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

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## ABSTRACT


**Aims:** The purpose of this study is to appreciate the estimation of TIEGCM (Thermosphere Ionosphere Electrodynamics General Circulation Model) and the 2012 version of IRI (International Reference Ionosphere) in African Equatorial Ionization Anomaly (EIA) region throughout the diurnal variation of F2 layer critical frequency (foF2).

**Study design:** 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 and that over seasons.

**Place and Duration of Study:**Data concern solar cycle 22 foF2 data of Ouagadougou station (Lat: 12.4° N; Long: 358.5°E, dip: 1.43° for 2013) provided by Télécom Bretagne.

**Methodology:**Our study is made on the one hand under geomagnetic quiet time conditions determined by daily Aa inferior or equal to 20 nT and on the other hand during solar cycle maximum and minimum phases given by sunspot number Rz superior to 100 and Rz inferior to 20, respectively.We take into account seasons 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.

**Results:**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. The Mean Relative Error (MRE) shows better prediction for IRI-2012 except in September for the both solar cycle phases involved. The worst prediction during solar minimum and maximum is seen in September for IRI-2012 and that of TIEGCM is observed in solstice and June, respectively.Models predictionsare better during solar maximum than during solar minimum and strongly dependent to pre-sunrise and post sunset periods.

**Conclusion:**As foF2 type of profile is link to E-region electric current and ionosphere electrodynamics mechanisms, models' predictions highlight that they do not well express all the dynamic process in this African sector. Therefore, for this sector they must be revisited for improving.



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

# 1. INTRODUCTION

Nowadays, firstly, for better communication by means of radio HF and satellite, secondly for climate change and its consequences in human being, ionosphere has been intensively investigated by analyzing data variability and or improving existing models for now coasting and or forecasting reasons. The present work interests F2 layer critical frequency (foF2) parameter that has been investigated by means of IRI model over all sector of latitudes (e.g. Adeniyi and Adimula[1]; Abdu et al.[2]; Batista and Abdu[3]; Bertoni et al.[4]; Adewale et al.[5]; Ouattara [6] Sethi et al. [7]). We also focus our interests on TIEGCM model that has been alsointensivelyused to investigate ionosphere parameters in other sectors of latitude and regions except in Africa sector (e.g.Cnossen and Richmond[8], Crowley et al.[9], Lei et al.[10], Pedatella et al. [11], Qian et al.[12], Burns et al.[13] and Solomon et al. [14]).

After testing IRI version of 2007 with Ouagadougou station foF2 databy Ouattara[6], 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 work is to see on the one hand if the latest version of IRI corrected the problems pointed out by Ouattara and Rolland [15] with the 2001 version and Ouattara[6] 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 Nanema andOuattara[16] which analyzes this model estimation at Ouagadougou 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 the work traits the materials and methods. The third section is devoted to the results and discussions. The paper is ended by 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°) data that are provided by Telecom Bretagne are used. Mayaud[17-18]aa geomagnetic index is considered for determining the magnetic state of the choice days. 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 day foF2 values of the month. The quiet period correspond to daily 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 expresses by F10.7=70 for local point determining 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 throughout $foF2 = 9NmF2^{0.5}$. 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 day hourly values are obtained by running its two subroutines CCIR (ComitéConsultatif International des Radio communications) and URSI (Union Radio ScientifiqueInternationale). For a given hour, month quiet value corresponds to the arithmetic mean estimated values. In the present paper we only consider the URSI predicted values because they are better than ~~these~~ of CCIR. This result has been pointed out by Ouattara and Fleury[15] with the previous version of IRI.

## 2.4 Methodology

In the present study we consider 1985 as solar minimum year and 1990 ~~that of~~ solar maximum. These solar cycle phases are determined by using sunspot number Rz and following Ouattara et al. [19] 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[17-18] 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 is given by table1.

**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 Errorand n the number of day 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 $HRE^j = \frac{|foF2^j_{est} - foF2^j_{exp}|}{foF2^j_{exp}} x100$with $foF2^j_{est}$ the hourly foF2 estimated by the model and $foF2^j_{exp}$ the hourly experimental foF2.

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 well estimates data in (1) December and March during solar minimum and (2) March and June during solar maximum. The model of TIEGCM well predicts data in equinox during solar minimum and maximum.

**Table 2: MRE values between models and Data**

| Season | Month | MRE (%) between IRI-2012 and Data | | MRE (%) betwennTIEGCM 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 |

## 3. RESULTS AND DISCUSSION

In this part, we firstly present and analyze our results, secondly compare data and predicted values and thirdly discuss the results.
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 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 and only in June.
In December, TIEGCM profile fairly shows dome profile.
According to error bars, figure 1 showsthatthe 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.

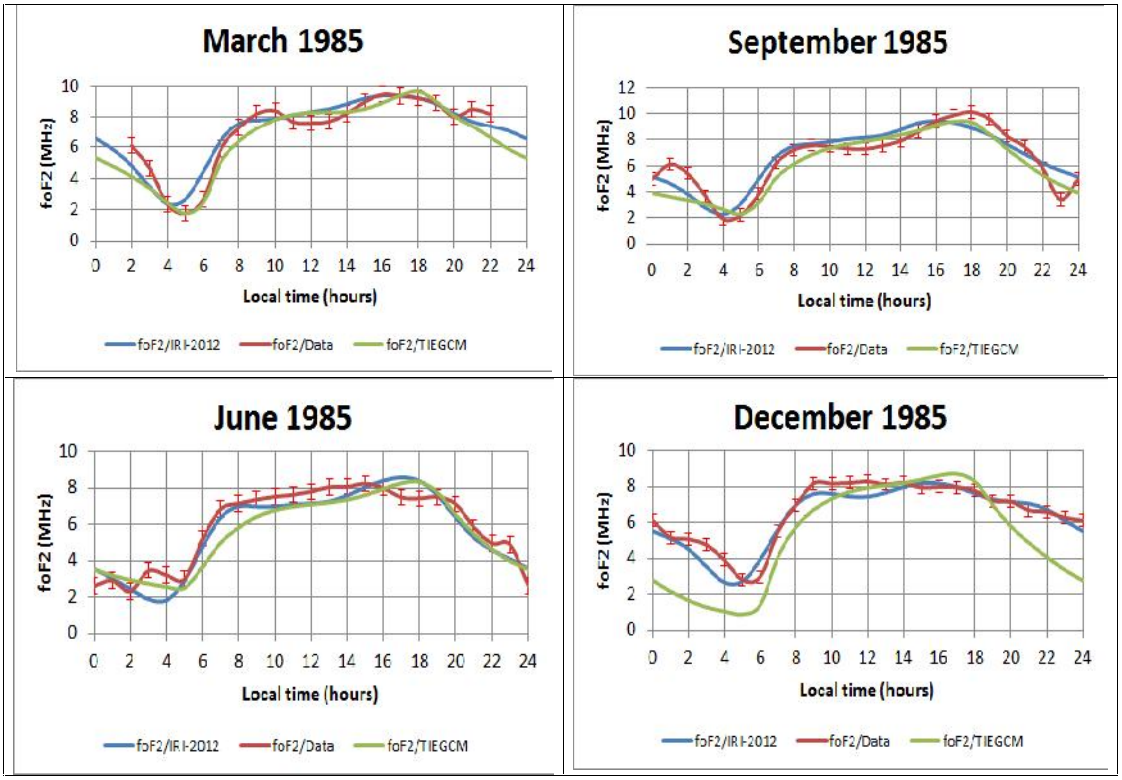


**Figure 1: foF2 diurnal variation during solar cycle 22 minimum**

In the top panels of figure 2, it can be seen that data profile is noon bite out profile with pronounced morning peak in March. This observation shows the profile equinoctial asymmetry. During solstice (bottom panels) data profile is noon bite out 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.

According to Rishbeth [20], Fairley et al. [21], Fejer [22] and Fejer et al. [23], 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 work one can assert that models do not reproduce the electrodynamics effect of this layer in this sector.

Fayot and Vila [24], Vassal [25], Acharya [26] and Acharya [27] 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 [24], Vassal [25] 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 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.

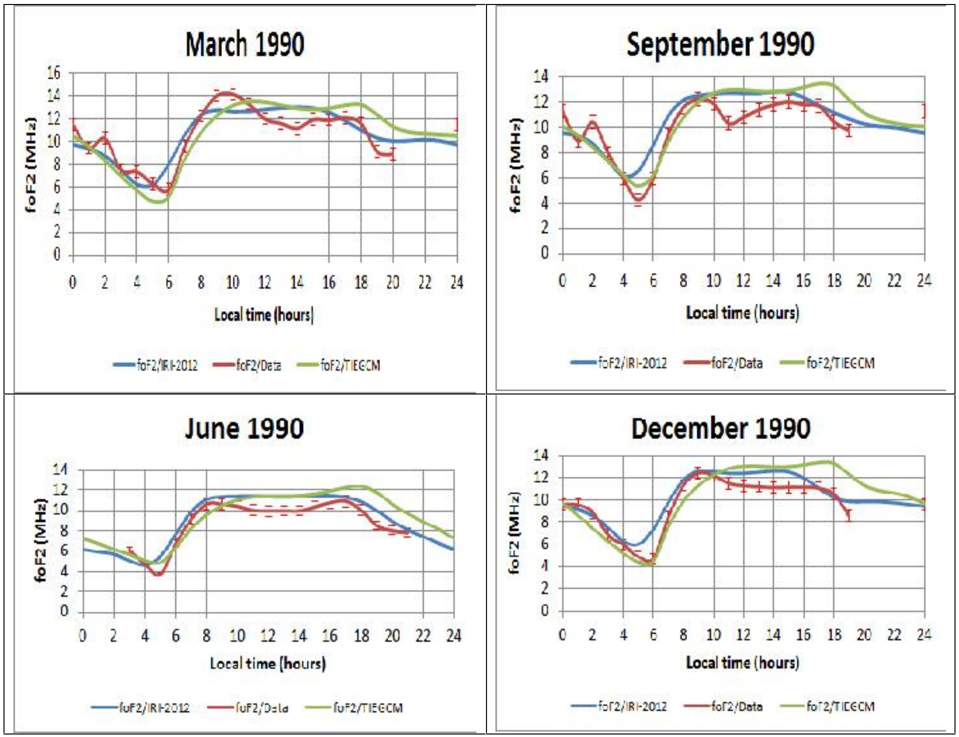


**Figure 2: foF2 diurnal variation during solar cycle 22 maximum**

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 March the MRE of TIEGCM is always higher than that of IRI-2012. This shows that during solar minimum IRI-2012 well express the data variability. The left panel of figure 1 exhibits the equinoctial asymmetry. During December IRI-2012 ~~is the best model while TIEGCM is the worst~~.

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 models 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. Our assertion is still true by looking models' predictions during solar minimum and in December. It can be seen in this panel that the higher MRE for TIEGCM comes from its bad predictions ~~during~~ 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 models' estimations are good.

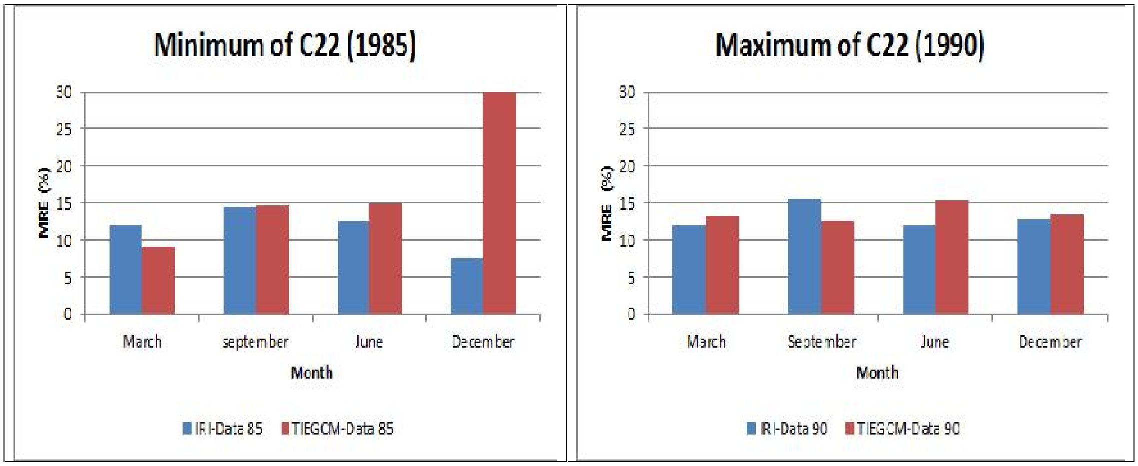


**Figure 3: MREbetween models and data**

## 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 may be due to the non-integration of the all electrodynamics mechanismsof this layerin the sector; (4) IRI-2012 better models data than TIEGCM in this sector; (5) the prediction is strongly dependent to pre-sunrise and nighttime periods.

## COMPETING INTERESTS

Authors have declared that no competing interests exist

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