



RESEARCH ARTICLE

HIGHLIGHTING SEASONAL ANOMALY IN IONOSPHERE DURING MINIMUM AND MAXIMUM SOLAR CYCLE PHASES

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Abstract

Ionosphere is the part of atmosphere where waves reflect for telecommunication because of its concentration in particles. The morphology of ionosphere layer is not uniform. The density in particles in this layer varies from daytime to nighttime, from winter to summer, via spring and autumn. Time parameter and solar activity also influence this variation. This study is focused on the electron density in ionosphere layer during minimum and maximum of solar cycle 22, at Ouagadougou station. It uses International Reference Ionosphere model. The seasonal peak of electron density and total electron content parameters are carried out by running the 2012-version of the model. Comparison from winter to summer shows out a decrease of the peak of electron density and total electron content in ionosphere. Winter anomaly is highlighted by the time profiles of these two parameters. This correlates with previous results found by other authors.

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Introduction:-

The major constituents of ionosphere layer are N₂, O₂ and O (Nier et al., 1964; Schaefer and Brown, 1964; Reber and Nicolet, 1965). Solar radiations coming from the Sun hit these particles and cause their ionization. This ionization phenomenon releases electrons and ions (Nicolet and Mange, 1954). The density in particles (ions, electrons, atoms, molecules) gives to ionosphere layer high or low reflectivity to waves emitted from stations on the Earth. This layer behaves as an obstacle for waves diffusion. The reflectivity of ionosphere layer to waves transmission is dependent on its concentration in particles. Below a given limit of waves frequency value, pointing out the critical frequency, waves are reflected in ionosphere layer. This is used for data signals (telecommunication, navigation, etc.) transmission. This limit value is variable. It is dependent on time, solar cycle phase, season, solar activity. Thus, ionosphere layer is important for telecommunication and must be well known for a good prediction of waves behavior. Many models are developed for ionosphere investigation (Rishbeth, 1964; Roble et al., 1988; Wang et al., 2004; Richmond et al., 1992; Burns et al., 2004; Goodrich et al., 2004; Weimer, 2005; Qian et al., 2010; Jin and Park, 2007; Richmond et al., 1976; Bittencourt and Chryssafidis, 1994). This study uses International Reference Ionosphere (IRI) model to carry out particles density. IRI is a semi-empirical model using data that are recorded on different stations. The model is on-line accessible. Peak of electron density (NmF2) points out the volume concentration of electrons while total electron content (TEC) is the bulk surface density in electrons in the layer. The two parameters are closely linked to time variation. The morphology of ionosphere layer is closely linked to the

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height (rising from the Earth) because at different heights, the concentration in particles is different (Rishbett and Gariott, 1969). This study also considers the quiet periods for minimum and maximum of solar cycle phase 22 and low latitudes for running the model.

Material and Methods:-

Fundamentals

The study is based on the four following core principles (Nanéma et al., 2018): (i) Minimum and maximum phases of solar cycle. The minimum and maximum phases are respectively determined by the sunspot number $Rz \leq 20$ and $Rz \geq 100$. (ii) Quiet days. The quiet days are given by Aa index inferior to 20 nT. In this range, the five quietest days are considered for the study. So, the five lowest values in the characteristic month are used. (iii) Integrating the values. The average value on the five quietest days of each parameter at the same time is the hourly value for this parameter. (iv) Characteristic month. Each season in the year is well described by its characteristic month (March for spring, June for summer, September for autumn and December for winter).

Ouagadougou station (latitude: 12.5°N, longitude: 258.5°E), located in West Africa is considered to run the model.

Results And Discussion:-

Table 1 is derived from the principles (i), (ii) and (iv). 1985 and 1990 are respectively minimum and maximum of solar cycle 22.

Table 1:- Characteristic months and quietest days at minimum and maximum of cycle 22.

Cycle	Phase	Year	Months			
			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

Running the model for each day in Table 1 gives the hourly values of the parameters. Then, the use of the principle (iii) leads to the equations (1) and (2) as follows.

The peak of electron density is expressed by:

$$NmF2_i = \frac{\sum_{j=1}^5 NmF2_{i,j}}{5} \quad (1)$$

And total electron content expression is:

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

In equations (1) and (2), “i” points out the time all daylong while “j” designates the quietest day. So, $i \in [0, 24]$, $NmF2_i$ and TEC_i are respectively the average hourly value (calculated on the five quietest days) of peak of electron density and total electron content. $NmF2_{i,j}$ and $TEC_{i,j}$ are respectively the hourly value at each quietest day.

Peak of electron density and total electron content values calculated above with equations (1) and (2) are now represented on three-axis graphs in an Excel file. Figures 1 and 2 represent the seasonal time profiles of peak of electron density and total electron content during solar minimum and maximum respectively. The figures x.a, x.b, x.c and x.d represent the time variability of the parameters on spring, summer, autumn and winter ($x = 1$ or 2). On each three-axis graph, peak of electron density is represented on the primary vertical axis, and total electron content on the secondary vertical axis. Time variation is on the x-axis.

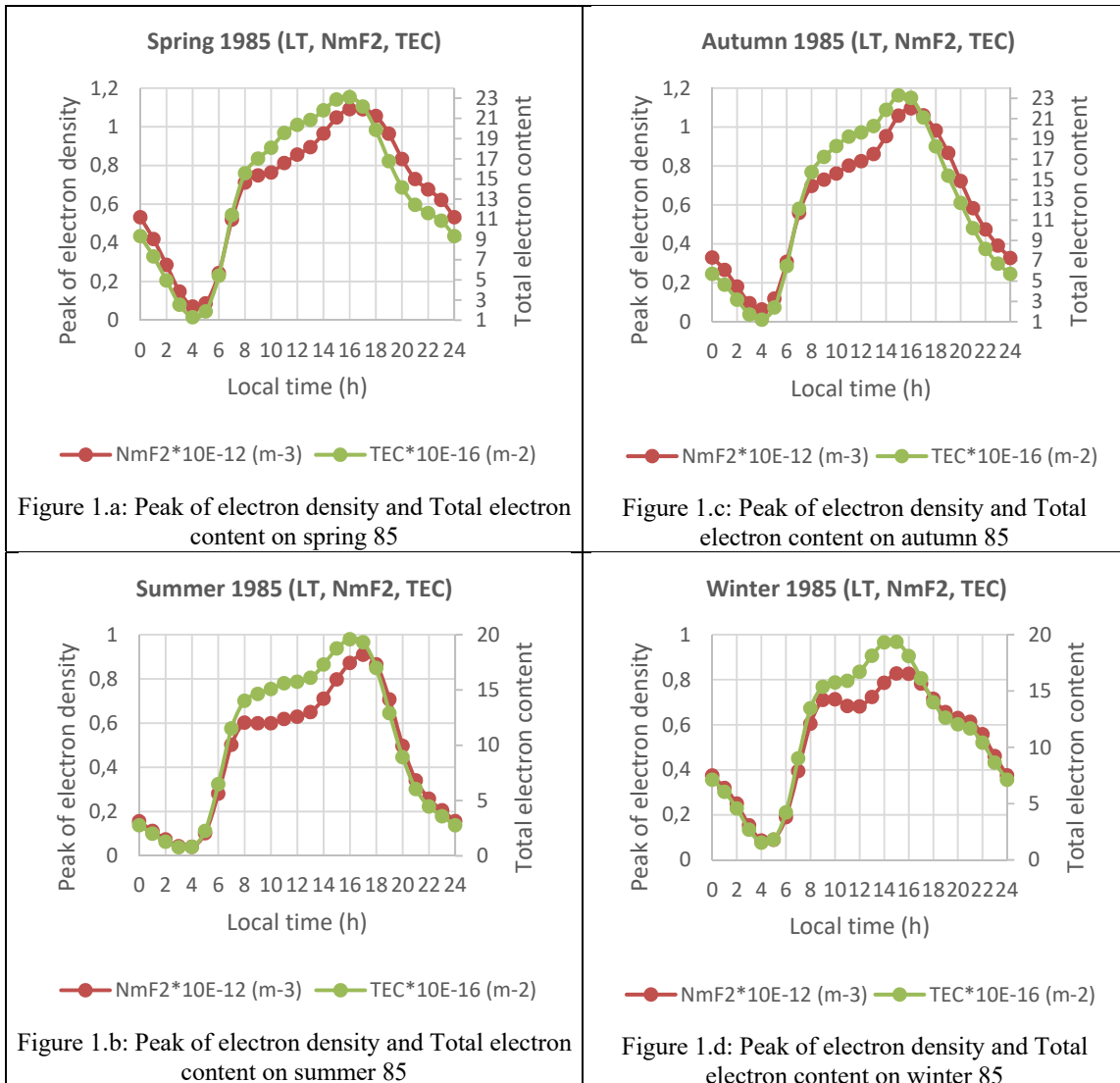
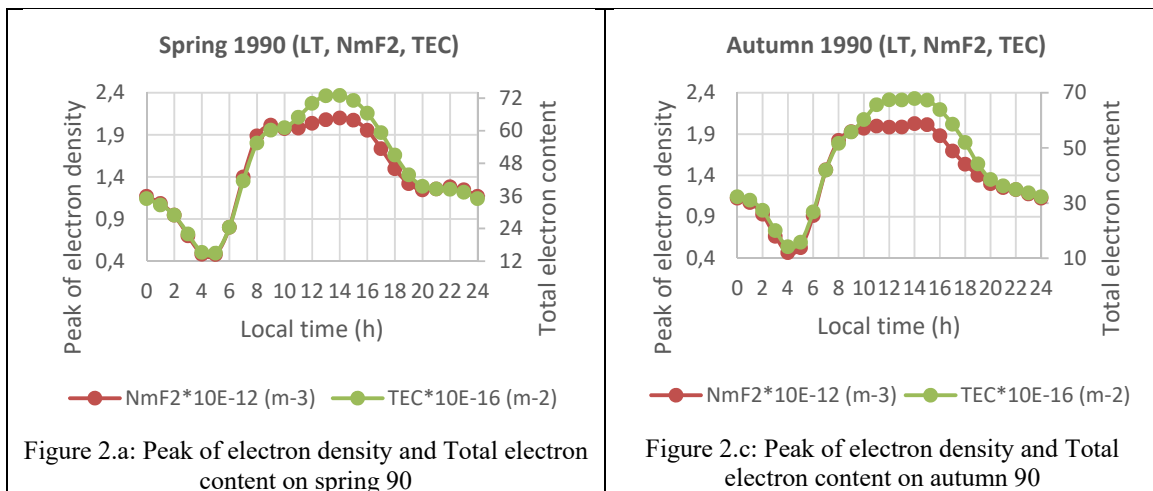


Figure 1:- Seasonal time profiles of Peak of electron density and Total electron content at solar minimum.



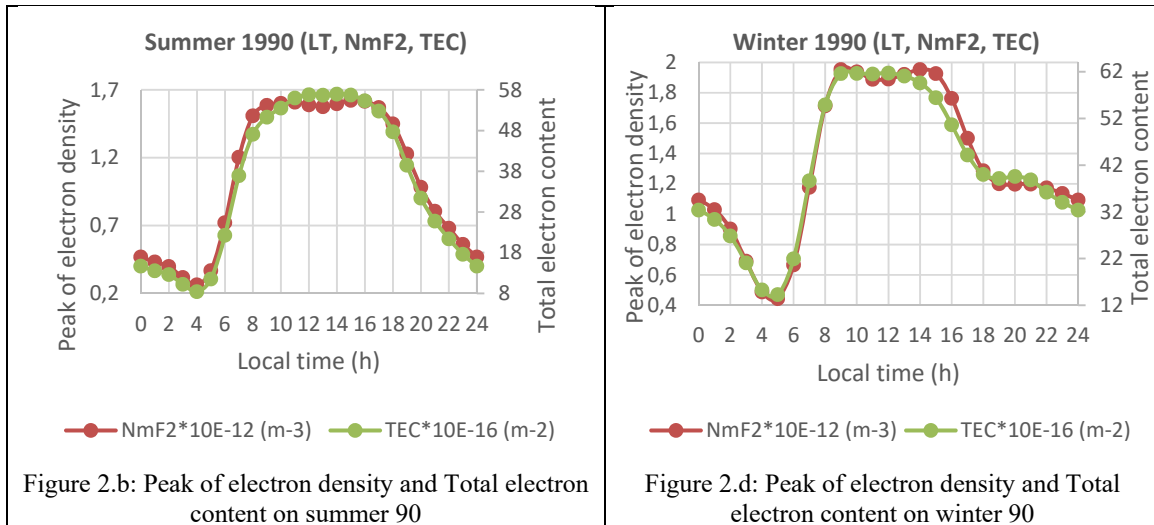


Figure 2:- Seasonal time profiles of Peak of electron density and Total electron content at solar maximum.

Figures 1.a, 1.b, 1.c and 1.d shows that at nighttime (from 00.00 LT to 04.00 LT and from 17.00 LT to 24.00 LT) peak of electron density and total electron content values decrease while they increase at daytime (from 05.00 LT to around 16.00 LT). This means that on daytime, the concentration in electrons in F2 layer grows with the time. During this period, solar radiations are more intensive than those at nighttime. The ionization of the ionosphere is more important. The maximum values of the parameters are got at around 16.00 LT on spring and summer and 15.00 LT at autumn and winter. The decreasing phase of the concentration in electrons moves from winter (at around 15.00 LT) to spring (at 16.00 LT) via autumn and summer and the maximum value come belatedly.

Figures 2.a, 2.b, 2.c and 2.d show decreasing profiles for peak of electron density and total electron content at nighttime and increasing profiles at daytime. On spring, the parameters time variations present a peak at 14.00 LT while the maximum value stay for a long time on summer, autumn and winter.

The table 2 presents the minimum and maximum values of NmF2 and TEC at summer and winter on minimum and maximum phases.

Table 2:- Minimum and maximum values of NmF2 and TEC on summer and winter.

Units	Variables	Minimum phase		Maximum phase	
		Winter 85	Summer 85	Winter 90	Summer 90
10 ⁻¹² m ⁻³	NmF2 _{min}	0.086	0.043	0.444	0.263
	NmF2 _{max}	0.826	0.909	1,953	1,622
10 ⁻¹⁶ m ⁻²	TEC _{min}	1.54	0.78	14.3	8.44
	TEC _{max}	19.36	19.58	61.64	56.94

The table 2 shows that on winter during maximum solar cycle phase, peak of electron density and total electron content values are higher than those on summer. This is also shown on comparison between the other hourly values of these parameters. This means that on winter, the concentration in electrons is higher than that on summer. The ionization of ionosphere layer is more intensive on winter than that on summer. However, solar radiations are more intensive on summer than that on winter. This is winter anomaly that has already been found (Rishbeth et al., 2000; Rishbeth and Muller-Wodarg, 2006; Yonezawa and Arima, 1959; Shapley and Beynon, 1965). This phenomenon is not highlighted on minimum solar cycle by the present approach of calculation of the parameters values.

The average values of the parameters on all the season long can be expressed by equations (3) and (4) as follows:

$$NmF2_{\text{seasonal}} = \frac{\sum_{i=1}^{24} NmF2_i}{24} \tag{3}$$

And

$$TEC_{\text{seasonal}} = \frac{\sum_{i=1}^{24} NmF2_i}{24} \tag{4}$$

Figure 3 presents the seasonal mean values of peak of electron density and total electron content calculated by equations (3) and (4).

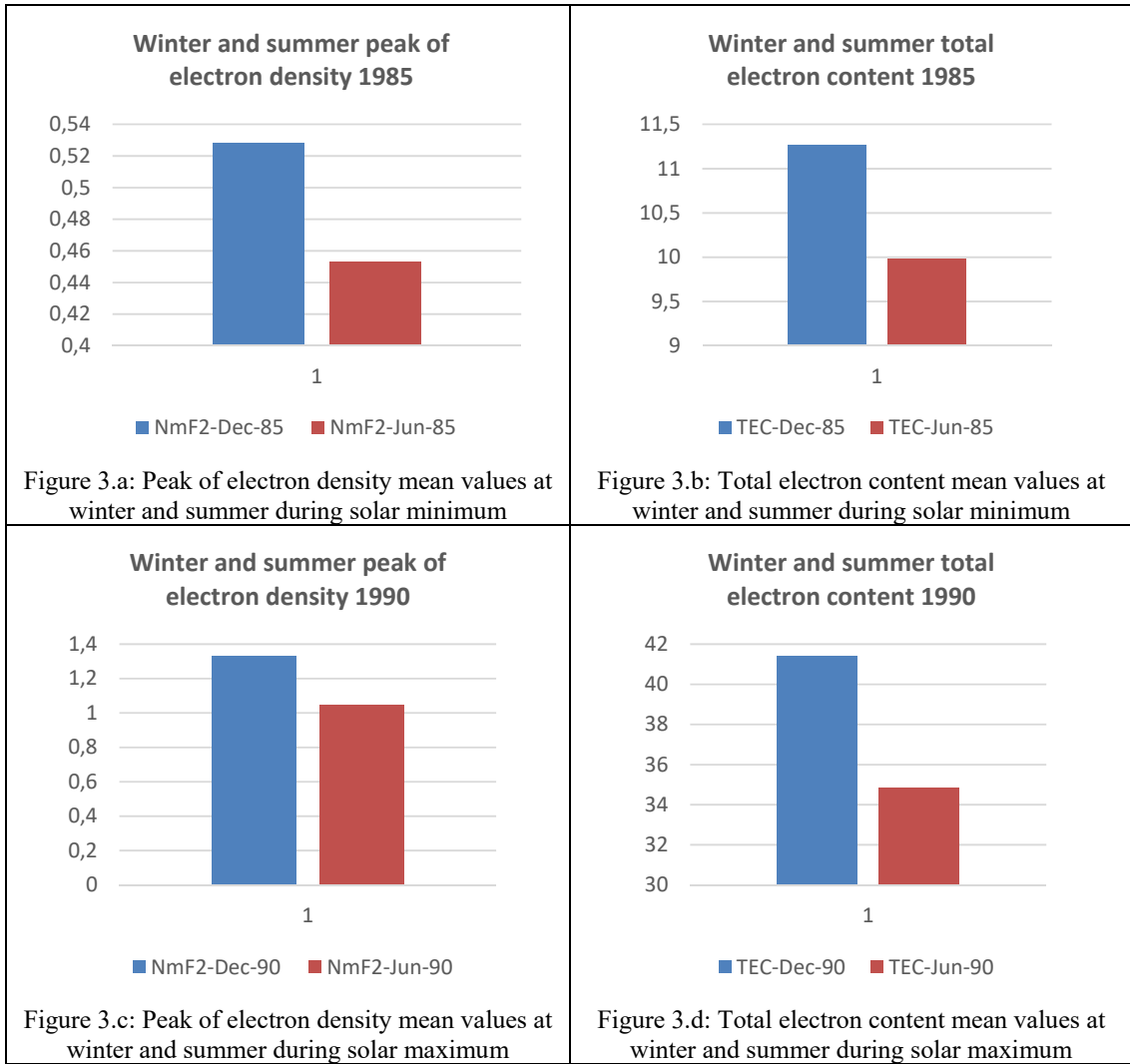


Figure 3:- Seasonal mean values of Peak of electron density and Total electron content

Figures 3.a and 3.b present the comparison between peak of electron density average values on winter and summer and total electron content during these seasons at minimum phase. The average values of these parameters on winter are higher than those on summer. The concentration of electrons in ionosphere layer is then higher on winter than that on summer. This concentration is 116.57% for the peak of electron density and 112.87% for the total electron content. This approach highlights the winter anomaly on minimum solar cycle phase.

Figures 3.c and 3.d shows the same phenomenon on solar maximum (126.72% for the peak of electron density and 118.70% for the total electron content). This has been found previously.

Conclusion:-

In this study, IRI model is used to carry out peak of electron density and total electron content in ionosphere layer. The intensity of solar radiations, growing up from night to day, and from minimum to maximum solar cycle phases,

causes ionization of ionosphere constituents by hitting the molecules and atoms. Solar radiations intensity is also closely linked to solar activity and seasons. On winter, the concentration in electrons (volume or surface) in ionosphere is 10% superior to its value on summer during solar minimum. During solar maximum, this value grows up to more than 18% between winter and summer. Analyzing time variation of these parameters enables to highlight the winter anomaly phenomenon on the peak of electron density and the total electron content at minimum and maximum solar cycle phases.

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