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### RESEARCH ARTICLE

#### SEASONAL EFFECT ON FoF2 VARIABILITY DURING ONE-DAY-SHOCK AT OUAGADOUGOU STATION DURING SOLAR CYCLES 20, 21 AND 22

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#### Abstract

The seasonal effect on the F2 sublayer critical frequency of the ionosphere (foF2), during one-day-shock, at Ouagadougou station during three solar cycles (20, 21, and 22) is examined in this work. It appears that summer has an effect tending to decrease the values of foF2 in the maximum, ascending and descending phase. At solar cycle maximum, winter and autumn do not modify the foF2 amplitudes. At solar cycle minimum, winter decreases foF2 values in the morning (08:00 a.m. to 1:00 p.m.), while spring amplifies them (09:00 a.m. to 1:00 p.m.). In the ascending phase, winter, spring and autumn increase foF2 values in the morning. In the descending phase, winter and autumn do not modify the foF2 values while spring increases them.

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#### Introduction:-

Magnetically the Sun acts on the Earth's environment through the emission of solar wind, electromagnetic radiation and coronal mass ejections. Solar wind is a manifestation of the solar magnetic field poloidal component, while coronal mass ejections and radiation are a manifestation of the toroidal field or closed field.

These solar events are at the origin of four geomagnetic activities according to the classification of [1] Legrand and Simon (1989): 1) activity on calm days caused by slow solar winds, 2) fluctuating activity caused by fluctuating solar winds, 3) recurrent activity caused by fast solar winds, and 4) shock activity caused by coronal mass ejections. Thus, the solar wind and shock activity are the main sources of geomagnetic activity.

Electromagnetic radiation is at the origin of the formation of the ionosphere, this layer of the upper atmosphere where ions and electrons are in sufficient quantity to influence the propagation of radio waves [2]. From this follows the importance of the study of the variability of the ionosphere, in particular of the F layer. It is well known that the variability of this layer depends on the phase of the solar cycle ([3] ; [4]; [5] ; [6]), on season ([7],[8] ,[9] ; [10] ; [11] ;[12] ), on solar wind speed ([13] ; [14] ; [15] ; [16],[17] ; [18] ) on shock activity ([19] ; [20]).

The first statistical study on the variability of foF2 Ouagadougou station was conducted by Ouattara et al ([21], over a period of three solar cycles. From the pixel diagram the shock activity can be divided into three categories: one-day shocks, two-days- shocks and three-day -shocks([22]). From 1966 to 1998, the latter recorded 323 shocks, including 168 one-day, 105 two-day and 50 three-day shocks. This made it possible to make a comparative study of

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the effect of these different types of shock on the variability of foF2. In the present work which is a continuation of it, it is a question of evaluating the impact of the season by phase of the solar cycle on the variability of foF2 at Ouagadougou station, during geomagnetic storms linked to one-day shocks, the latter constituting the majority of the shocks detected during this period. Section 2 is devoted to the methodology. Section 3 is reserved for results and discussion. In conclusion, we will present the main results and perspectives.

## Data and Methodology:-

### Data

Ouagadougou station (12.4° N, 358.5 E; dip: +1.45) is located at the bottom of the equatorial ionization anomaly. It operated for about 3 solar cycles (cycles 20, 21, 22) namely from June 1966 to February 1998. The data for this station was provided to us by the National School of Telecommunications of Brittany (ENST Bretagne).

The indices aa, Rz and the dates of the SSCs are obtained from the site of the international service of geomagnetic indices (GIS). The Aa indices and the dates of the SSCs allowed the construction of the pixel diagram. This diagram highlights the three types of shock. The solar index Rz makes it possible to determine the different phases of the solar cycle.

### Determination of the phases of the solar cycle

It is based on the criteria established by Ouattara et al (2009)[23]:

Minimum phase :  $R_z < 20$

Ascending phase :  $20 \leq R_z \leq 100$

Maximum phase :  $R_z \geq 100$

Descending phase :  $100 \geq R_z \geq 20$

It should be noted that  $R_z$  designates the annual average value of the sunspot index which makes it possible to estimate the activity of the Sun. Moreover, for solar cycles for which  $R_z \text{ max} < 100$ , the maximum phase is obtained by considering  $R_z > 0,8R_z \text{ max}$ .

### Determination of seasons

The distribution of the seasons was made in accordance with Table 1.

**Table 1:-** Distributions of the seasons of year.

Seasons	Months
Winter	December, January, February
Spring	March April May
Summer	June July August
Autumn	September, October, November

### One-day shock determination

Shock activity is caused by coronal mass ejections (CME) that reach Earth and is characterized by an index  $Aa > 40$  nT. This class is determined by taking from the pixel diagram 1, 2 or 3 disturbed days after an SSC (Sudden Storm Commencement) without recurrence.

From the pixel diagram, we can distinguish three types of shocks taking into account their duration of effect: one-day-shocks, two-days-shocks and three-days-shocks. The figure 1 gives an example of determining these shocks. For more details regarding the pixel diagram, we could consult the following references: [24], [25], [26], [27].

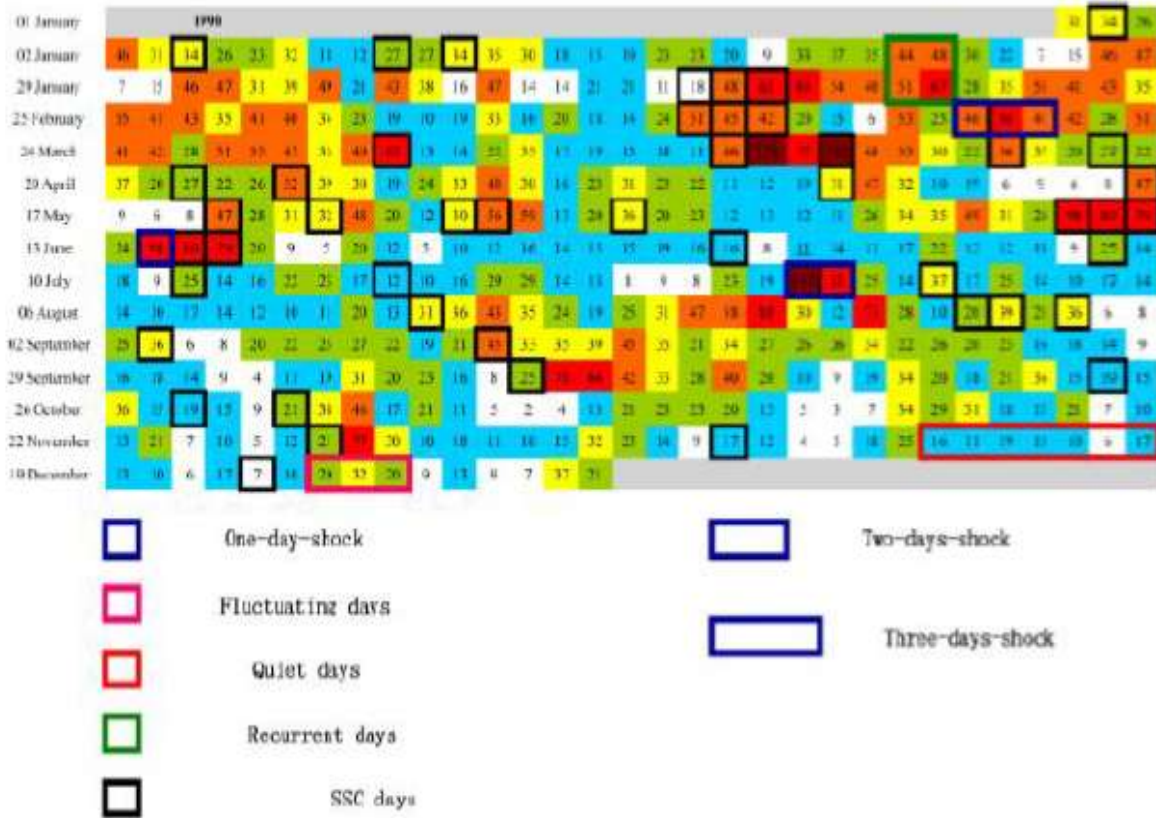


Figure 1:- Example of a pixel diagram showing the different types of shock(Gyébré et al, 2018).

**Méthoded’analyse des données**

In each graph we plot the statistical hourly averages of foF2 for a given phase solar cycle during the season whose impact on foF2 we want to estimate, and we denote it  $foF2_{solarp\ phase}$  (seasonwhoseimpactwewanttoestimate). We also plot the hourly averages during the same phase of the solar cycle and during all the seasons that we note:  $foF2_{solarp\ phase}$  (allseasons).The error bars plotted on  $foF2_{solarp\ phase}$  (allseasons) make it possible to estimate the effect of the season per phase on the variability of foF2.

**Results And Discussion:-**

**Maximum phase**

Panel a (respectively b, c, and d) of figure 2 gives the diurnal variations of foF2 during one-day-shock at the maximum of the solar cycle (all seasons) and during winter (respectively spring, summer and autumn).

Panel a of figure 2 shows the same morphology in winter and at the maximum (all seasons) of the solar cycle. Moreover, the amplitudes are substantially equal according to the observation of the error bars. We can therefore say that at the maximum of the solar cycle, the winter season has no impact on the variability of the amplitude of foF2.

Panel b in figure 2 shows that from 12:00 a.m. to 3:00 a.m. and from 1:00 p.m. to 7:00 p.m.  $foF2_{maximum}$  (allseasons) <  $foF2_{maximum}$  (spring). For the other hours of the day, the amplitude of foF2 is not modified.

Panel c in figure 2 shows that almost all day  $foF2_{maximum}$  (alseasons) >  $foF2_{maximum}$  (summer).

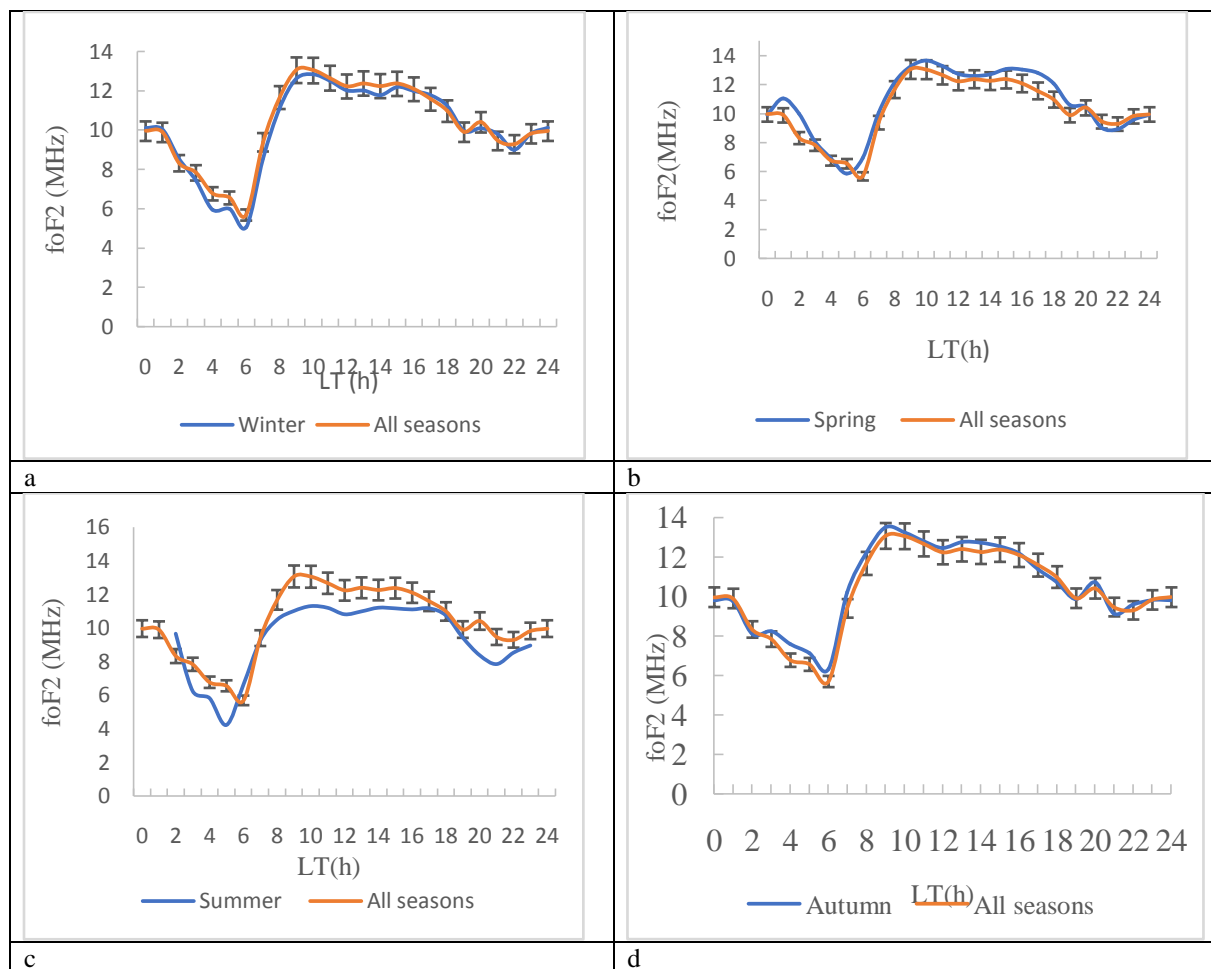
Panel d of figure 2 shows that autumn has no effect on the variability of foF2 at the maximum of the solar cycle nor in the variability of the currents nor in their amplitude.

Thus, at the maximum of the solar cycle, winter and autumn do not modify the foF2 amplitudes, while summer tends to decrease the foF2 values throughout the day.

This last result is comparable to the phenomenon of the winter anomaly for which the foF2 values in summer are lower than those in winter. It could therefore be explained by temperature variations, the transport of ionization, the seasonal change in the chemical composition of the neutral atmosphere ([28]Rishbeth and Setty, 1961).

According to Azzouzi ([29])the main seasonal effect is caused by the circulation of the prevailing winds from the summer hemisphere to the winter hemisphere. This circulation leads to a molecular mass bulge from the summer polar region towards mid and low latitudes. On the other hand, in the winter hemisphere the molecular mass bulge is confined to high latitudes. Regions of increased average molecular weight have a greater proportion of molecular species, thus accelerating the recombination of ions. In these predominant regions in the summer hemisphere the ion density decreases at the peak of the F2 region. On the contrary in the regions where the average molecular mass decreases correspond to a decrease in the recombination of ions, therefore an increase in the ionic density observed at the middle latitudes of the winter hemisphere.

This result is also in agreement with the work of D. Vijaya et al[30] who established that the majority of negative storms take place in summer regardless of the locality.



**Figure 2:-** Impact of the season on the variability of foF2 in maximum phase. Respectively panels a, b, c, and d relate to winter, spring, summer and autumn.

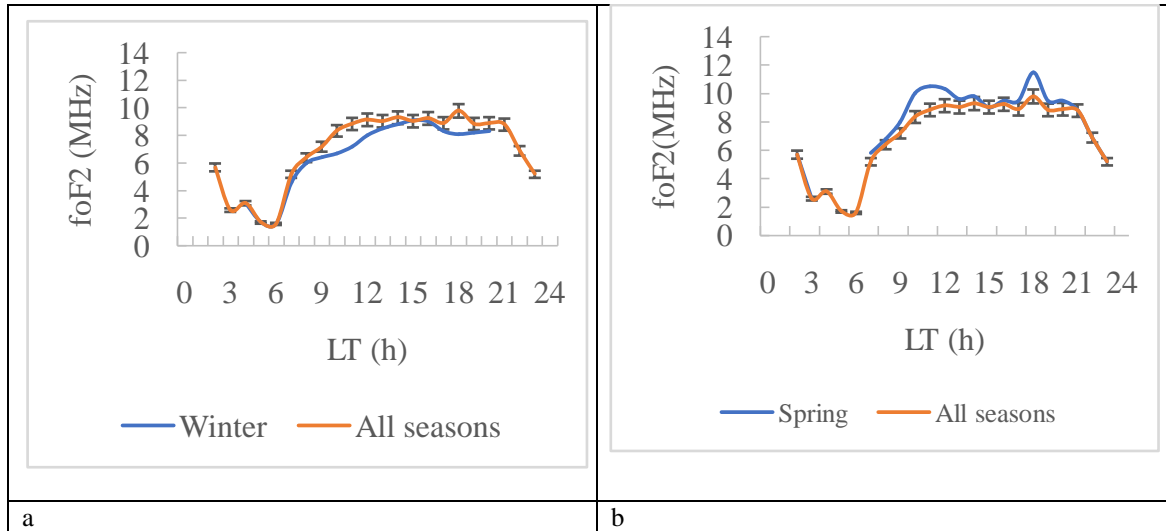
**Minimum phase**

One can observe the absence of one-day-shock during summer and autumn. Panel a (respectively b) of figure 2 gives foF2 diurnal variations during one-day-shock at the minimum of the solar cycle (all seasons combined) and during winter (respectively spring).

From 8 a.m. to 1 p.m., we see that  $foF2_{minimum} (allseasons) > foF2_{minimum} (winter)$  by observation of panel a in figure 2.

Panel b in figure 2 shows that from 9 a.m. to 1 p.m. and from 5 p.m. to 7 p.m.  $foF2_{minimum} (allseasons) < foF2_{minimum} (spring)$ .

Thus, it is remarkable that at the minimum of the solar cycle that winter decreases the foF2 values in the morning (08:00 to 13:00), while spring amplifies them (09:00 to 13:00).



**Figure 3:-** Impact of the season on the variability of foF2 at the minimum of the solar cycle. Panel a (respectively b) concerns winter (respectively spring)

### Ascending phase

Panel a (respectively b, c, and d) of figure 3 gives the diurnal variations of foF2 during one-day shock in the ascending phase of the solar cycle (all seasons) and during winter (respectively spring, summer and autumn).

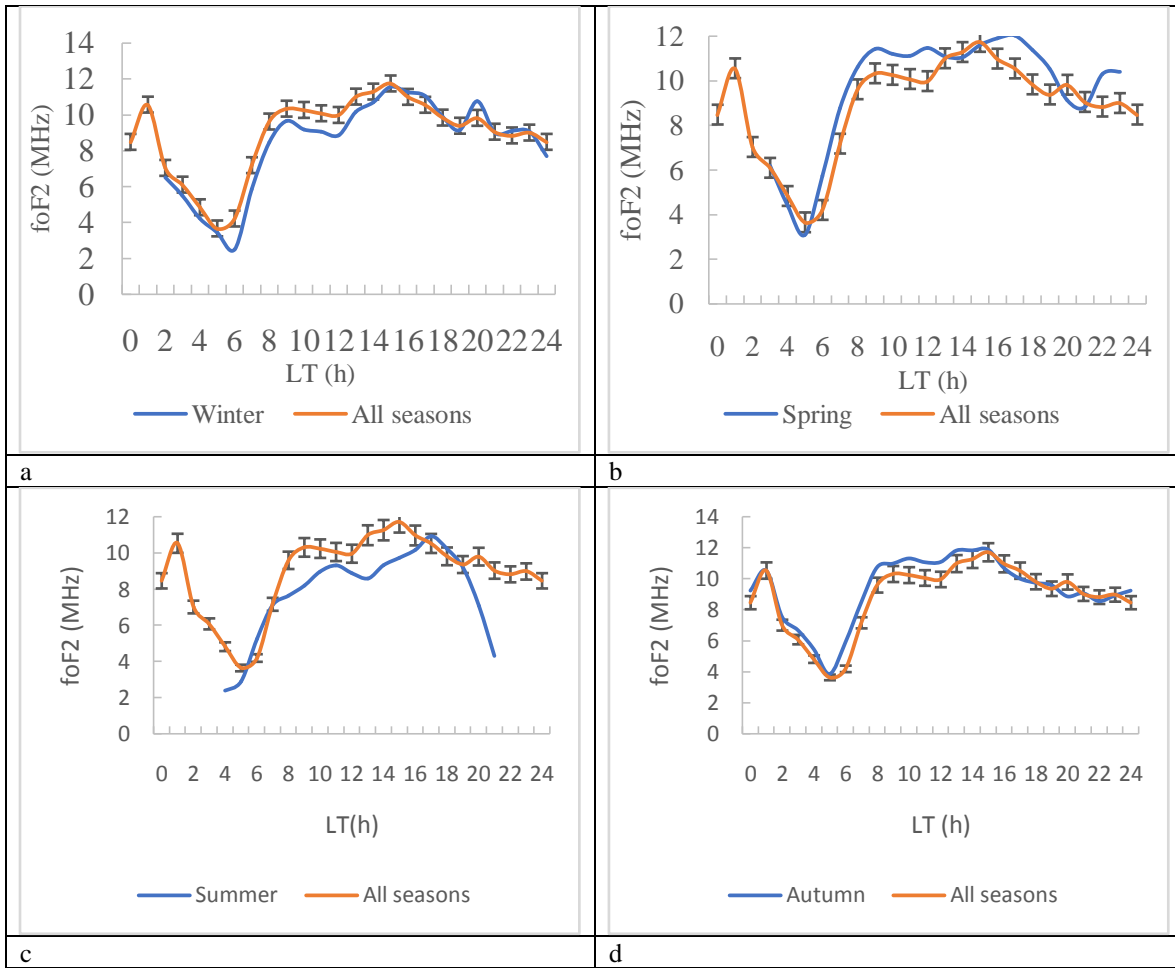
The panel showed the same morphology of foF2 for the winter curve and that concerning the statistical averages of all the seasons. However, the following relationship is noted with respect to the amplitudes:  $foF2_{ascending} (allseasons) < foF2_{ascending} (winter)$  from 06:00 to 14:00.

Panel b in Figure 3 shows that from 6 a.m. to 1 p.m., 3 p.m. to 8 p.m., and 9 p.m. to 11 p.m.  $foF2_{ascending} (allseasons) < foF2_{ascending} (spring)$

It can be observed through panel c in Figure 3 that  $foF2_{ascending} (allseasons) > foF2_{ascending} (summer)$  during the following time intervals: 7:00 a.m. to 4:00 p.m.; 7:00 p.m.-9:00 p.m.; 4:00 a.m.-5:00 a.m. and that  $foF2_{ascending} (allseasons) > foF2_{ascending} (allseasons)$ : 5:00 a.m.-7:00 a.m.

Panel d of figure 3 shows that except between 09:00 and 13:00 or  $foF2_{ascending} (allseasons) < foF2_A (autumn)$  we can note that  $foF2_{ascending} (allseasons) \approx foF2_A (autumn)$ .

In summary, what is remarkable in the ascending phase is that only summer has an effect tending to reduce the values of foF2. The reasons mentioned in the maximum phase of the solar cycle can explain this result.



**Figure 4:-** Impact of the season on the variability of foF2 at the ascending phase. Panel a (respectively b, c and d) concerns winter (respectively spring, summer and autumn)

**Descending phase**

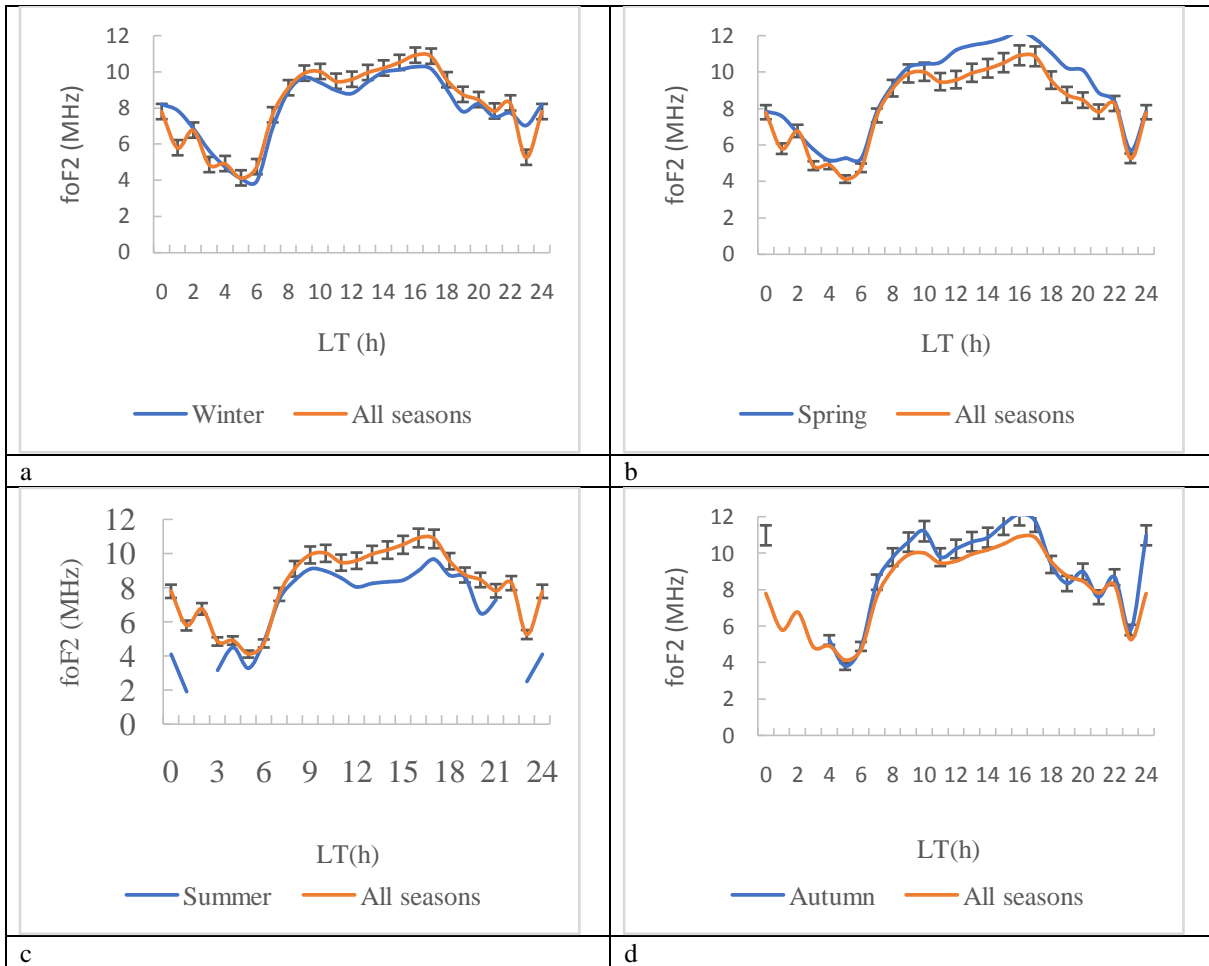
Panel a (respectively b, c, and d) of figure 4 gives the diurnal variations of foF2 during one-day -shock in the descending phase of the solar cycle (all seasons combined) and during winter (respectively spring, summer and autumn).

The panel showed that winter does not modify foF2 amplitudes by observing error bars:  $foF2_{descending} (all\ seasons) \approx foF2_{descending} (winter)$ .

Panel b of Figure 4 shows that spring tends to increase foF2 values from 0900 to 2000 hrs.

Panel c in Figure 4 shows that summer has an effect tending to decrease foF2 values between 9:00 a.m. and 6:00 p.m..

Panel d in Figure 4 shows that autumn does not significantly change foF2 values.



**Figure 5:-** Impact of the season on the variability of foF2 at the descending phase of the solar cycle. Panel a (respectively b, c, and d) concern winter (respectively spring, summer and autumn)

### Conclusion and perspectives:-

Thus, the analysis of the variability of foF2 during one-day shocks at the Ouagadougou station shows a seasonal variability by phase of the solar cycle. At the maximum of the solar cycle, winter and autumn do not modify the foF2 amplitudes, while summer tends to decrease the foF2 values throughout the day. At the minimum of the solar cycle, winter decreases foF2 values in the morning (08:00 a.m. to 1:00 p.m.), while spring amplifies them (09:00 a.m. to 1:00 p.m.). Only summer has an effect tending to decrease the foF2 values in the ascending phase. In perspective, a more in-depth quantitative study by phase could be carried out using the deviation percentages, firstly. Secondly, the different shocks do not behave in the same way, it would be interesting to resume the study during the two-day and three-day shocks. At last, one could also be interested in the variability of morphology.

### Data availability

Sunspot Index Rz data is available at [https://omniweb.gsfc.nasa.gov/form/om\\_filt\\_min.html](https://omniweb.gsfc.nasa.gov/form/om_filt_min.html)

Geomagnetic Index aa data is available at <https://isgi.unistra.fr/>

### Conflicts of interest

The authors declare no conflict of interest

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