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Research Article

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Critical frequency quiet time variability in ionosphere at different heights using Thermosphere-Ionosphere-Electrodynamics General Circulation Model at low latitudes

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Abstract Ionosphere region is the site of radio waves reflection because of its composition in particles. The density in particles in this region is variable from daytime to night time and during the seasons of the year. The solar cycle phases also influence the composition of ionosphere. Different models are developed for ionosphere investigation. The main goal of this work is to use Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM)to give a better approach for ionosphere description. TIEGCM has been developed at National Center for Atmospheric Research (Bouler, Denver, Colorado State, USA). This model is used to carry out the Critical frequency of F2-layer and the Height of F2-layer in ionosphere. Local time is used to link these parameters during quiet time periods for solar cycle 22. The study takes place at Ouagadougou station, in West Africa, near equator. The study also proposes a new approach to evaluate the annual values of these parameters. It gives good correlation with the results found by running International Reference Ionosphere (IRI) model in the same conditions.

Keywords Ionosphere, Solar cycle phases, Quiet time periods, TIEGCM, IRI, Height of F2-layer, Critical frequency of F2-layer

1. Introduction

Many models are developed to investigate ionosphere region [1-9]. The main goal of ionosphere investigation is to get its parameters that enables to have a better knowledge of this region. This part of the atmosphere is important because of its composition in particles. It's the site of radio waves reflection for telecommunication, in the F2 layer. In recent works, we used International Reference Ionosphere (IRI) model to carry out the critical frequency of F2 layer (foF2), the height of F2 layer (hmF2), the peak of electron density of F2 layer (NmF2) [10-15]. Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) is developed by a research team of High Altitude Observatory (HAO) at National Center for Atmospheric Research (NCAR)for ionosphere parameters determining. It's a numeric simulation model of the Earth's upper atmosphere, including the upper Stratosphere, Mesosphere and Thermosphere [16]. The original versions are Thermosphere General Circulation Model (TGCM) [17-18], Thermosphere-Ionosphere General Circulation Model (TIGCM) [19-20], that lead to Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) [21]. Running this model enables to carry out more than ninety parameters. The present study is devoted to the use of TIEGCM to evaluate the critical frequency variability in the ionosphere at different heights at Ouagadougou Station, in West Africa, during quiet time of solar cycle 22. The behavior of foF2 and hmF2 time variation obtained by running TIEGCM is compared to those got with IRI in the same conditions. This study also presents an approach to evaluate annual ionosphere parameters time variation.

2. Methodology – Fundamentals

The study uses the minimum and the maximum of solar cycle phase for parameters determining. The minimum is obtained by sunspot number Rz< 20, while Rz ≥ 100 during the maximum. These conditions are added to the following core principles: (i) the five quietest days of each characteristic month in the season (March for spring, June for summer, September for autumn, and December for winter). In each quietest day, Aa index is inferior to 20 nT, (ii) the average value of the parameter on each characteristic month. Solar cycle 22 is considered in this study. Table (1) presents the results of selected months and days during solar minimum and maximum by considering the principle (i).

Table 1: Selected days during maximum and minimum of solar cycle 22

			Months			
Cycle	**Phase**	**Year**	**March**	**June**	**September**	**December**
22	Min	1985	9,13,21,22,25	3,14,16,18,19	2,3,4,5,29	8,9,21,23,29
	Max	1990	4,10,16,17,31	16,17,20,21,30	2,3,27,29,30	10, 11, 19, 21, 29

The following equations (1) and (2) are derived from the principle (ii):

$$foF2_i = \frac{\sum_{j=1}^{5} foF2_{i,j}}{5} \quad (1)$$

In equation (1),$foF2_i$ is the hourly mean value of critical frequency of F2-layer for a selected month at "i" hour; $foF2_{i,j}$ pointing out the hourly average value of foF2 at "i" hour, and "j" quiet day.

$$hmF2_i = \frac{\sum_{j=1}^{5} hmF2_{i,j}}{5} \quad (2)$$

In equation (2), $hmF2_i$ is the hourly mean value of Height of F2-layer for a selected month at "i" hour; $hmF2_{i,j}$ pointing out the hourly average value of height of F2-layer at "i" hour, and "j" quiet day.

3. Results and discussion

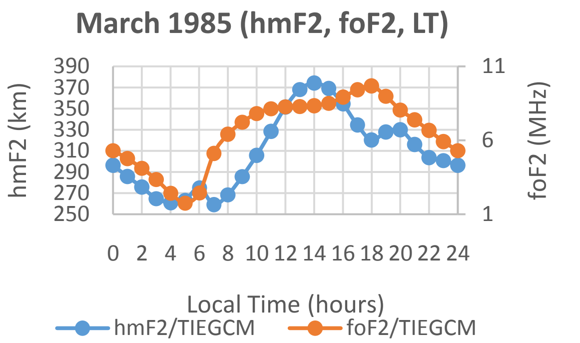
TIEGCM model has been ran under its 1.94 version at High Altitude Observatory during 2013 for the selected quietest days presented on Table 1, for Ouagadougou station (Latitude: 12.4°N and Longitude: 358.5°E).Universal Time (UT) is considered for Local Time (LT). This enables to carry out foF2 and hmF2 time values.

Figure (1) presents height of F2-layer and critical frequency parameters time variation during solar minimum. Panels (a), (b), (c) and (d) are respectively the parameters time variation onspring, summer, autumn and winter.

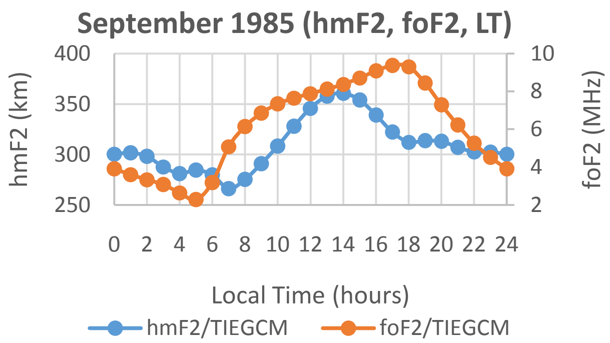
Figure (2) presents height of F2-layer and critical frequency parameters time variation during solar maximum. Panels (a'), (b'), (c') and (d') are respectively the parameters time variation onspring, summer, autumn and winter.

Figure (3) presents annual variability of height of F2-layer and critical frequency in the ionosphere.

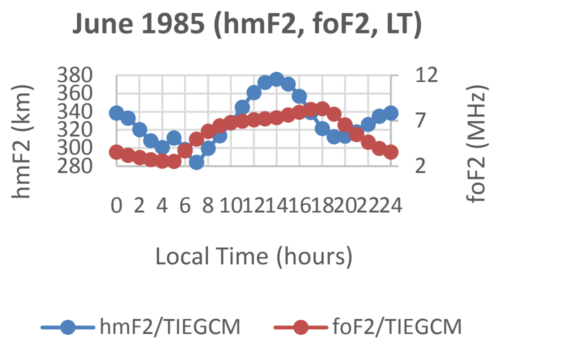
On the panels of figures 1, 2 and 3, local time is represented on the horizontal axis while hmF2 is on the primary Y-axis and foF2 on the secondary Y-axis



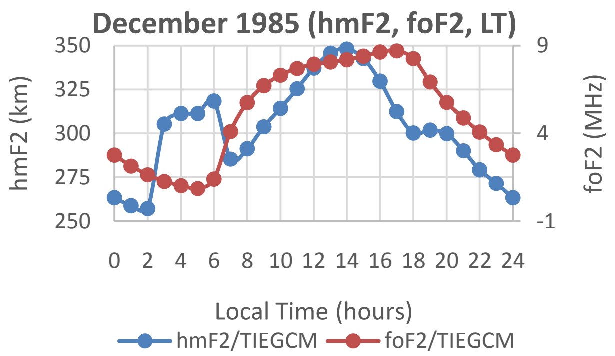
Panel(a) : hmF2 and foF2 time variation during March 85



Panel (b) : hmF2 and foF2 time variation during September 85

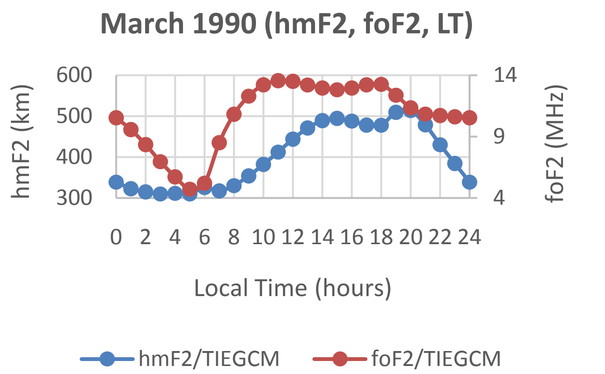


Panel (c) : hmF2 and foF2 time variation during June 85

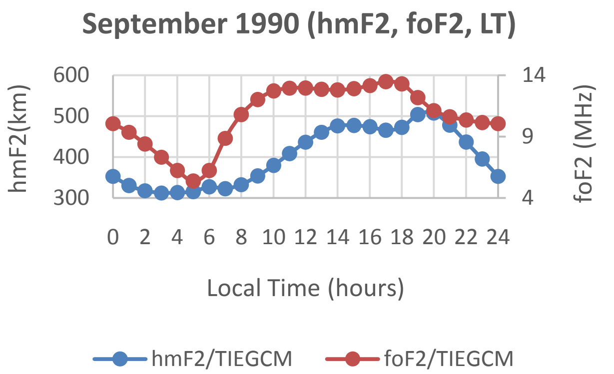


Panel (d) : hmF2 and foF2 time variation during December 85

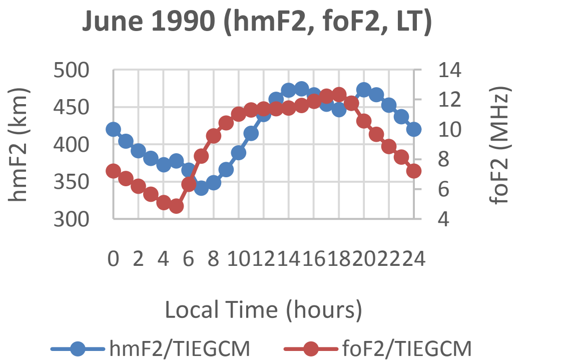
Figure 1: hmF2 and foF2 time variation during solar minimum



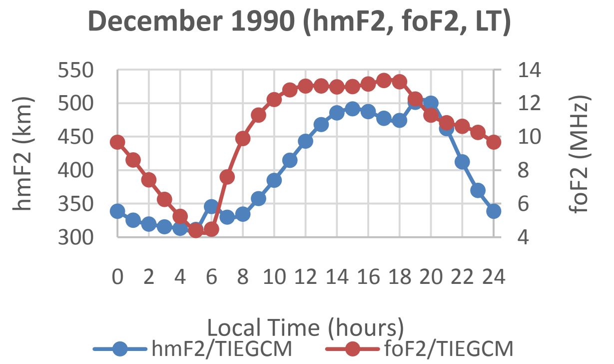
Panel(a') : hmF2 and foF2 time variation during March 90



Panel (b') : hmF2 and foF2 time variation during September 90

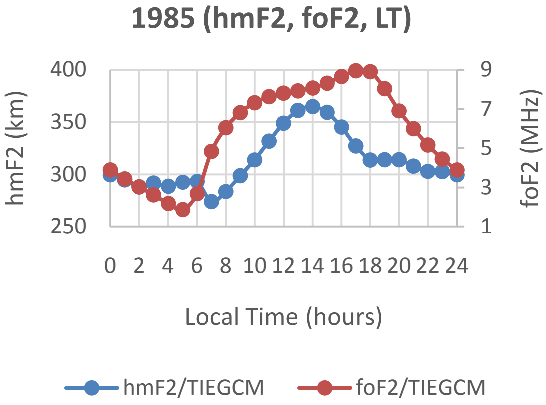


Panel (c') : hmF2 and foF2 time variation during June 90

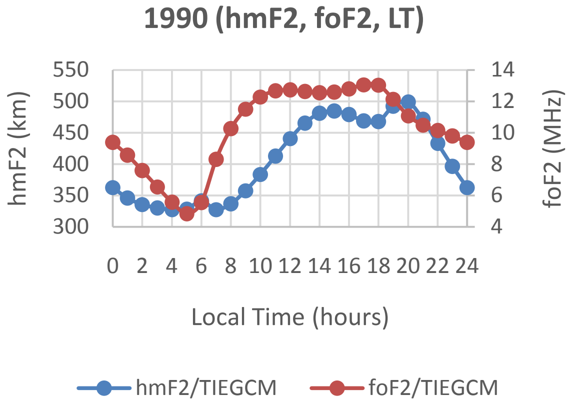


Panel (d') : hmF2 and foF2 time variation during December 90

Figure 2: hmF2 and foF2 time variation during solar maximum



Panel (a'') : hmF2 and foF2 annual variability during solar minimum



Panel (b'') : hmF2 and foF2 annual variability during solar maximum

Figure 3: hmF2 and foF2 annual variability

The panels (a), (b), (c) and (d) of figure (1) show foF2 time variation on minimum solar cycle phase at different heights. At nighttime (from 00.00 LT to 05.00 LT and from 18.00 LT to 24.00 LT), foF2 decreases to its lowest values at 05.00 LT. The highest values of foF2 at minimum solar cycle phase are arounds 17.00 LT and 18.00 LT. The height of F2 layer also decreases at nighttime. The lowest value of this parameter comes belatedly, at 07.00 LT, apart on December when it comes at 02.00 LT. During this phase, the highest value of foF2 comes at 14.00 LT. Table 2 highlights critical frequency and height of F2 layer minimum and maximum values at minimum solar cycle phase.

Table 2: Critical frequency and height of F2 layer minimum and maximum values at minimum solar phase

	$foF2_{min}$(MHz)	**Local time (h)**	**$foF2_{max}$(MHz)**	**Local time (h)**	**$hmF2_{min}$(km)**	**Local time (h)**	**$hmF2_{max}$(km)**	**Local time (h)**
March 85	1,76	5	9,67	18	259,14	7	374,22	14
June 85	2,49	5	8,33	18	284,04	7	375,76	14
September 85	2,28	5	9,31	17	266,16	7	360,72	14
December 85	0,87	5	8,71	17	257,2	2	348,18	14

At daytime, foF2 increases. During this period, the F2 layer raises until its highest value at 14.00 LT before decreasing.

On solar maximum (panels (a'), (b'), (c') and (d') of figure (2)), nighttime is characterized bydecreasing profiles for foF2. hmF2 highlights pics on its profiles during nighttime. During daytime, both hmF2 and foF2 increase. Table 3shows critical frequency and height of F2 layer minimum and maximum values at maximum solar cycle phase.

Table 3: Critical frequency and height of F2 layer minimum and maximum values at maximum solar phase

	$foF2_{min}$(MHz)	**Local time (h)**	**$foF2_{max}$(MHz)**	**Local time (h)**	**$hmF2_{min}$(km)**	**Local time (h)**	**$hmF2_{max}$(km)**	**Local time (h)**
March 90	6,97	3	13,55	11	310,08	5	514	20
June 90	4,86	5	12,34	18	341,36	7	472,96	20
September 90	5,36	5	13,46	17	312,5	3	507,86	20
December 90	4,39	5	13,36	17	311,16	5	501,54	19

Tables 2 and 3 show that both minimum of foF2 and hmF2 do not match at the same time (except on December on maximum solar cycle phase). Time and F2 layer position are not only the factors that influence critical frequency. This parameter is closely linked to the peak of electron density by equation (3).

$$\mathrm{foF2} = 9.\sqrt[2]{\mathrm{NmF2}} \quad (3)$$

Figures (1), (2) and equation (3) mean that calibration of radio waves station takes into account local time (LT), height of F2-layer (hmF2) and peak of electron density (NmF2). hmF2 and NmF2 parameters depend of solar cycle phase.

Panels (c') and (d') highlight winter anomaly during solar maximum. Comparison between figure (1) and (2) shows that both of hmF2 and foF2 limit values are inferior from solar minimum to maximum. These resultshave already been found with IRI model.

Figure (3) is obtained by extending the assumption that characterizes a month by its five quietest days. Using this approach, foF2 and hmF2 time variations in each cycle phase (for the four seasons) lead tothe annual variability of each parameter. Panels (a") and (b") present foF2 and hmF2 annual variability during solar minimum and maximum respectively. They show decreasing and increasing profiles during nighttime and daytime respectively. The limit values of the parameters have also the same behavior between the minimum and the maximum of solar cycle. This approach can be used to describe foF2 and hmF2 time variation throughout a year.

4. Conclusion

In this work, Thermosphere-Ionosphere-Electrodynamics General Circulation Model is used to investigate ionosphere region. The model is used to carry out height of F2 layer and critical frequency parameters. The study uses local time to link hmF2 and foF2. The results found by use of TIEGCM model correlate with those found by running IRI model in the same conditions. The study also proposes an approach to describe foF2 and hmF2 time variation throughout a year.

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