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Modeling the Ionosphere during Quiet Time Variation at Ouagadougou in West Africa

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Abstract

Ionosphere parameters determination is used to characterize its composition in particles. These results have been compared to data curried from Ouagadougou station. The present study deals with Total Electron Contents (TEC) results determined by Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) version 1.94 and International Reference Ionosphere (IRI) version 2012 during solar cycle 22. The minimum and maximum phases of solar cycle 22 are considered in this study for TEC determination. The station is located at Ouagadougou, in western Africa, characterized by its latitude (12.4˚N) and longitude (358.5˚E). The present study completes the two previous articles on hmF2 and foF2 parameters determination on the same station by comparison between TEC results carried out from TIEGCM and IRI models. So that, quiet time condition is determined by Aa (≤20 nT) for the five quietest days in each characteristic month of seasons. Rz values characterize minimum and maximum solar cycle phases.

Keywords

Ionosphere, TEC, Solar Cycle Phases, TIEGCM, IRI

1. Introduction

During the recent two decades several works deal with the modeling of the ionosphere parameters [1]-[12]. For the modeling, many authors used several models [13]-[26].

TIEGCM is a model developed at the National Center for Atmospheric Research (NCAR, Boulder, Colorado State, USA). Running this model can help to determine different parameters of the ionosphere (considered as the plasma) such as the TEC. Ionization phenomena in the ionosphere determine the TEC.

IRI model can be easily run in the internet.

The interest of this work is that it is the first time an Africa Equatorial Ionization Anomaly (EIA) station is investigated by TIEGCM model with TEC parameter. The knowledge of ionosphere parameters can help to the best understanding of climate change because of ionization effects. Ionosphere behaviors like a plasma.

In this paper, quiet time conditions are considered. Solar cycle phase impact is analyzed by taking into account the minimum (1985) and maximum (1990) of solar cycle 22. The other solar cycle phases are not used here like during Ouattara (2013) study because generally TIEGCM is running under solar minimum and maximum conditions. Seasonal effect is also investigated by analyzing equinoctial (March and September) and solstice (June and December) months predicted and TEC results variability.

2. Materials and Methods

TEC results are analyzed under quiet time conditions determined by using geomagnetic aa index values. In previous studies, we determined hmF2 [27] and foF2 [28] by use of TIEGCM (Thermosphere Ionosphere Electrodynamics General Circulation Model) and IRI (International Reference Ionosphere) models. The quiet time periods are determined by considering Aa ≤ 20 nT. We consider in the present paper the five quietest days results per chosen month. The present study also considers seasons and solar cycle phases. Equinox months are March and September and solstice months are June and December. Solar phases are obtained by applying the following criteria [29] [30] [31]: 1) minimum phase: Rz < 20, where Rz is the yearly average Zürich Sunspot number; 2) ascending phase : 20 ≤ Rz ≤ 100 and Rz greater than the previous year value; 3) maximum phase : 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]; and 4) descending phase: 100 ≥ Rz ≥ 20 and Rz less than the previous year's value. The maximum year is 1990 and the minimum year 1985.

For the comparison between TEC values, we used, for a given month, the arithmetic mean values for the five quietest days. **Table 1** gives the retained days.

Predicted values are obtained by running TIEGCM for the selected days under solar maximum condition given by F10.17 = 200 and solar minimum condition expresses by F10.7 = 70 for local point determining by its geographic longitude, latitude and local time. We do not consider all solar cycle phase as the model generally is running for both solar maximum and minimum conditions.

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. It is important to precise that this method does not introduce significant error in the

Table 1. Retain days for the study.

Solar cycle	Phase	Year	March (Equinox)	June (Solstice)	September (Equinox)	December (Solstice)
			Months			
C22	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

model result of TEC because there is small difference between magnetic and geographic longitude at low latitudes.

TEC prediction accuracy is appreciated by analysis hourly plots variability. For plots variability analysis error bars will help us. Error bars are obtained by applying $\sigma = \sqrt{\Delta}$ where Δ is the variance defined by $\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2$ with $\bar{x}$ mean value and N the total number of observations for a particular dataset.

3. Results and Discussion

Figure 1 (Panels (a), (b), (c), (d)) gives the time variation of TEC for solar minimum (year 1985) and Figure 2 (panels (a'), (b'), (c'), (d')) presents the time variation of TEC for solar maximum (year 1990) of C22. Blue curve concerns TEC results after running TIEGCM model and red curve is for TEC results given by IRI model.

On solar minimum, TEC profiles show Reversed profiles for TIEGCM TEC values for both equinox and solstice seasons while noon bite out profiles appear on December, June and March for TEC values under IRI running condition. Reversed profile is observed for this model on September.

During solar maximum phase, Morning Peak, Reversed and Dome profiles are observed respectively on December, Reversed for both June and September and Dome on March for Tec values given by TIEGCM running. IRI model focuses two profiles which are Plateau on December and March and Dome on June and September.

These profiles express the signature of electric current. In fact, Reversed profile is due to the presence of the intense counter electrojet while Dome and Plateau profiles highlight the absence of the electrojet [32] [33]. This shows that only daytime effects cannot explain Reversed profile.

These profiles show suitable results with those found by use of TIEGCM and IRI for determination of NmF2 and foF2 profiles in the same conditions on maximum and minimum phases of solar cycle 22.

This study also shows at least that TEC parameters in the ionosphere are not only due to the daytime effects. This is previously highlighted in the study of NmF2 and foF2.

In Figure 3 (panel (a''), TEC mean values given by TIEGCM model is compared to those given by IRI model for minimum solar cycle phase of C22. Panel

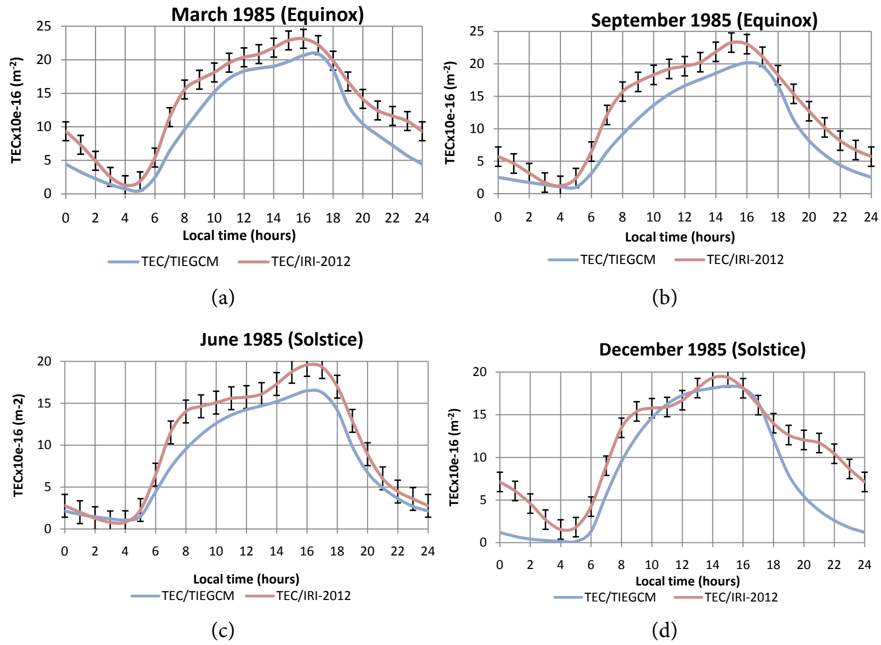


Figure 1. Time variation of TEC on minimum solar cycle phase of C22. (a) TEC profiles given by TIEGCM and IRI on March 1985; (b) TEC profiles given by TIEGCM and IRI on September 1985; (c) TEC profiles given by TIEGCM and IRI on June 1985; (d) TEC profiles given by TIEGCM and IRI on December 1985.

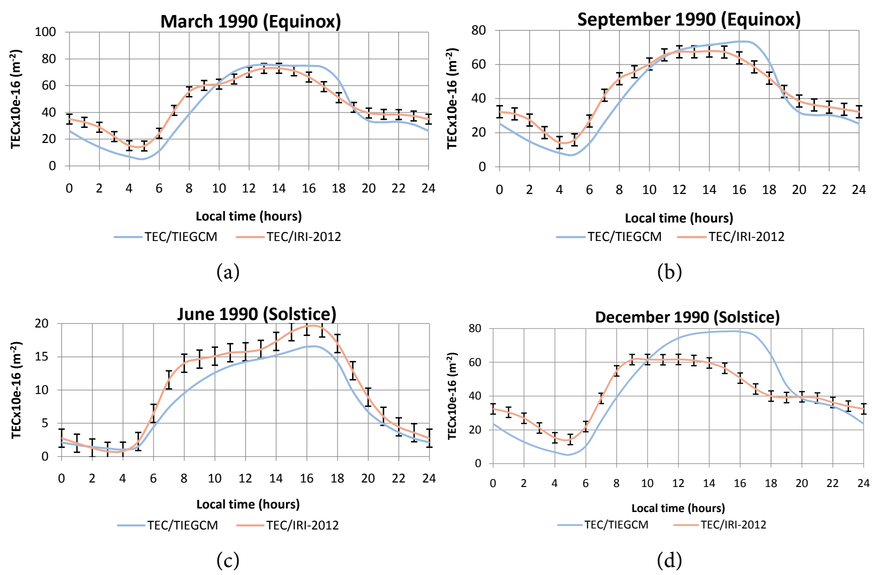
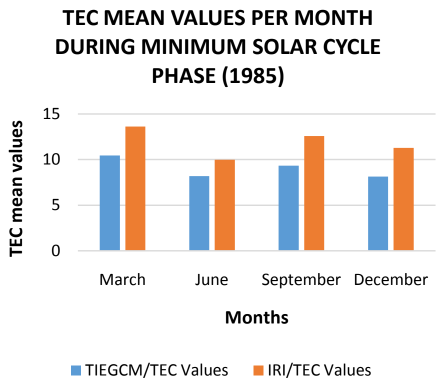


Figure 2. Time variation of TEC on maximum solar cycle phase of C22. TEC profiles given by TIEGCM and IRI on March 1990; TEC profiles given by TIEGCM and IRI on September 1990; TEC profiles given by TIEGCM and IRI on June 1990; TEC profiles given by TIEGCM and IRI on December 1990.

(b”) shows the comparison during solar maximum phase at the same cycle.

Figure 3 shows that between TIEGCM and IRI models, TEC values are given with mean relative error variation in the range of [18]-[28] on minimum solar cycle phase. This range is [3]-[8] on maximum solar cycle phase.



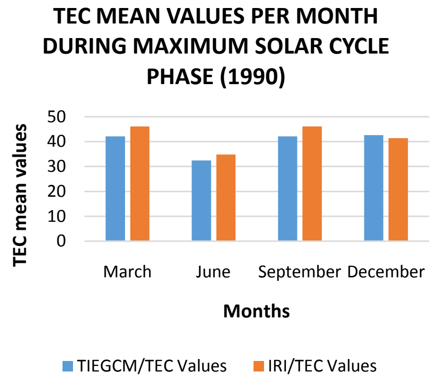


Figure 3. Comparison of TEC mean values given by TIEGCM and IRI models; (a) Comparison of TEC mean values given by TIEGCM and IRI models on minimum solar cycle phase (1985); (b) Comparison of TEC mean values given by TIEGCM and IRI models on maximum solar cycle phase (1990).

These ranges of mean relative error of TEC variation per month show that TIEGCM and IRI models give approximate values on maximum solar cycle phase. On minimum solar cycle phase, TEC values present great differences.

The conclusion we can find out from these comparisons is that TIEGCM and IRI models are almost suitable on maximum solar cycle phase for TEC determination.

4. Conclusion

TEC results given by TIEGCM and IRI models at Ouagadougou station on minimum and maximum solar cycle phases present different profiles previously found by other authors. The two models are suitable for TEC determination at maximum solar cycle phase but have bad correlation on minimum solar cycle phase. We have found the same result for foF2 study in comparison between data, TIEGCM and IRI.

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