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Seasonal Study of foF2 Diurnal Variation at Maximum Phase During Solar Cycles 21 and 22 at Dakar Station under the Shock Activity of Variable Duration

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Abstract

The study of foF2 diurnal variation at Dakar station during the solar maximum under the shock activity conditions of variable duration (One-day-Shock, Two-days-Shock and Three-days-Shock) confirms the seasonal dependence profiles. Thus, in spring and summer, we note the absence of electrojet which prove the Plateau and Dome profiles. In autumn, except Three-days-Shock where foF2 data graph gives afternoon peak profile, the noon bit out profile is recorded during this season. In winter, foF2 data show the noon bit out profile with a high morning peak trending towards that of the morning peak. The winter anomaly is observed during the different types of shock activity. Spring and autumn are marked by the signature of the reversal electric field.

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Keywords

One-day-Shock, Two-days-Shock, Three-days-Shock, Solar Maximum, foF2.

Introduction

The ionosphere is the region of the upper atmosphere that is composed of layers of electrically charged particles that transmit, refract and reflect radio waves, allowing them to travel great distances. It is therefore the zone of the atmosphere carrying communications over long distances. The critical frequency of F2 layer (foF2) is one of the most important parameters that allow an ionospheric study. Previous work was carried out on the foF2 diurnal variation at Dakar station. This clearly shows a seasonal dependence of ionospheric variability during different phases. The analysis of the long series of data available for the Aa geomagnetic indices allowed us to understand that in the context of the sunspot cycle, the different classes of activity have different occurrences through the phases of the sunspot cycle. Thus, the quiet activity occurs mainly during the minimum phase, while, the shock activity which is due to coronal mass injections or CMEs is preponderant during the solar maximum (Jean Louis Zerbo *et al.*, 2013). This situation leads us to make a seasonal study of the ionospheric variability from foF2 during the solar maximum under different types of shock activity (one-day-shock, two-days-shock and Three-days-shock).

The objective of this study is to understand the ionospheric variability during the different seasons under the period of shocks of variable duration at solar maximum.

The second part of this work concerns materials and methods used, the third part shows the results and discussion and we end our research work with a conclusion.

Materials and Methods

The data used in this works include two solar cycles (21-22) and concerns only the maximum phase.

These data are:

The values of the critical frequency of F2 layer at Dakar station ((lat: 14.8°N; long: 342.6°E; dip: +8.44°) provided by Télécom Bretagne (France);

The pixel diagrams which are made from the Aa geomagnetic indices are provided by LAREME (Laboratoire de Recherches en Energies et Méteorologie de l'Espace) of the University of Koudougou (Burkina Faso);

The values of the sunspot number Rz which make it possible to determine the different phases of the solar cycle are obtained from the SPIDR database whose URL is: http://spidr.ngdc.noaa.gov/spidr/.

The years of different phases are determined using the following conditions (criteria of Ouattara *et al.*, 2013): 1) Phase minimum: $Rz < 20$ where Rz is the annual average value of the spot number; 2) increasing phase: $20 \leq Rz \leq 100$ and Rz greater than the value of the previous year; 3) Phase maximum: $Rz > 100$. For solar cycles where Rz maximum (Rzmax) is smaller than 100, the phase maximum is obtained by considering $Rz > 0.8$. Rzmax. ; 4) Decreasing phase: $100 \geq Rz \geq 20$ and Rz smaller than the value of the previous years.

The table below gives us the years of the maximum phase of the solar cycle 21-22.

The shock activity days are determined from the dates of the SSCs (Sudden Storm Commencement) for which the Aa values remain above 40 nT over one, two or three days. For more details, see the works of Gybré *et al.*, (2018); Ali *et al.*, (2022).

The seasons are as follows: winter (December, January, and February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November).

For the analyzes of the results, we focused on the work of (Faynot and Villa, 1979). These two authors classified foF2 profiles in the equatorial region of Africa. They had obtained five types of foF2 profiles, namely: (1) "noon bite out" profile; (2) the "morning peak" profile; (3) the "reverse" profile; (4) the "plateau" profile and (5) the "dome" profile. Those different profiles characterize the presence or absence of the electrojet or counter-electrojet (Fayot and Vila, 1979); Vasal (1982).

Thus, the "noon bite out" type profile shows the presence of a strong electrojet, the "morning peak" profile characterizes the presence of mean intensity electrojet; the "inverse" profile or R profile testifies to the presence of intense counter electrojet; and finally the "plateau" and "dome" type profiles show the total absence of this current.

Results and Discussion

We recorded 173 numbers of shock activity (One-day-Shock, Two-days-Shock, and Three-days-Shock) during the solar maximum of the cycle 21and 22. One-day-Shock exhibits the majority with a percentage (45.66%) followed by Two-days-Shock (30.06%) and Three-days-Shock (24.28%).

In terms of occurrence per season, Figure 1 shows that the different types of shock activity occur predominantly in winter.

Figure 2 deals with the foF2 diurnal variation at solar maximum during different seasons under One-day-Shock activity.

Figure 2 (a) which related to winter shows a noon bit out profile with morning peak dominance with 3, 84 MHz as foF2 values.

A plateau profile proving the absence of electrojet (Faynot and Vila, 1979) with a small dip observed around 15H 00 is seen in figure 2 (b) which is devoted to spring (Ali *et al.*, 2015). In this figure, there is also, a night peak located at 22H00 with 11.55 MHz as the value (Fejer *et al.*, 1979, 1981); (Farley *et al.*, 1986); (Rishbeth, 1971). In summer, Dome profile is observed in Figure 2 (c), (Ali *et al.*, 2015). This type of profile shows the absence of electrojet, (Faynot and Vila, 1979).

During the one-day shock, the last figure, which corresponds to autumn, exhibits a noon bit out with a morning peak located at 11H00 (13.9 MHz) and an afternoon peak observed at 17H00 (14 MHz). The trough is located at 15H00.

During this one-day shock, winter foF2 values are superior to those of summer, except in the morning (05H00-07H00). This type of anomaly has already been observed by Arauje-Pradere, (1997); Zou *et al.*, (2000) and Rishbeth *et al.*, (2000); Rishbeth and Garriott, (1969); Ouattara and Amory-Mazaudier, (2009); Ali *et al.*, (2015) and constitutes the winter anomaly.

Figure 3 is devoted to two-days-shock.

Figure 3 (a) which corresponds to winter, presents a slightly disturbed noon bit out profile with a morning peak located at 10H00 (15,65 MHz) and an afternoon peak observed around 15H00. The trough is observed at 14H00 (13 MHz).

During this two-day shock, plateau profile and Dome profile remain on the spring and summer graphs, respectively, (Ali *et al.*, 2015).

The graph of figure 3 (b) also presents a night peak. This peak is located at 20H00 with 12,28 MHz as foF2 values

Figure 3 (d) which deals autumn shows the signature of the vertical drift even if the profile seems slightly disturbed. The curve shows a morning peak at 10H00 (13,775Mhtz) with a trough around 12H00 followed by another small peak at 13H00. The afternoon peak is located at 18H00. During the two-day shock, there is also the winter anomaly except from the interval 16H00-20H00. Figure 4 concerns the Three-days-Shock. During the spring and summer, we can observe the same types profile as in previous shock activities (One-day-Shock, Two-days-Shock). These are the Plateau and Dome type profiles.

However, in autumn, we record the presence of a counter electrojet proving the presence of the afternoon peak profile.

As for the winter, the trend towards a morning peak profile seems to be the most probable with a maximum of the peak located at 10H00 (14.6 MHz); even if we observe a small dip at 11H00 (13.9Mhtz).

During this period, we also record the winter anomaly except in the evening (16H00-19H00).

This work shows that the morphological study of the foF2 diurnal variation during the solar maximum at Dakar station under the different shock days (One-day-Shock, Two-days-Shock and Three-days-Shock) presents various profiles. This study confirms the seasonal dependence of the recorded profiles.

During one-day-shock, through spring and summer, there is no electrojet; however winter and autumn are marked by the signature of vertical drift ExB.

FoF2 data shows the same foF2 diurnal variation as for the previous shock period during two days shock.

The three days shock period is distinguished from two periods of geomagnetic shock mentioned above through winter and autumn. A morning peak profile proving the presence a mean intensity electrojet is observed in winter and an inverse type profile showing an intense counter electrojet is spotted in autumn.

The sign of the pre-reversal of the electric field is also observed and the study clearly shows the existence of the winter anomaly during these different shock periods of variable duration.

Table.1 Years of the maximum phase of the solar cycle 21-22

Solar Cycles	Years of solar maximum
21	1979- 1980- 1981 1982
22	1989- 1990- 1991

Fig.1 Number of types of shock activity per season during the solar maximum of the 21-22 cycle.

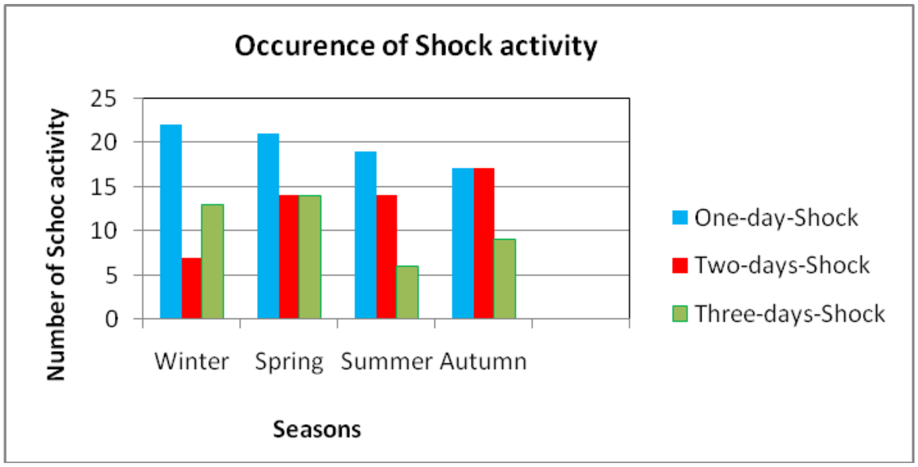


Fig.2 Curves of foF2 diurnal variation at solar maximum during One-day-Shock (a) Winter, (b) Spring, (c) Summer, (d) Autumn.

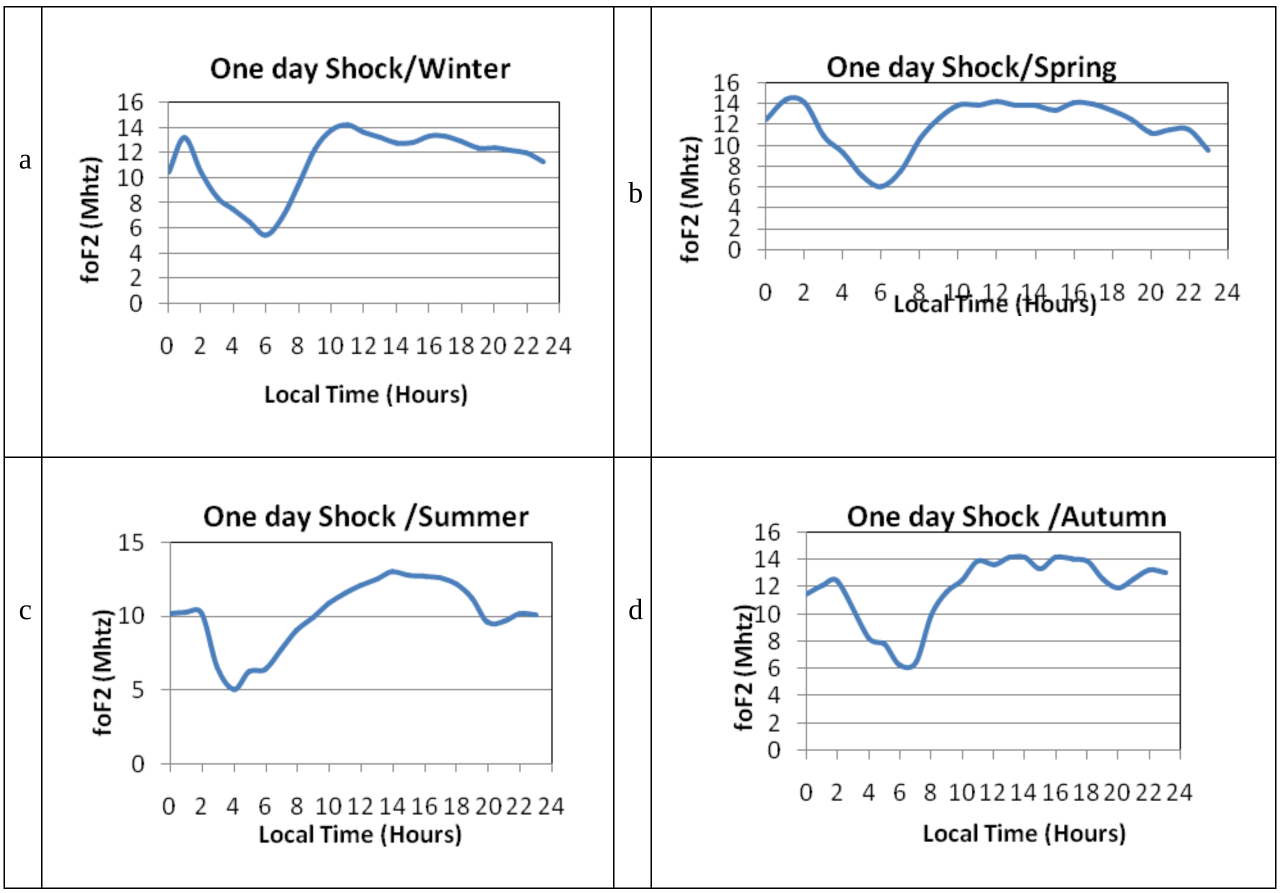


Fig.3 Curves of foF2 diurnal variation at solar maximum during Two-days-Shock (a) Winter, (b)Spring, (c) Summer, (d) Autumn.

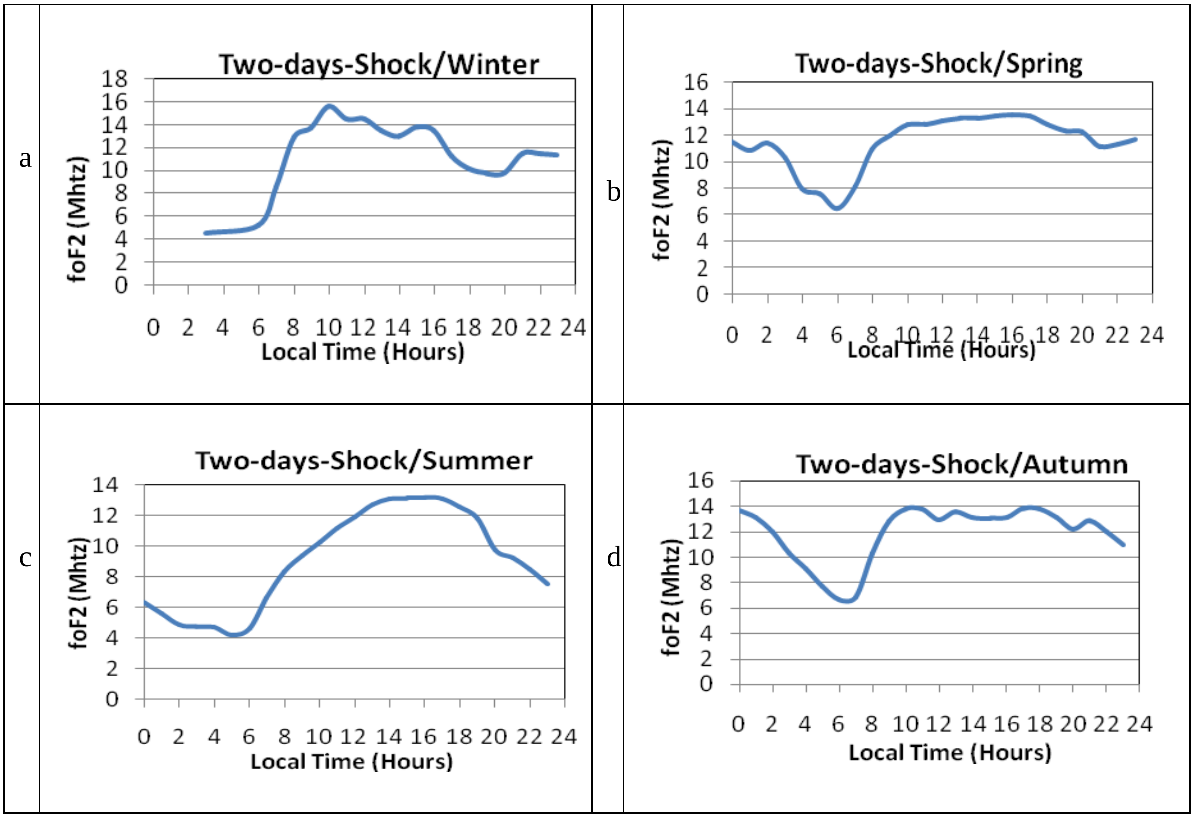
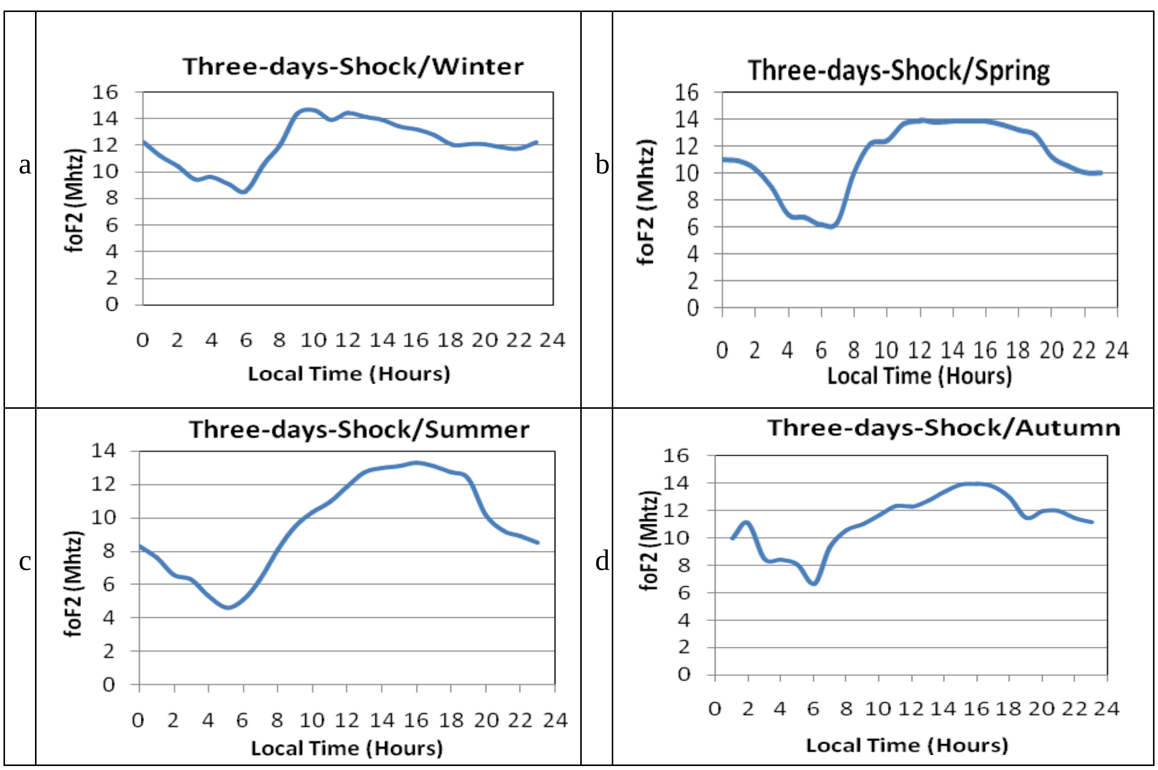


Fig.4 Curves of foF2 diurnal variation at solar maximum during Three-days-Shock (a) Winter, (b) Spring (c) Summer, (d) Autumn.



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