AND MAXIMUM OF CYCLE 21-22

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ARTICLE INFO

Article History:
Received 25th June, 2022
Received in revised form
19th July, 2022
Accepted 14th August, 2022
Published online 28th September, 2022

Key words:
F2 layer critical frequency (foF2), one-day shock, two-day shock, three-day shock.

ABSTRACT

This paper deals with the comparative study of foF2 diurnal variation between the Dakar and Ouagadougou stations during shock activity of variable duration (one-day, two-day and three-day shock) for the solar minimum and maximum phases of cycle 21-22. At solar minimum, the curves of the diurnal variation of foF2 of two stations exhibit the signature of vertical drift indicating the presence of a strong electrojet. Except for the one-day shock, the ionization is strong at the Dakar station compared to the Ouagadougou station during this phase throughout the day. On the other hand, during the solar maximum, globally, the graph of Dakar shows the afternoon profile while that of Ouagadougou produced the profile of the morning peak tending towards that of the plateau profile. During this phase, we record a high ionization at the Dakar station compared to the Ouagadougou station from midday until sunrise.

Citation: ***Ali Mahamat Nour, Ouattara Frédéric and Anamo Anatole Temsala*, 2022.**" Comparative study of foF2 diurnal variation between the Dakar and Ouagadougou stations during the one-day, two-day and three-day shock periods for the solar minimum and maximum of cycle 21-22..", *Asian Journal of Science and Technology*, 11, (09), 12190-12192.

INTRODUCTION

Given the important role of the ionosphere in telecommunications, it is necessary to be able to predict ionospheric disturbances following solar events. Most studies on the variation of the ionosphere use the foF2 parameter from the F2 layer which is directly related to its electron density. It is important to note that the peak electron density of the F2 region (NmF2) or the critical frequency of F2 layer (foF2) is a main parameter for the determination of the Maximum Usable Frequency (MUF) for oblique radio wave propagation. Important results have been obtained after comparative studies through the foF2 parameter in the equatorial West African sector (Ouattara *et al*, 2009); (Ouattara *et al*, 2012); (Gnabahou *et al*, 2013), (Ouattara *et al*,2015). (Legrand and Simon, 1989), (Simon and Legrand, 1989), classified geomagnetic activity into four classes: Quiet day activity, Recurrent activity, Shock activity and Fluctuating activity. This classification was validated by (Ouattara *et al*, 2009); (Ouattara and Amory Mazaudier, 2009); and used by (Zerbo *et al*, 2011). The shock activity due to CMEs (coronal mass ejections) is investigated by taking into account the one-day, two-day and three-day shock.

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The study of the effects of different shock days on the diurnal variation of foF2 at the Ouagadougou station (Gyebré Aristide *et al*, 2018) and the work done by (SEGDA Abdoul-kader *et al*, 2019) during the One-Day-Shock, Two-Days-Shock and Three-Days-Shocks from 1966 to 1998 at the same station leads us to a comparative study of the diurnal variation of the critical frequency foF2 during different days of shocks between the Dakar station located near the equatorial ionization anomaly peak of the African sector and the Ouagadougou station, which is positioned at its trough. The data used in this section cover two solar cycles 21-22. The objective of this work is to know from the parameter foF2 the ionospheric variability during different days of shock between the two stations mentioned above. The second part of this work concerns the materials and methods used, the third part deals with the results with discussion and we end this article with a conclusion.

MATERIALS AND METHODS

Solar cycle phases are determined by considering the following conditions (criteria from Ouattara *et al*., (2013): 1) Minimum phase: $Rz < 20$ where Rz is the annual average value of the sunspot number 2) Ascending phase: $20 \leq Rz \leq 100$ and Rz greater than the value of the previous year; 3) Maximum phase: $Rz > 100$. For solar cycles where maximum Rz (Rzmax) is smaller than 100, the maximum phase is obtained by considering $Rz > 0.8$ Rzmax; 4) Descending

The data used in this work are:

- The values of the critical frequency of the F2 layer (foF2) measured by ionosonde at the station of Ouagadougou (lat: 12.4°N; long: 358.5°E dip: 1.43°) and Dakar (lat: 14.8 °N; long: 342.6 °E; dip: +8.44°) Dakar station situates between the crest and the trough of the EIA region of African sector. These values are provided by Télécom Bretagne (ENST-Bretagne);
- The sunspot number values Rz are obtained from the SPIDR database whose URL is http://spidr.ngdc.noaa.gov/spidr/ ;
- The Aa data used in this document are archived as pixel diagrams.

These diagrams are provided by the “Laboratoire de Recherche en Energetique et Méteorologie de l'Espace” (LAREME) of the University of Koudougou thanks to Professor Frédéric Ouattara. The shock days are determined from the dates of SSCs (Sudden Storm Commencement) for which the values of Aa remain above 40 nT on one, two or three days. The figure below illustrates the determination of different shock days using the pixel diagram of the year 1984.

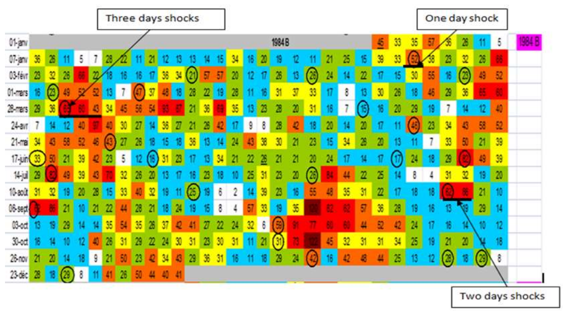

Figure 1. Pixel diagram of the year 1984 showing the determination of different shock days

The percentage deviation is obtained using the following formula:

Percentage = $100 * \frac{foF2\,Dakar - foF2\,ouaga}{foF2\,Dakar}$ where foF2 Dakar and foF2 Ouagadougou are respectively the average values of foF2 of the station of Dakar and Ouagdougou.

RESULTS AND DISCUSSION

Previous studies on the diurnal variation of foF2 in the African Equatorial Region show five types of profiles which are: the noon bit out profile, the morning peak profile, the afternoon peak profile, the plateau profile and the dome profile. Faynot, J.M. and Vila, P. (1979) and (Vassal, J. 1982) relate these profiles to the presence or absence of electrojet or counter electrojet. Figure 2 shows the comparative study of foF2 during the minimum phase on different days of shock.

The dashed lines represent the foF2 data from Dakar and the solid lines are for the Ouagadougou station. Figure 2-a) concerns the one-day shock during this phase. The curves of the data from two stations show the noon bit out profile. Both curves show the afternoon peak at the same time (17h00). Here, we note a shift in the "noon bit out" troughs that would normally be observed around midday. In diurnal profile of foF2, the presence of troughs around midday (noon bite out profile) expresses the signature of the E x B vertical drift (Fairley, 1986); (Rishbeth, 1971); (Fejer, 1979); and (Fejer, 1981). The percentage deviation shows us that during one-day shock, a large deviation is recorded at 04:00 and followed by other larger deviations during the nighttime at 21:00 and 22:00 with distinct values. Figure 2-b) focuses on the two-day shock. Here, both curves show a similar variation during all daytime. The noon bit out profile is also recorded at both stations. Both curves present the morning peak, trough and afternoon peak at the same time. Here, during all day time, there is more ionospheres at Dakar station than Ouagadougou compared to Figure 2-a) testifying to the position of two stations relative to the

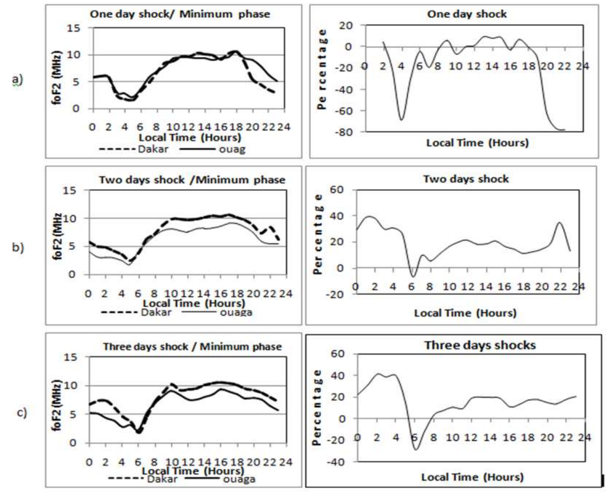

Figure 2. Comparison of foF2 between the Dakar and Ouagadougou stations during the days of Shock at solar minimum: a) one-day shock, b) two-day shock, c) three-day shock

In addition, the Dakar graph shows a nighttime peak at 22:00 with 8.45MHz.as foF2 values. It is well known that the nighttime peak on the graphs of the diurnal variation of foF2 exhibits the signature of the reversal electric field in the equatorial region as suggested by: (Fairley, 1986); (Rishbeth, 1971); (Fejer, 1979); and (Fejer, 1981). Indeed, during the day and in the equatorial region, in the E and F layers, the eastward electric field reverses during the night and is oriented towards the west (Fejer, 1981). During the two-day shock, the deviation is always recorded at nighttime at 22:00 (34%) and 01:00 (38%). Figure 2-c) deals with the diurnal variation of foF2 during the three-day shock. In this figure, both profiles are the “noon bit out” (SEGDA *et al*., 2019) with a morning peak observed at the same time at 10:00 with different foF2 values. In both graphs, we notice a shift observed between the troughs of two stations. The Ouagadougou station shows this trough at 12:00 while, the Dakar station exhibits around 13:00 (Ouattara *et al*., 2015). During the daytime, foF2 values are higher at the Dakar station than Ouagadougou. During the three-day shock, the highest percentages are observed at 3:00 and 4:00 with values of 38% and 39% respectively.

At solar minimum, during different days of shock, the different graphs present the signature of a strength electrojet proving the signature of the vertical drift E*B. Except one-day shock, a strong ionization is recorded at the Dakar station during all daytime. Figure 3 is devoted to the diurnal variation of foF2 during the maximum phase on different shock days. The dashed lines represent the foF2 values from the Dakar station and the solid lines are for the Ouagadougou data. In panel 3-d) Dakar’s graph shows a plateau profile that reflects the absence of electrojet, however the morning peak profile tending towards the plateau is observed at the Ouagadougou station, (SEGDA Aboul-Kader *et al*., 2019); the peak of this profile is located at 10h00 (12.78MHz). Except from 06:00 to 10:00, foF2 values at Dakar station are higher compared to those of Ouagadougou. Panel 3-e) concerns the two-day shock. The Ouagadougou data present a morning peak profile with a peak tending to the plateau profile showing the presence of a mean electrojet, while the Dakar curves highlight the reverse profile showing the presence of intense counter electrojet. Ionization is higher at Ouagadougou station from 00H00 to 12H00 and elsewhere it is the reverse. A similar variation of foF2 is observed in figure 3-f). The same types of profiles as in panel 3-e) are recorded at both stations with a strong ionization at Dakar station from 11h00. At solar maximum, the deviation is observed globally in the morning between 7h00 and 08h00. The most important difference is recorded during the two-day shock at 7:00 am with -32% as values. During

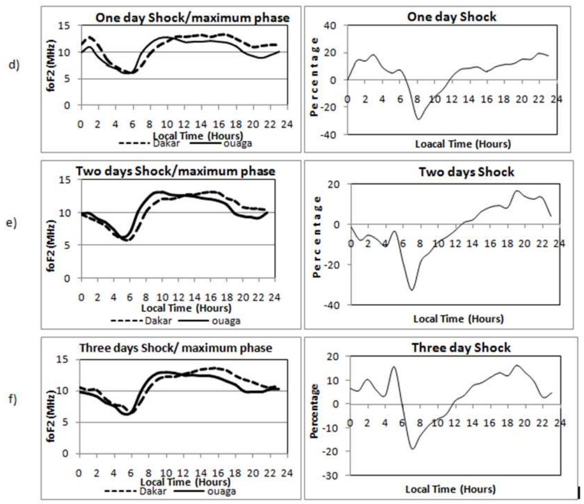

Figure 3. Comparison curves of foF2 between the Dakar and Ouagadougou stations during the days of shock at solar maximum d) one-day shock, e) two-day shock, f) three-day shock.

At solar maximum, during different days of shock, globally, the Dakar's graph shows the reverse profile while, Ouagadougou data produces the morning peak profile tending towards that of the plateau profile.

Conclusion

This work was made by taking account the different days of Shock activity: the one-day shock, two-days and three days shock. The comparative morphological study of foF2 clearly shows a difference between the two stations during the solar maximum. During this phase, we observe intense counter-electrojet at Dakar station; however, the Ouagadougou data show a mean electrojet tending to disappear. There is no vertical drift ExB effect during this phase. In addition, we record a strong ionization at Dakar station compared to the Ouagadougou station from midday until sunrise, while it is the reverse in the morning from 06h00 to 12h00. Whatever the duration of the shock, at solar minimum, data show the signature of a strength electrojet. The highest deviation percentages are observed at nighttime during the solar minimum.

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