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Modeling Total Electron Content and Critical Frequency at F1 and E Layer Boundary

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

This work investigates the variation of the total electron content TEC and the critical frequency fo in the boundary zone of the F1 and E layers at the low-latitude in the ionosphere. This study takes place at the Ouagadougou station (12.4°N and 358.5°E), in West Africa during the quiet geomagnetic activity of solar cycle 23. Ionosphere is the upper layer of the Earth's atmosphere ionized mainly by solar X- and UV-rays, extending from around 80km altitude up to 1000km [1] [2]. Ultraviolet light from the sun ionizes the atoms and molecules in the Earth's upper atmosphere [3]. For this study we use the 2016 version of International Reference Ionosphere (IRI) model. The

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quiet periods of maximum and minimum phase of solar cycle 23 are considered [4] [5]. From this study, it emerges that at the E and F1 layer boundary zone, TEC and fo increase during the day as solar irradiance increases and decrease as solar irradiance decreases.

Keywords: Total electron content; critical frequency; maximum phase; minimum phase; quiet days.

1. INTRODUCTION

This work is devoted to TEC and fo parameters variation Molecules and atoms in the atmosphere are not uniformly distributed [6] [7]. Three layers (D, E and F) are distinguished in ionosphere layer by their electrical properties. The D layer, located between 60 and 90 km, appears with sunrise and disappears immediately after sunset. The E layer is estimated between 90 and 150 km. It reflects waves from a few MHz up to a limit frequency that depends of the angle of incidence of the wave on the layer and its density. The F layer, from 150 to 800 km, has a very high level of ionization during the maxima of solar cycle 23 [9] [10]. Its altitude fluctuates with solar radiation, and during the day it breaks down into two sub-layers, F1 and F2. These two sub-layers recombine at night, several hours after sunset, but may persist throughout the night at times of maximum solar activity 23. International Reference Ionosphere (IRI) is a semi-empirical model including two sub-programs that are the Committee on Space Research (CCIR) and the International Union of Radio Science (URSI) [10] [11].

2. MATERIALS AND METHODS

Solar cycle phase is defined by the mean annual value Rz. The year corresponding to the cycle phase is at minimum if Rzmoy < 20 and the year corresponding to the maximum cycle phase corresponds to Rzmoy > 100. March, June, September and December of the years 1996 and 2008 [12] [13] during universal time according to the geographical coordinates of the Ouagadougou station are used. The daily average values of the geomagnetic index Aa define the conditions that characterize disturbed, recurrent, fluctuating shock and calm periods. Aa index ≤ 20nT corresponds to so-called calm periods [14] [15] [16].

$$\lim_{x\to 150} TEC = \lim_{x\to 150} \frac{1}{n} \sum_{i=1}^{n} TEC^i \qquad (1)$$

$$\lim_{x\to 150} foF = \lim_{x\to 150} \frac{1}{n} \sum_{i=1}^{n} foF^i \qquad (2)$$

$$\lim_{x\to 150} foE = \lim_{x\to 150} \frac{1}{n} \sum_{i=1}^{n} foE^i \qquad (3)$$

Table 1. Selected days corresponding to the quietest periods of solar cycle 23[17] [18]

Minimum phase (1996)			
March	**June**	**September**	**December**
4,7,9,18,24	2,9,11,18, 29	5,10,13,18, 21	5,14,18,22,30
Maximum phase (2008)			
March	**June**	**September**	**December**
8,12,16,25, 28	1,7,11,21, 28	3,9,13,19,2 4	6,13,23,26 ,31

$$\lim_{x\to 150} fo = \lim_{x\to 150} \frac{1}{n} \left(\sum_{i=1}^{n} foF^i + \sum_{i=1}^{n} foE^i \right) \qquad (4)$$

$$\lim_{x\to 150} fo = 9.\sqrt{\lim_{x\to 150} Nm} \qquad (5)$$

n designed quiet days number and, x designed altitude.

3. RESULTS AND DISCUSSION

3.1 Minimum Phase

The profiles in Fig. 1 show that the values of critical frequency and TEC are respectively low in the morning, evening and night, between 0:00 and 9:00 and from 1:00 to 24:00. This is because solar irradiation is low at these times, so the ionization of the boundary region between the E and F1 layers of the ionosphere due to this irradiation experiences a drop in intensitý, so the fo and TEC profiles are decreasing.

In contrast, during the day when solar irradiation begins to increase hencѐ a rise in ionization of the boundary region of the E and F1 layers of the ionosphere, fo and TEC values begin to increase during the day until reaching their maximum values around peak hours between 12 pm and 3 pm. This is because solar irradiance is high at these times, so the TEC and fo profiles increase. [19].

3.2 Maximum Phase

The profiles in Fig. 2 show that critical frequency and TEC values are respectively low in the morning, evening and night, from 0 to 5 and from 5 to midnight. Indeed, at these times solar irradiation is low, consequently, ionization of the boundary region between the E and F1 layers of the ionosphere due to this irradiation experiences a decrease in intensitý, thus the fo and TEC profiles are decreasing.

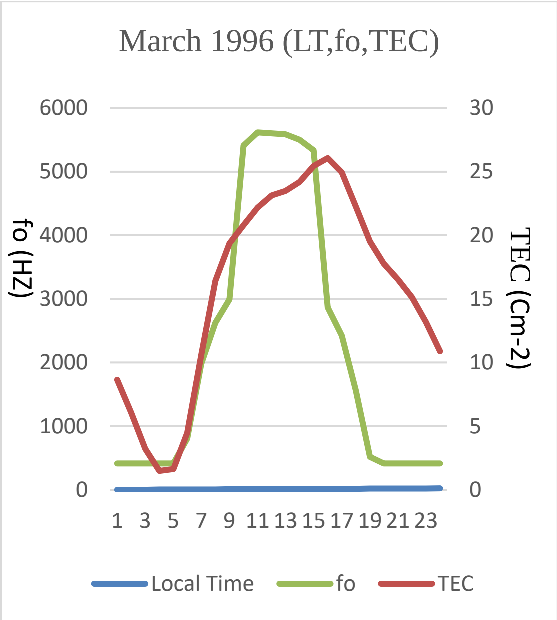

Fig. 1.a. fo and TEC variability in Spring 96

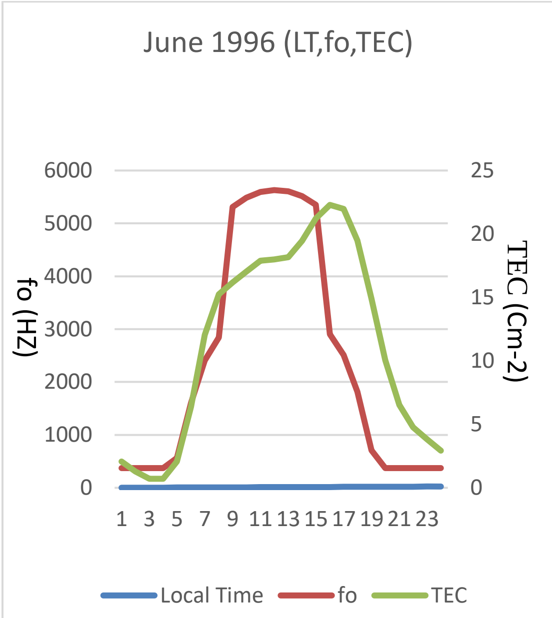

Fig. 1.b. fo and TEC variability in Summer 96

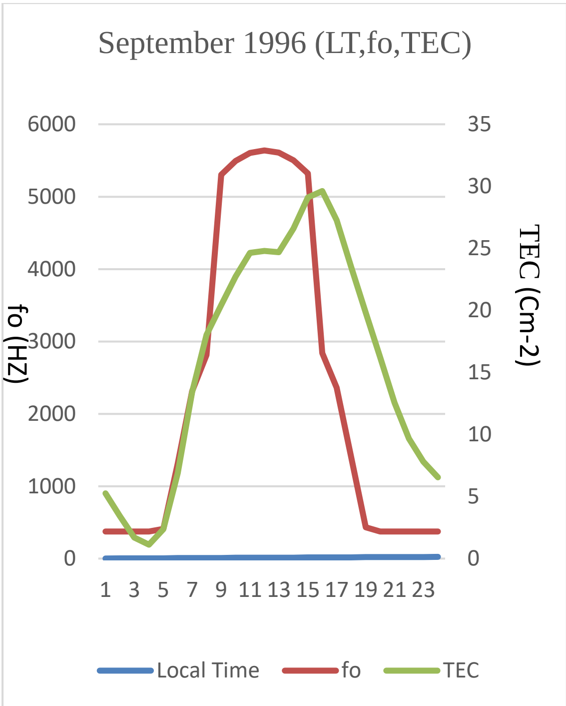

Fig. 1.c. fo and TEC variability in Autumn 96

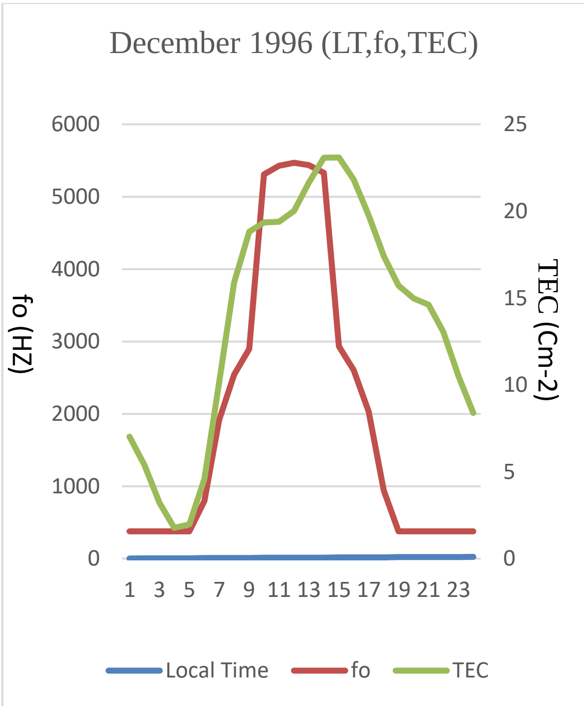

Fig. 1.d. fo and TEC variability in Winter 96

Fig. 1. Profiles of critical frequency and total electron content in spring, summer, autumn and winter at phase minimum of solar cycle 23

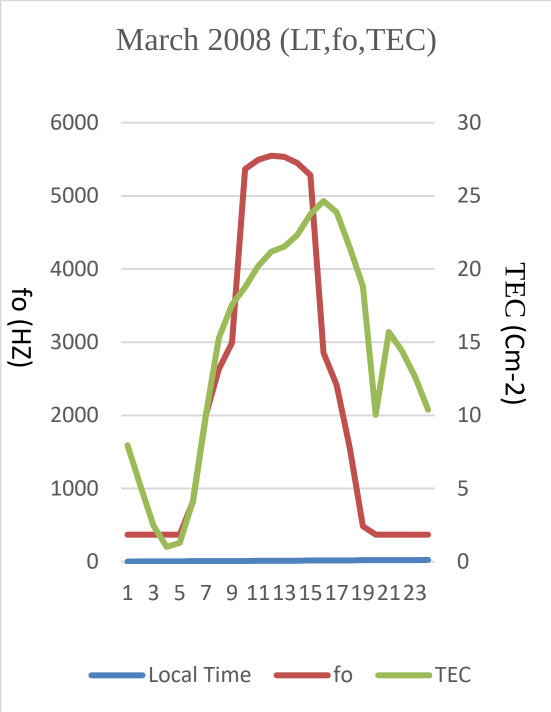

Fig. 2.a. fo and TEC variability in Spring 2008

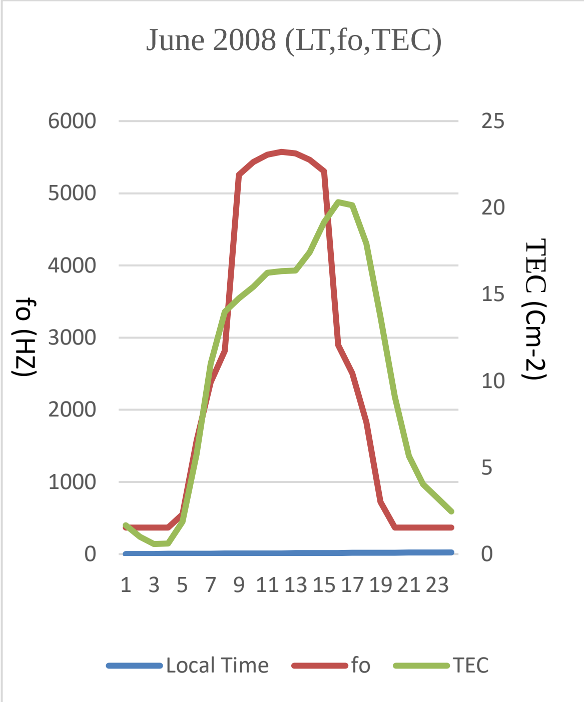

Fig. 2.b. fo and TEC variability in Summer 2008

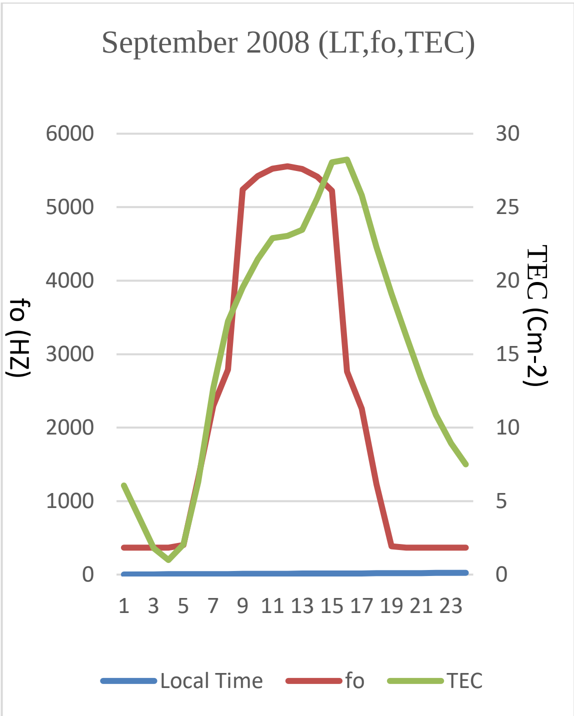

Fig. 2.c. fo and TEC variability in Autumn 2008

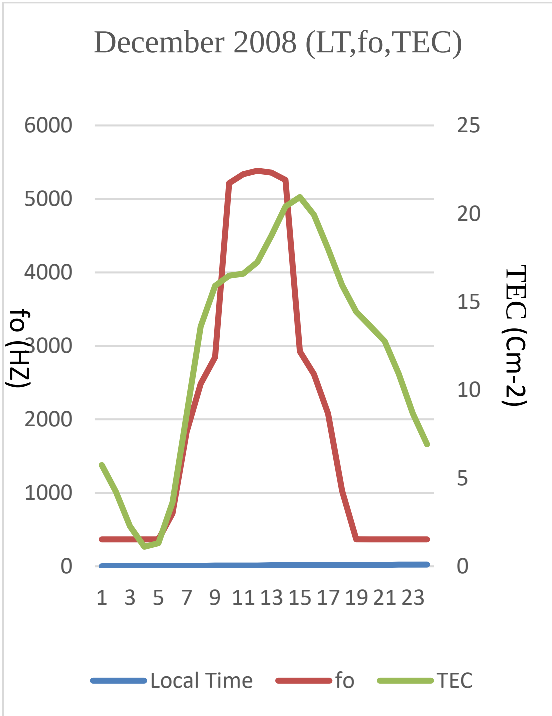

Fig. 2.d. fo and TEC variability in Winter 2008

Fig. 2. Profiles of critical frequency and total electron content in spring, summer-autumn and winter at phase maximum of solar cycle 23

In contrast, during the day when solar irradiation begins to increase, a rise in ionization of the boundary region of the E and F1 layers of the ionosphere, fo and TEC values begin to increase over the day until reaching their maximum values around peak hours between 11 am and 3 pm. This is because solar irradiation is high at these times, so the TEC and fo profiles increase [20].

4. CONCLUSION

This study focuses on the variation of fo and TEC parameters at the boundary zone of the E and F1 layers. The study is being carried out at the Ouagadougou station during geomagnetic calm periods, the minimum and maximum phases of solar cycle 23. Latitudes using the IRI-2016 model. This study presents the profiles of fo and TEC. Two main phases are observed: an increasing phase when solar irradiation increases, and a decreasing phase when solar irradiation decreases. [23] [24].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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