Quiet time foF2 variation at Ouagadougou station and comparison with TIEGCM and IRI-2012 predictions for 1985 and 1990

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ABSTRACT

The purpose of this study is to appreciate the estimation of TIEGCM (Thermosphere Ionosphere Electrodynamics General Circulation Model) and that of the 2012 version of IRI (International Reference Ionosphere) in African Equatorial Ionization Anomaly (EIA) region through the diurnal variation of F2 layer critical frequency (foF2). The comparison is made between data and theoretical values carried out from TIEGCM and IRI-2012 during solar cycle minimum and maximum phases and under quiet time condition over seasons. Data concern solar cycle 22 foF2 data of Ouagadougou station (Lat: 12.4° N; Long: 358.5°E, dip: 1.43°N for 2013) provided by Télécom Bretagne. Quiet time condition is determined by Aa inferior or equal to 20 nT and solar cycle maximum and minimum phases correspond to sunspot number Rz superior to 100 and Rz inferior to 20, respectively. Seasons are estimated by considering December as winter month, March as spring month, June as summer month and September as autumn month. The seasonal Hourly quiet time foF2 is given by the arithmetic mean values of the five quietest day hourly values. Data profiles show noon bite out profile with more and less pronounced morning or afternoon peak in equinox and that during solar maximum and that also in solar minimum except during solstice where the profile fairly is dome or plateau. During solar minimum, both models present more or less pronounced afternoon peak with more or less deep trough between 1000 LT and 1400 LT. During solar maximum, in general, TIEGCM shows afternoon peak and IRI-2012 present plateau profile. This result exhibits the non-well estimation of the dynamic process of this region. Model accuracy is highlighted by the Mean Relative Error (MRE) values. These values show better prediction for IRI-2012 except in September for both solar cycle phases involved. The non-good prediction of TIEGCM is observed in December during solar minimum and in June during solar maximum. Models predictions are better during solar maximum than during solar minimum and strongly dependent on pre-sunrise and post sunset periods.

Keywords: foF2 diurnal variation, IRI-2012, TIEGCM, Mean Relative Error (MRE), E-region electric current, ExB signature

1. INTRODUCTION

Nowadays, first, for better communication by means of radio HF and satellite, second for climate change and its consequences on human being, ionosphere has been intensively investigated by analyzing data variability and or improving existing models for now casting and or forecasting reasons. The present work concerns the investigation of F2 layer critical frequency (foF2) parameter by means of the 2012 version of IRI (International Reference Ionosphere) model and TIEGCM (Thermosphere Ionosphere Electrodynamics General Circulation Model).

It is well-known that foF2 has been investigated by means of IRI model over all sectors of latitudes. In fact, in African sector, Adeniyi and Adimula [1] compared IRI-90 predictions with NmF2 and hmF2 data of Ibadan station (Lat: 7.40°N; Long: 3.90°E; dip: 6°S). The comparison between IRI NmF2 and data showed that at low solar activity agreement was observed between 0500 LT and 0900 LT and for June solstice. At high solar activity the agreement is seen during December solstice and that between 0500 LT and 1800 LT. IRI hmF2 gives larger values at low solar activity during the day and good agreement in high activity. In the work of Ouattara [2], IRI 2007 predictions are compared with experimental foF2 of Ouagadougou station (Lat: 12.4° N; Long: 358.5°E; dip: 1.43° N). He showed that IRI-2007, one the one hand, matches the peaks observed in experimental foF2 diurnal profiles and good predicts data variability during solar minimum phase and on the other hand, does not reproduce night time peak in data time profile and does not express ExB effect. In American sector, the works of Abdu et al. [3] showed that IRI-90 seems to reproduce the climatology and the average behavior of the low latitude ionosphere during medium level of solar activity. They pointed out that some persistent trends of discrepancy between model and observation exist especially during low and high solar activity epochs. For improving IRI predictions, more data sets coming from more longitude sectors are necessary. Bertoni et al. [4] compared IRI-2001 predictions with HmF2 and foF2 data of two low latitudes stations of Brazil. They found that even though the model generates good results some improvements are still necessary in order to obtain better predictions for equatorial ionospheric regions. In Asian sector, Sethi et al. [5] showed that during summer IRI values agree comparatively well with the observations at daytime. They observed major discrepancies when IRI underestimates observed hmF2 during winter and equinox from 1400 LT to 1800 LT and from 0400 LT to 0500 LT.
TIEGCM has been intensively used to investigate ionosphere parameters in other sectors of latitude and regions except in Africa sector. This model has been used by Cnossen and Richmond [6] for long term change studies, Crowley et al.[7] and Lei et al.[8] for geomagnetic storms, Pedatella et al. [9], for tides studies, Qian et al. [10] for flare studies and Burns et al. [11] and Solomon et al. [12] for the effects of high speed solar wind.

After testing IRI-2007 with Ouagadougou station foF2 data by Ouattara [2], during this study we analyze the predictions of its 2012 version. Added to that, we also compare TIEGCM predictions with data too.
The novelty of the present work is to see on the one hand if the latest version of IRI corrected the problems pointed out by Ouattara and Rolland [13] with the 2001 version and Ouattara [2] with the 2007 version of IRI. On the other hand to estimate and appreciate the predictions of TIEGCM in this sector after the study of Nanéma and Ouattara [14] which analyzes this model estimation at Ouagadougou with the hmF2 parameter.
This paper concerns the diurnal variation of foF2 data of Ouagadougou station for solar cycle 22 minimum and maximum phases over seasons under quiet time conditions. We analyze during this study the predictions of IRI-2012 and TIEGCM and compare them to data.
After the introduction, the second section of this work treats the materials and methods. The third section is devoted to the results and discussions. The paper ends with the conclusion as the forth section.

2. MATERIAL AND METHODS

2.1 Data used

Ouagadougou station (Lat: 12.4° N; Long: 358.5°E, dip: 1.43°N) data that are provided by Telecom Bretagne are used. Data concern those of equinox (March and September) and solstice (June and December) months in 1985 (the minimum of solar cycle 22) and 1990 (the maximum of solar cycle 22). Mayaud [15-16] aa geomagnetic index is considered for determining the magnetic state of the days chosen. The daily magnetic state is given by the daily value of aa name Aa (see Mayaud [15]). Sunspot number Rz allows us to obtain the years of solar minimum and maximum.
At a given time, monthly foF2 value corresponds to the arithmetic mean value of the five quietest days foF2 values of the month. The quiet period corresponds to Aa inferior or equal to 20 nT.

2.2 TIEGCM running conditions

TIEGCM predicted values are obtained by running TIEGCM for the selected days under solar maximum condition given by F10.7=200 and solar minimum condition expressed by F10.7=70 for local point determined by its geographic longitude, latitude and local time. TIEGCM integrates 174 values for longitude and 72 values for latitude. The position of Ouagadougou station is not exactly held by the model. Yet, closest values to Ouagadougou station parameters are used after interpolation. The daily TIEGCM foF2 is estimated by means of NmF2 through $foF2 = 9x(NmF2)^{0.5}$. It is important to note that NmF2 is directly carried out by running TIEGCM model.

2.3 IRI running conditions

IRI-2012 estimates foF2 at Ouagadougou station for 350 km height. The quietest days hourly values are obtained by running its two subroutines CCIR (Comité Consultatif International des Radio communications) and URSI (Union Radio Scientifique Internationale). In the present paper we only consider the URSI predicted values because they are better than those of CCIR. This result has been pointed out by Ouattara and Fleury [13] with the previous version of IRI.

2.4 Methodology

In the present study, we consider 1985 as solar minimum year and 1990, as solar maximum. These solar cycle phases are determined by using sunspot number Rz and following Ouattara et al. [17] methods (i.e. Solar minimum year is given by Rz<20 and solar maximum years are obtained by 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 max]. Our work is developed under quiet time condition given by Aa<=20 nT with Aa the daily mean value of aa, Mayaud [15-16] geomagnetic index. Monthly hourly values are given by the arithmetic hourly mean values of the five quietest days in a month. Our study considers seasons that are obtained as follows: winter (November, December, and January), spring (February, March and April), summer (May, June and July) and autumn (August, September and October). We chose March as spring month, September as autumn month, June as summer month and December as winter month. Equinoctial months are March and September and solstice months June and December. The retained quietest days per season are shown in table 1.

Table 1: Five quietest days in 1985 and 1990 for Equinox and Solstice and their Aa values

Solar cycle	Phase	Year	Retained days and Aa (nT)	Months																			
				March (Equinox)					June (Solstice)					September (Equinox)					December (Solstice)				
C22	Minimum Rz=17.9 F10.7=70	1985	Retained days	9	13	21	22	25	3	14	16	18	19	2	3	4	5	29	8	9	21	23	29
			Aa (nT)	6.7	8.1	7.7	9.2	10.6	8.5	3.8	6.3	6.8	6.7	7.1	7.6	5.1	4.7	8.7	6.8	8.6	6.7	10.7	9.1
	Maximum Rz=142.6 F10.7=200	1990	Retained days	4	10	16	17	31	16	17	20	21	30	2	3	27	29	30	10	11	19	21	29
			Aa (nT)	10.4	14	15	5.5	13.3	8.6	5.1	4.5	10.1	8.1	6.4	7.5	15.9	13.8	9.0	4.0	5.1	5.8	7.3	7.4

In order to appreciate the model accuracy we use the Mean Relative Error (MRE) value of the month (consigned in table 2) expressed as: $MRE = \sum_{i=1}^{24} \frac{MHRE^i}{24}$ with $MHRE^i$ the Mean Hourly Relative Error. $MHRE^i$ is estimated by $MHRE^i = \sum_{j=1}^{n} \frac{HRE^j}{n}$ where HRE^j is the Hourly Relative Error and n the number of days involved. For the present study the maximum value of n is five (the five quietest days in a month). HRE^j is obtained by using $HRE^j = \frac{|foF2_{est}^j - foF2_{exp}^j|}{foF2_{exp}^j} x100$ with $foF2_{est}^j$ the hourly foF2 estimated by the model and $foF2_{exp}^j$ the hourly experimental foF2.

Table 2: MRE values between models and Data

Season	Month	MRE (%) between IRI-2012 and Data		MRE (%) between TIEGCM and Data	
		Minimum (1985)	Maximum (1990)	Minimum (1985)	Maximum (1990)
Equinox	March	11.97	12.03	9.11	13.28
	September	14.57	15.46	14.71	12.60
Solstice	June	12.70	12.07	14.95	15.34
	December	7.56	12.80	30.00	13.43

For a good description of foF2 diurnal variation, we consider the five types of profile pointed out by Fayot and Vila [18] in African equatorial region; in fact they classified foF2 diurnal profiles in five types: (1) Morning peak profile characterized by a predominance morning peak, (2) Plateau profile, (3) Dome profile, (4) Reverse profile characterized by predominance afternoon peak, and (5) noon bite out profile due to the presence of double peaks (morning and afternoon peaks) with trough around midday.

3. RESULTS AND DISCUSSION

In this part, for a given solar cycle phase, we first present the results, second compare data and predicted values, and third discuss the results and appreciate the models' accuracy.
Figure 1 shows time variation of experimental foF2 during the solar cycle 22 minimum for different seasons. The top panels concern equinox months and the bottom ones for solstice. The top panels show the noon bite out profile as experimental diurnal foF2 profile with more and less pronounced afternoon peak. The predicted profiles show the same variability even though on the one hand the theoretical two peaks do not match those of the data and on the other hand the trough located between 1000 LT and 1400 LT in experimental profiles is not so deep in the theoretical ones and sometime appears with time delay as seen in TIEGCM profile during March.
The bottom panels data profiles fairly exhibit dome and plateau profiles respectively in June and December. Calculated profiles are noon bite out profile in solstice months for IRI 2012. For TIEGCM, the profiles are noon bite out in June and fairly dome in December
According to error bars, figure 1 shows that the prediction is better in equinox than in solstice. During solstice, IRI 2012 predictions are better than those of TIEGCM especially in December.

The night peak observed in March and June experimental is not reproduced by the model.

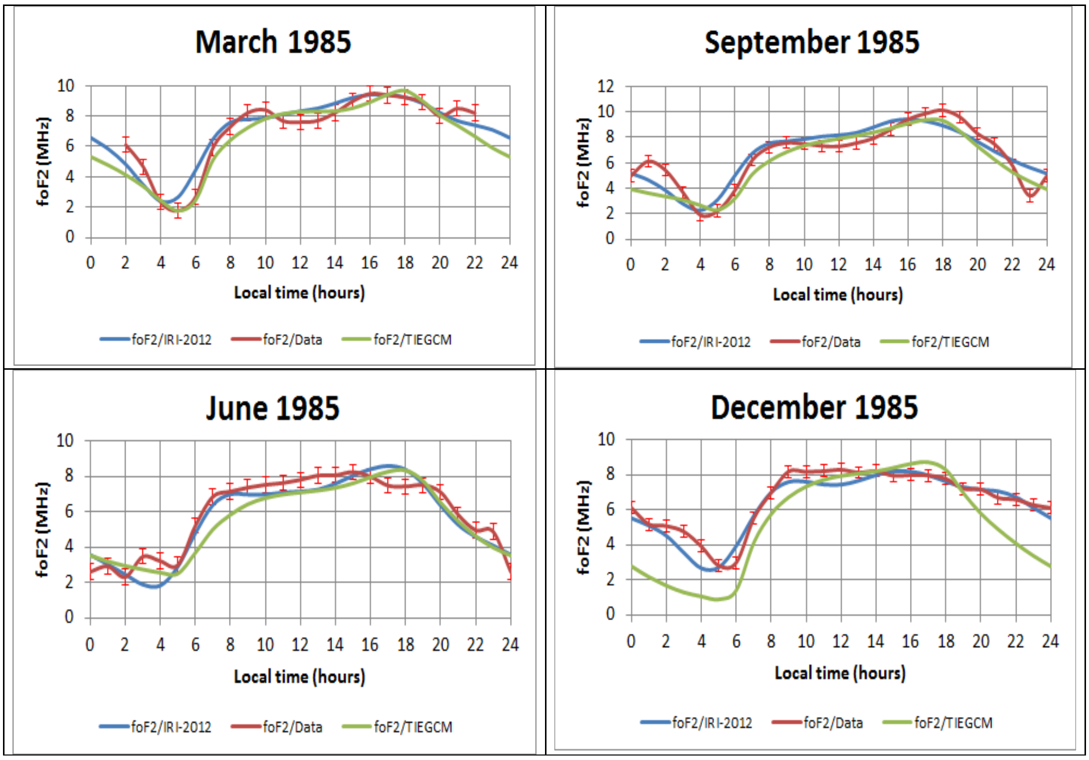

Figure 1: foF2 diurnal variation during solar cycle 22 minimum

The top panels of figure 2 highlight noon bite out profile for data. Only in March experimental profile expresses pronounced morning peak. This observation shows equinoctial asymmetry of the profile. During solstice (bottom panels) there exist noon bite out profile in June and morning peak profile in December.

Calculated profiles present in equinox (top panels) plateau profile for IRI 2012 and morning peak profile in March and afternoon peak profile in September for TIEGCM. It appears that the equinoctial asymmetry appears in data profile in a profile amplitude and variability is only seen in amplitude in IRI 2012 profile while is expressed in amplitude and variability in TIEGCM profile.

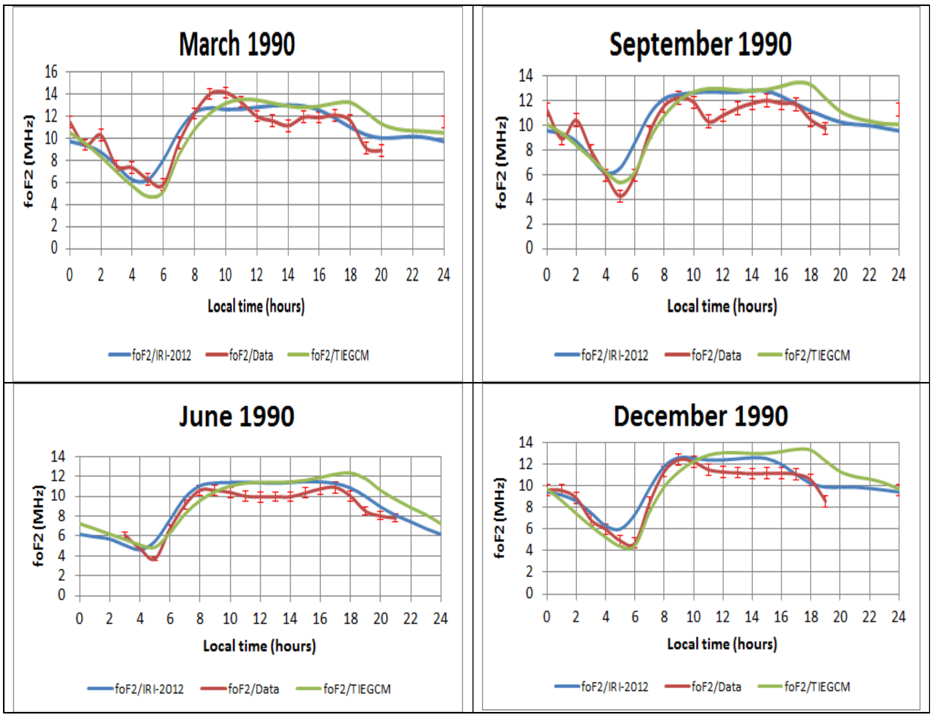

Figure 2: foF2 diurnal variation during solar cycle 22 maximum

According to Rishbeth [19], Fairley et al. [20], Fejer [21] and Fejer et al. [22], the trough observed in the noon bite out profile (see figures 1 and 2) expresses the effect of ExB and the presence of nighttime peak in the profiles highlights the signature of the pre-reversal electric field. Based on their works one can assert that models do not reproduce the electrodynamics effect of this layer in this sector.

Fayot and Vila [18], Vassal [23], Acharya [24] and Acharya [25] show that it is possible to link ionosphere variability to the nature, the force or the absence of E region electric currents. Based on the five types of foF2 profile highlights by Fayot and Vila [18], Vassal [23] established the link between each type of profile and E region electric current. Therefore, the noon bite out profile (double peaks with trough around midday) corresponds to the presence of strength electrojet, the morning peak profile is due to the presence of mean electrojet, the afternoon peak profile or the reversal profile results from the presence of intense counterelectrojet, the plateau profile is due to the presence of weak electrojet and the dome profile characterizes the absence of electrojet. By taking into account the signatures of the electric currents through the different foF2 profiles, we can assert that models during solar maximum phase (figure 2) do not highlight the presence of real electric current.

The analysis of table 2 shows that the best estimation of IRI-2012 is observed in December and March while that of TIEGCM is seen in March and September during solar minimum and solar maximum, respectively. IRI-2012 good estimates data in: (1) December and March during solar minimum and (2) March and June during solar maximum. The model of TIEGCM good predicts data in equinox during solar minimum and maximum.

Figure 3 shows the histograms of the mean relative error (MRE) of each model compared with data. It can be seen in the left panel that except in March the MRE of TIEGCM is always higher than that of IRI-2012. This shows that during solar minimum IRI-2012 good expresses the data variability. The left panel

of figure 3 exhibits the equinoctial asymmetry. During December, IRI-2012 gave a better result. Such result may be due to the fact that IRI is a semi empirical model that integrates data in its data base.
In the right panel, devoted to solar maximum, except September, IRI-2012 is the better than TIEGCM. TIEGCM best prediction is observed in September and the worst in June. IRI-2012 best prediction is seen in March and the worst in September. The histograms of solar maximum show the equinoctial asymmetry too.
Comparing the two panels of figure 3, it emerges that the model predictions are better during solar maximum than during solar minimum. The MRE maximum value is around 15% during solar maximum and 30% during solar minimum.
Keep in mind that the bad predictions are generally observed before sunrise and after sunset (figures 1 and 2). Based on this observation, one can assert that when the prediction is good during these periods the MRE is weak. In fact, during solar minimum (figure 1) in March, the data are not complete after 2200 LT till 0200 LT so MRE is better than the other months. It can be seen in this panel that the higher MRE for TIEGCM comes from its non-good predictions before sunrise and after sunset periods.
During solar minimum MRE is higher than during solar maximum because during solar maximum on the one hand the data are not complete after around 1900 LT-2000 LT (see figure 2) and on the other hand before sunrise model estimations are good.

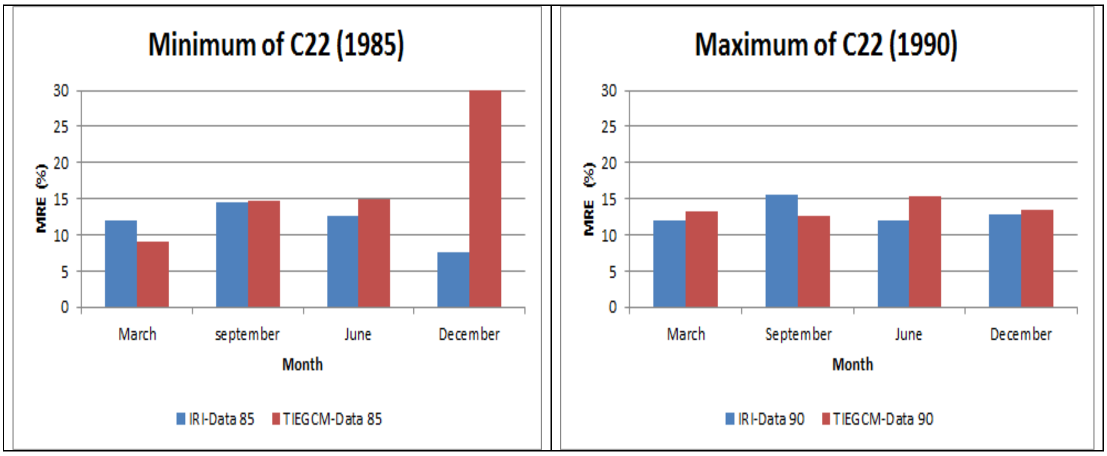

Figure 3: MRE between models and data

4. CONCLUSION

Our study pointed out that: (1) models do not match the first peak in foF2 noon bite out profile and the reversal profile is well reproduced by models; (2) the trough located between 1000 LT and 1400 LT due to the effect of ExB is not well reproduced by the models; (3) At nighttime (after around 1900 LT-2000 LT) till before sunrise, models show bad predictions. This may be due to the non-integration of all the electrodynamics mechanisms of this layer in this sector of latitude; (4) IRI-2012 better models data than TIEGCM in this sector; (5) the prediction is strongly dependent on pre-sunrise and nighttime periods.
Our results exhibit first, the necessity to improve the two models by taking into account the pre-sunrise and nighttime physical processesin models algorithms and second, to better TIEGCM by integrating migrating and non-migrating tides effects in its computing processes.

COMPETING INTERESTS

Authors have declared that no competing interests exist

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