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RESEARCH ARTICLE

SEASONAL ANOMALIES AND IRI-2016 PREDICTION OF F2-LAYER CRITICAL FREQUENCY UNDER GEOMAGNETIC ACTIVITY RECURRENT CONDITIONS DURING SOLAR CYCLES 21 AND 22 AT OUAGADOUGOUSTATION

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Abstract

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The ionosonde values of F2-layer critical frequency at Ouagadougou under recurrent geomagnetic activity during solar cycles 21 and 22, show a mild winter anomaly during the morning from 0900LT to 1000LT, in afternoon from 1500LT to 1700LT and during the night from 2000LT to 2300LT.URSI and CCIR subroutines reproduce this anomaly in accordance with the experimental values during the night from 2100LT to 2300LT.The Spring and autumn experimental profiles are similar, with absolute values of the relative deviation lower than 10%. The modeled profiles during these seasons are similar and no equinoctial asymmetry is reported except in the morning from 0200LT to 0500LT with CCIR. The ionosonde values does not predict a semi-annual anomaly. Like the experimental results, IRI-2016 model does not predict this anomaly except from 0000LT to 0300LT with the CCIR. The model gives a good estimate of the equinoctial asymmetry and the semi-annual anomaly. As for the winter anomaly, the predictions of the model during the day are contrary to the ionosonde measurements.

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Introduction:-

The Seasonal asymmetries in F2 layer critical frequency (foF2) or in the Total Electron Content (TEC) values time variation have been the subject of several studies (Yonezawa, 1959; Rishbeth et Garriot, 1969 ;Mayr et Mahajan, 1971 ; Russell and McPheron, 1973 ;Torr and Torr, 1973;Essex, 1977 ; Campbell, 1982 ; Crooker et al, 1992 ; Gonzalez et al, 1993 ; Huang et Cheng, 1996 ; Fuller-Rowell, 1998 ;Zou et al., 2000; Svalgaard et al., 2002 ; Cliver et al, 2000,2002,2004 ; Ma et al., 2003 ; Qian et al., 2009; Ren et al., 2011; Chen et al., 2012 ; Ouattara et al.,2017; Guibula et al, 2018 ;Sandwidi et al, 2020…). The asymmetries that we will study are: the winter anomaly or solstice asymmetry, the equinoctial asymmetry and the semi-annual anomaly. there is a winter anomaly when winter values are higher than summer values (Rishbeth and Garriott, 1969, Rishbeth and Müller-Wodarg, 2006). There is an equinoctial asymmetry when there is a difference in the peak values of autumn and spring or a morphological difference in the profiles of the two seasons Liu et al. (2010).. The semi-annual anomaly is recorded for equinox

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values higher than that of solstices (Huang et Cheng, 1996 ;Arauje-Pradere, 1997 ; Zou et al., 2000 ; Rishbeth et al.,2000).

It is known that equinoctial asymmetry is explained by three mechanisms: 1) axial mechanism (Murayama, 1974 ; Svalgaard, 1977; Essex, 1977; Cliver et al.,2000); 2) equinoctial mechanism (Svalgaard, 1977 ; Cliver et al.,2000 ; Ren et al.,2011 ; Chen et al.,2012 ;) and 3) Russel-McPherron mechanism (Russell and McPheron, 1973). The winter anomaly or solstice asymmetry is generally explained by the variation of the Sun-Earth distance. This variation can be due to: 1) the variation of the O/O_2 ratio which modulates the electron loss in the F2-layer (Buonsanto, 1986), 2) the 7% variation in the flux of ionization; 3) interplanetary corpuscular radiation (Yonezawa and Arima, 1959) . According to Patel et al., 2017, The winter anomaly is caused by the increase in the thermospheric atomic/molecular $[O/N_2]$ ratio from the southern and northern hemisphere reported by anumber of authors (Cox and Evans, 1970, Torr and Torr, 1973, Titheridge, 1974, Hazarika and Bhuyan, 2014). As for the semi-annual anomaly, Ma et al. (2003) showed that it can be explained by asymmetry observed in the vertical drift ExB in equatorial region. Yonezawa (1971) had suggested that it can be explained by the variation of the terrestrial high atmosphere temperature variation. According to Mayr and Mahajan (1971) and R. Torr and G. Torr, (1973), it is due to semiannual variation of neutral atmosphere density at low latitudes with the geomagnetic activity. There are few investigations on the ability of ionospheric models to reproduce these anomalies of the F2 layer ionization. We can cite Karia et al., 2018, Kumar, 2019, Amaechi et al., 2021.

This work aims to study the different seasonal asymmetries at Ouagadougou equatorial station using the foF2 parameter, in order to make a comparison with the predictions of the 2016 version of "International Reference Ionosphere" model called IRI-2016. This study will allow us to assess the consideration level of anomalies by this model. In fact, we will be interested to periods of geomagnetic recurrent activity of cycles 21-22 (that is to say from 1976-196). This geomagnetic activity is related to highspeed solar wind streams coming from coronal holes (Legrand and Simon, 1989). In the following, we will first deal with data and methodology used, then we will present results and related discussions to finally draw a conclusion.

Data And Methods:-

Data

For this paper, the data used are: (1) The experimental values which are foF2 average hourly values taken from Ouagadougou ionosonde station (lat: 12.5°N; long: 358.5°E, dip: 1.43°). These values are obtained from the database of Brest Telecom (formerly ENST Bretagne). Interval of the study covered by our investigation is 1976 to 1996, corresponding to the solar cycle 21 (1976-1986) and the solar cycle 22 (1986-1996); (2) The predicted foF2 data are obtained with IRI-2016 subroutines (URSI and CCIR); (3) geomagnetic index Aa available from http://isgi.unistra.fr/data_download.php. These values are used in the determination of recurrent activity days by means of pixel diagrams.

Methods:-

Days under recurrent geomagnetic activity are selected through the geomagnetic activity classification of Legrand and Simon (1989) and improved by Zerbo and al., 2012. According Legrand and Simon (1989) the recurrent activity groups the days with index Aa ≥ 40nT on at least one rotation (27 days in average).The new classification of Zerbo et al., 2012 indicates that recurrent events take into account the corotating activity corresponding to. The Figure 1 gives an exemple of recurrent days selection with the pixel diagram.

Local seasons are classified as follows: Winter (December, January, February), Spring (March, April, May), Summer (June, July, August), Autumn (September, October, November).

We make a quantitative analysis based on the following quantities:

- Relative deviation between winter and summer values of foF2: $\Delta foF2_{solstice} = \frac{foF2_{winter} - foF2_{summer}}{foF2_{wi\ nter}}$;

- Relative deviation between spring and autumn values of foF2: $\Delta foF2_{equinox} = \frac{foF2_{spring} - foF2_{automn}}{foF2_{spring}}$;

- Relative deviation between equinox and solstice values of foF2: $\Delta foF2_{semi-annual} = \frac{foF2_{equinoxe} - foF2_{solstice}}{foF2_{équinoxe}}$

We will consider that when:

-$\Delta foF2_{solstice} > 10\%$, we have winter anomaly;

- $|\Delta foF2_{equinox}| > 10\%$,we have exquinox asymmetry;

- $\Delta foF2_{equinox} > 10\%$, we have semi-annual anomaly.

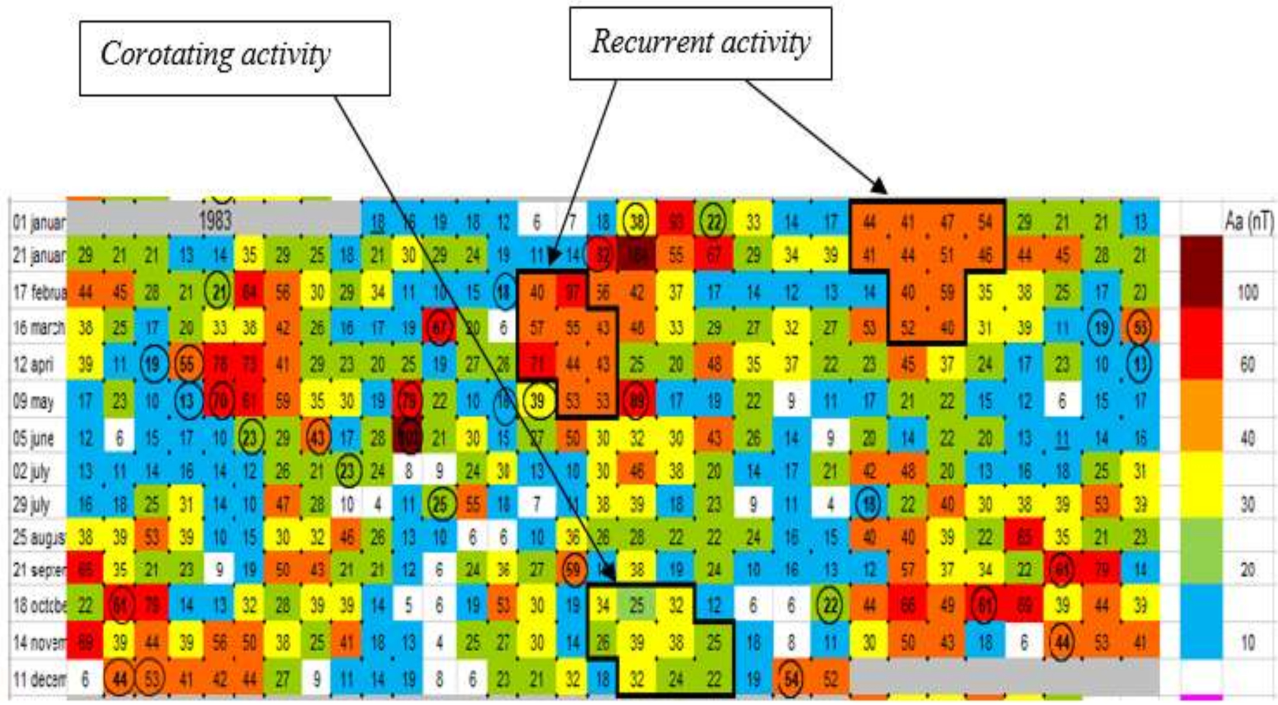


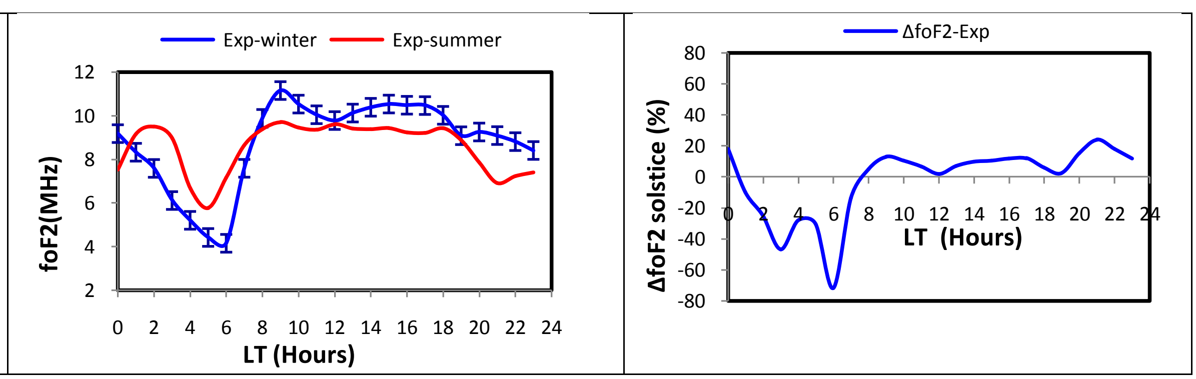
Figure 1:- Illustration for recurrent and corotating days selection.

Results And Discussion:-

Winter anomaly

The Figure 2 shows the hourly variations of the foF2 experimental and modeled values under recurrent activity during the solstice seasons as well as relative deviation $\Delta foF2_{solstice}$ between winter values and those of summer. Panels (a), (b) and (c) deal respectively with experimental values, values modeled by URSI and those modeled by CCIR. In each panel, the graphs on the left give the hourly variations in winter (blue curve) and in summer (red curve) and the graphs on the right give the hourly variations of $\Delta foF2_{solstice}$. In this analysis, we will focus on the comparison of winter and summer values to account for a possible winter anomaly (Rishbeth and Garriott, 1969).

a



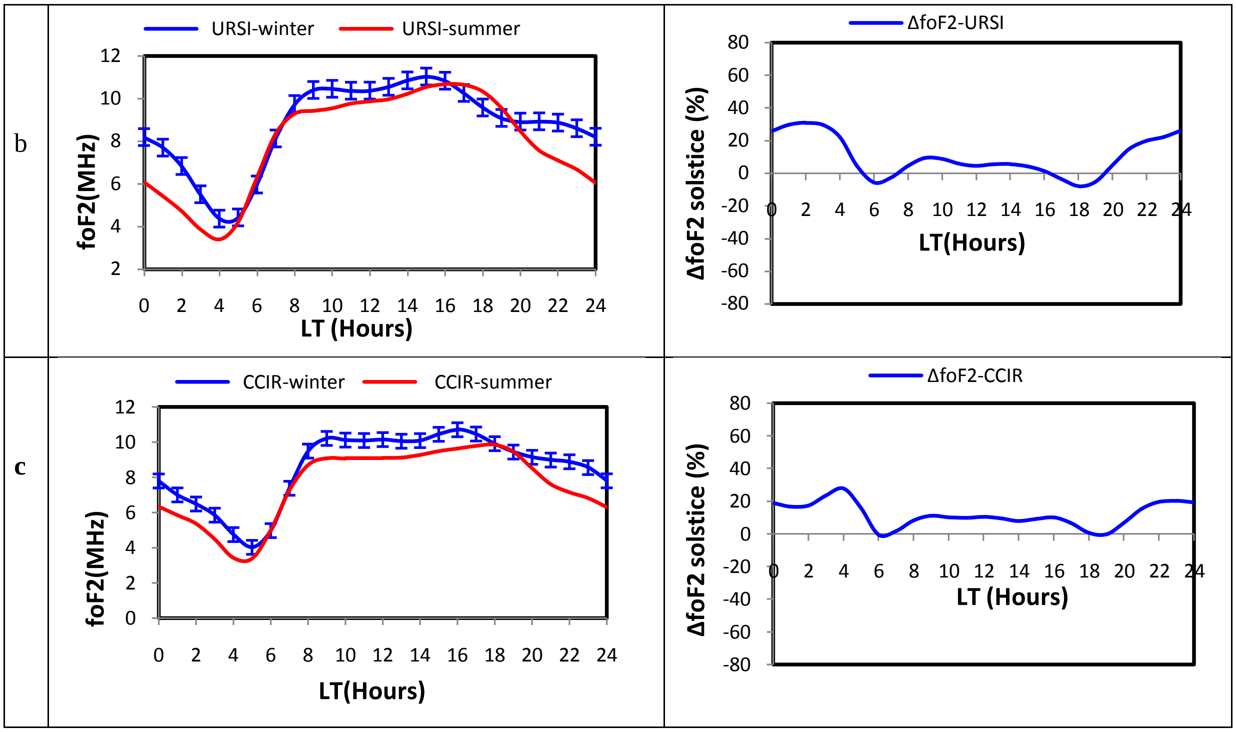


Figure 2:- Hourly variations of experimental and modeled valuesunder recurrent day during the solstice seasons and relative deviation between the winter and summer values

The measured values are higher in summer than in winter between 0100LT and 0700LT with significant gaps of up to -71.69% at 0600LT. On the other hand, with the signature of the vertical drift ExB in winter, we note a winter anomaly from 0900LT to 1000LT and from 1500LT to 1700LT. This anomaly is also observed at night from 2000LT to 2300LT. It is not very pronounced whith relative deviations of less than 15%. Like the ionosonde measurements, the Modeling with the URSI and CCIR sub-programs predictswinter values higher than those in summer during the night from 2100 LT to 2300 LT. However, the two subroutines indicate, contrary to experience, an anomaly between 0000LT and 0400LT with relative deviations of more than 15%.

The model gives a good estimate of the winter anomaly in the first half of the night. But the probable causes of the winter anomaly mentioned above are not taken into account by the prediction of the model during the day. Amaechi et al., 2021 investigated the capability of IRI-2016 to reproduce ionospheric anomalies in the African equatorial latitude region. They found that the model does not incorporate the change in the thermospheric composition.

Equinoctial asymmetry

The Figure 3 shows the hourly variations of the foF2 experimental and modeled values under recurrent activity during the equinox seasons as well as relative deviation $\Delta foF2_{equinox}$ between the spring and autumn values. Panels (a), (b) and (c) deal respectively with experimental values, values modeled by URSI and those modeled by CCIR. In each panel the graphs on the left give the hourly variations in spring (blue curve) and in autumn (red curve) and the graphs on the right give the hourly variations of $\Delta foF2_{equinox}$.

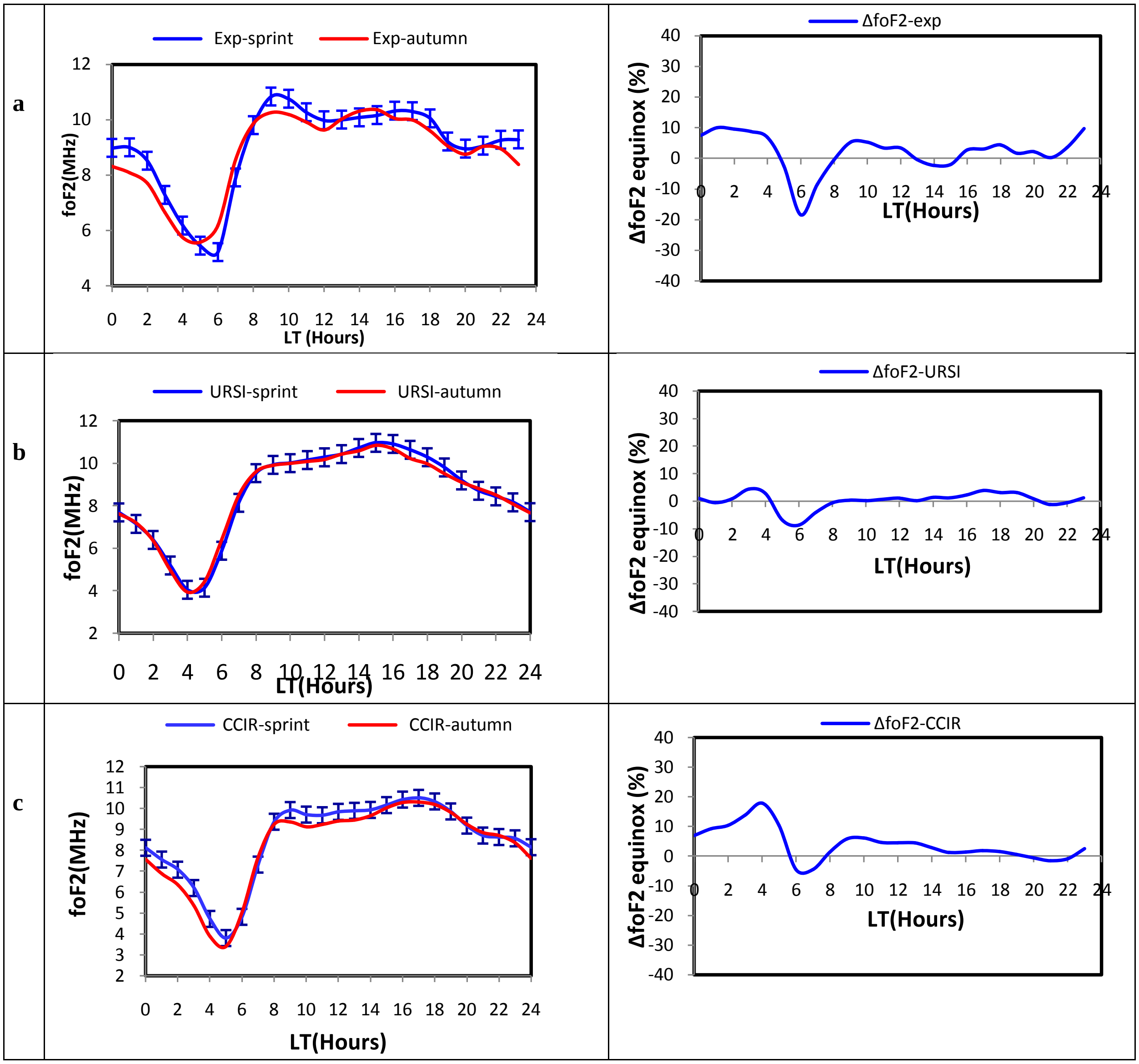


Figure 3:- Hourly variations of experimental and modeled values under recurrent day during the exquinox seasons and relative deviation between spring and autumn values

The spring and autumn experimental values have almost similar variations. Absolute values of the relative deviation $\Delta foF2_{equinox}$ indeed remain below 10% except at 0100LT and 0600LT. However, there is equinoctial asymmetry from the morphological point of view with an hourly delay of the morning and evening peaks of the spring profiles.

Both subroutines show similar profiles during spring and autumn seasons. They report no equinoctial asymmetry. The absolute values of the relative deviation are less than 10%, except from 0200LT to 0500LT with CCIR. Apart from morphological difference of the profiles, the model gives a good prediction of the three mechanisms that can explain equinoctial asymmetry namely the axial mechanism (Svalgaard, 1977; Essex, 1977), the equinoctial mechanism (Svalgaard, 1977; Cliver et al., 2000; Chen et al., 2012; Ren et al., 2011) and Russell-McPheron mechanism (Russell and McPheron, 1973).

Semi-annual anomaly

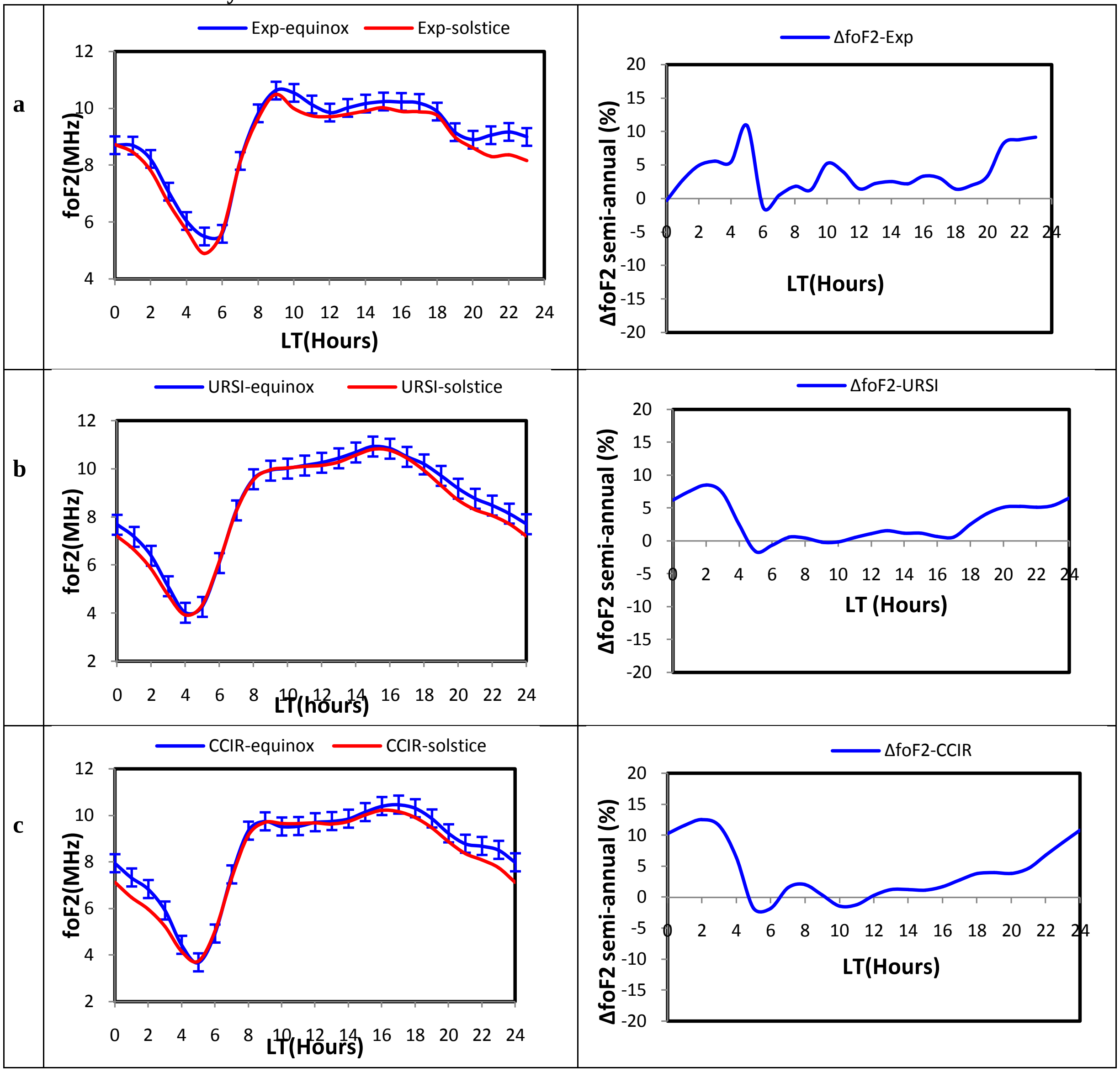


Figure 4:- Hourly variation of experimental and modeled values under recurrent day during the equinox and solstices seasons and relative deviation between equinox and solstice values.

Figure 4 shows the hourly variations of the foF2 experimental and modeled values under recurrent activity during solstices and equinoxes as well as the relative deviation $\Delta foF2_{semi-annual}$ between winter and summer values. Panels (a), (b) and (c) deal respectively with experimental values, values modeled by URSI and those modeled by CCIR. In each panel graphs on the left give hourly variations at equinoxes (blue curve) and at solstices (red curve) and graphs on the right give hourly variations of $\Delta foF2_{semi-annual}$ .the hourly profiles of experimental values at equinoxes and solstices are almost similar with absolute relative deviations of less than 10%. The signature of the vertical drift ExB is the same at solstice as at equinox No semi-annual anomaly is reported by the ionosonde measurements. In accordance with experience, absolute values of relative deviation $\Delta foF2_{semi-annual}$ predicted by URSI sub-routine remain below 10%. The same is true for CCIR modeling except from 0000LT to 0300LT where this sub-routine provides for a semi-annual anomaly that is not very pronounced with relative deviations of less than 15%.

The asymmetry absence in the vertical drift on the profiles of the ionosonde values can explain the semi-annuel anomaly absence (Ma et al., 2003). The model gives a good estimate of this anomaly except at the end of the night with CCIR subroutine.

Conclusion:-

We evaluated the capability of the IRI-10216 model to reproduce winter and semi-annual anomalies and equinoctial asymmetry during the recurrent activity days at Ouagadougou equatorial station. The following results are obtained:

1. The ionosonde values show winter anomaly in the morning from 0900LT to 1000LT, in the evening from 1500LT to 1700LT and at night from 2000LT to 2300LT. The IRI-2016 model through its URSI and CCIR subroutines reproduces this anomaly only at night from 2100LT to 2300LT.
2. The model IRI-2016 does not predict any equinoctial asymmetry in accordance with experimental measurements
3. As observed in the experimental data, the IRI-2016 model does not report any semi-annual anomaly except from 0000LT to 0300LT with the CCIR subroutine.

We therefore note satisfaction in the model prediction of the equinoctial asymmetry and the semi-annualanomaly. On the other hand, the poor estimation of the winter anomaly during the day shows the need to improve the IRI-2016 model to better guarantee a good prdiction of seasonal asymmetries in the équatorial regions. We believe that a good consideration of the thermospheric composition could increase th predictive capacity of the IRI model.

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