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Research Article

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Seasonal Variability of hmF2 in Low Latitudes using IRI

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Abstract The solar activity has an impact on the terrestrial environment and eventually on the upper atmosphere of the Earth, the ionosphere being a part of the latter where many atoms and molecules are strongly ionized. This layer contributes to the protection of the terrestrial environment against solar radiation. Its F2 region is the seat of the reflections of the electromagnetic waves whose most current use is that of the telecommunications. The quality of communications is sensitive to the situation of this height. This study deals with the knowledge of the long-term variation of the virtual height of the ionosphere in the evaluation of the climatic evolution in low latitude in the African sector. The aim is to present the variability of the virtual height (hmF2) of the so-called F2 layer at the Ouagadougou station in West Africa. The main objective is to study the temporal evolution of hmF2 of the quietest day of the month characteristic of each season during the solar cycles 21, 22 and 23 using the International Reference Ionosphere (IRI) model in its 2016 version. The present work gives a detailed description and allows to illustrate the hmF2 pattern per season as a function of cycle and cycle phase during the quiet geomagnetic activity. It results from this work a significant decrease on the seasonal average values of hmF2 at the phase maximum, between the preceding and following solar cycle by the IRI model.

Keywords IRI model, virtual height in F2-layer, Ionosphere, quiet time, solar cycle phase

1. Introduction

The solar activity has effects on the Earth's upper atmosphere and the near space environment of the Earth. The Sun acts on the Earth's environment mainly through the solar radiation channel (UV, EUV, visible, etc). The high energy photons from the Sun ionize the atmospheric layer (50-800 km) and generate electric currents. The ionosphere is the part of the Earth's upper atmosphere where the high energy solar radiation causes the ionization of particles and molecules present in this area [1]. This layer is very important for navigation and satellite communication. Radio waves emitted from the earth, below the critical frequency of the F2 layer of the ionosphere, are reflected. Many studies have been conducted not only to establish the long-term trend of the ionosphere [2]-[5], but also to understand the morphology of the variation of ionospheric parameters according to solar cycles, phases of the solar cycle, seasons and the impact of different classes of geomagnetic activity [6]-[23] through various data sources. Ouattara and Amory Mazoudier, 2008 showed that geomagnetic activities act differently depending on the activity class. Ouattara and Nanéma, 2013 highlighted the variability of the virtual F2 layer height of the low-latitude ionosphere in the African sector during solar cycle 22 for quiet geomagnetic activity classes. The knowledge of solar activity on the upper atmosphere and more precisely the behavior of the long-term virtual height during quiet geomagnetic activities has aroused the interest of our present study. The purpose of this study is to understand the seasonal variation of the virtual height of the F2 layer of the ionosphere at the Ouagadougou station (Latitude 12.5°N and Longitude 358.5°E) from 1976 to 2007 using the International Reference Ionosphere (IRI) model in its 2016 version. The aim is to study the daily mean variation of the virtual height hmF2 for the quietest day of the month characteristic of each season during cycles 21, 22 and 23.

2. Methodology

The study is conducted at the Ouagadougou station with geographic coordinates: latitude 12.4ºN and longitude 358.5ºE. The years 1976 to 2007 correspond to solar cycles 21, 22 and 23. The phases of the solar cycle are taken into account and are determined by the annual average sunspot number of Zürich, Rz. The months characterizing spring, summer, autumn and winter are March, June, September and December respectively. The study is based on the daily mean value of the virtual height of the quietest day of the characterizing month of each season during three solar cycles. The hmF2 values are extracted from IRI version 2016 which is a global ionosphere modeling model, allowing to reproduce ionospheric characteristics and to validate dynamo theories. The data are then exported in an Excel file for the determination of hmF2 profiles.

Equation (1) is used to calculate the daily average value of the virtual height:

$$hmF2_d = \frac{\sum_{h=0}^{25} hmF2_{d,h}}{25} \quad (1)$$

In this expression, $hmF2_d$, denotes the value of the average virtual height of the sublayer F2 for day d of the characteristic month under consideration; $hmF2_{d,h}$ is the value of the virtual height at time h for day d. Under these conditions, the index $h \in [0, 24]$, the index and $d \in [1, 31]$. The calculation of the virtual height shrinkage is given by the equation:

$$CH_{hmF2} = hmF2(C) - hmF2(C+1) \quad (2)$$

Where CH_{hmF2} is the value of the virtual height difference between two successive phase maxima; hmF2(C) and hmF2(C+1) are respectively the value of the virtual height at the phase maximum and that of the following phase.

Table 1 shows the quietest day of each month characteristic of each season for solar cycles 21, 22 and 23.

Table 1: The quietest days of each month

Solar cycle	Year	Month			
		March	**June**	**September**	**December**
		Quiet day			
	1976	22	14	11	15
	1977	4	11	6	8
C21	1978	4	9	19	10
	1979	14	28	7	7
	1980	15	17	21	24
	1981	9	12	1	6
	1982	6	17	29	1
	1983	27	4	30	9
	1984	9	21	18	24
	1985	9	16	5	21
	1986	10	25	22	29
	1987	20	30	3	8
	1988	21	4	29	7
	1989	25	18	11	10
	1990	17	20	2	10
C22	1991	29	29	22	6
	1992	19	4	1	26
	1993	5	21	1	9
	1994	4	23	23	22
	1995	18	12	29	13
	1996	2	13	3	19
	1997	9	21	19	8
	1998	8	14	17	17
	1999	19	14	25	26
	2000	15	16	11	31
	2001	15	28	10	9

C23	2002	28	1	23	17
	2003	25	12	7	19
	2004	24	22	10	4
	2005	12	21	24	7
	2006	13	26	15	2
	2007	3	6	10	3
	2008	8	6	13	2

In this study, the seasonal variations of hmF2 are investigated as a function of cycles to understand the temporal evolution of the virtual height. The seasonal comparative analysis is performed to evaluate the shrinkage of the virtual height.

3. Results and discussion

Figure 1: shows the virtual height profiles for the four seasons from 1976 to 2007.

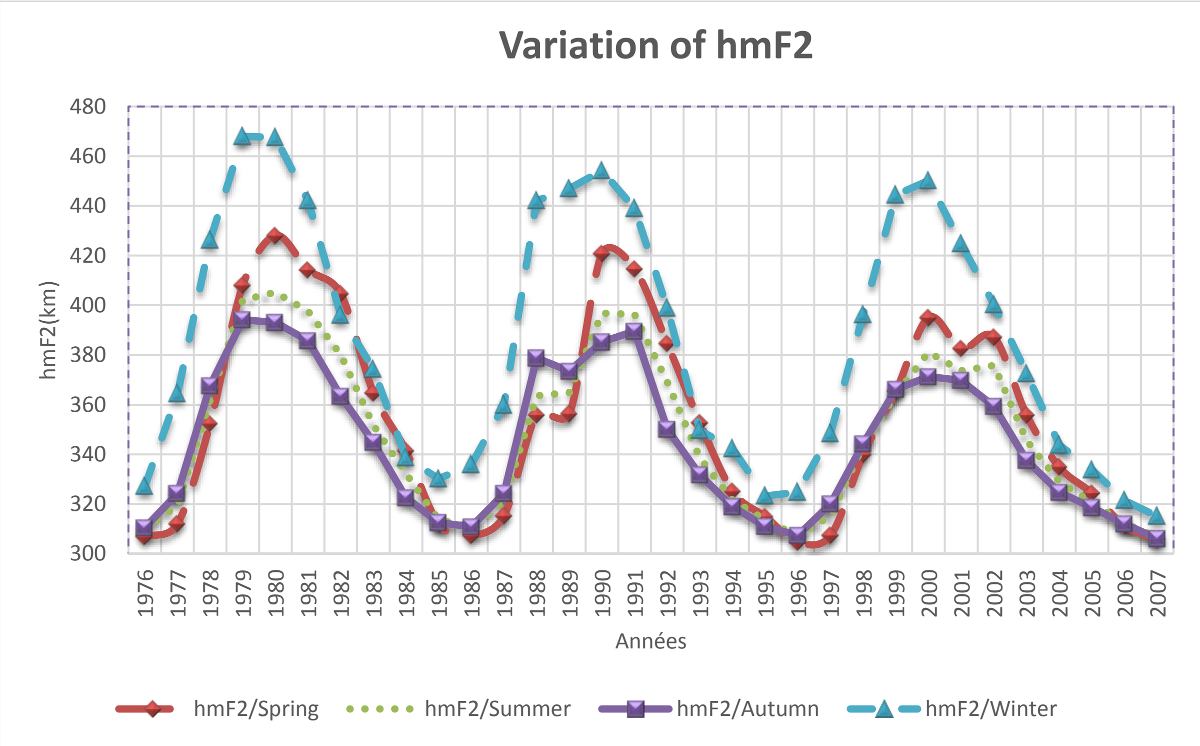
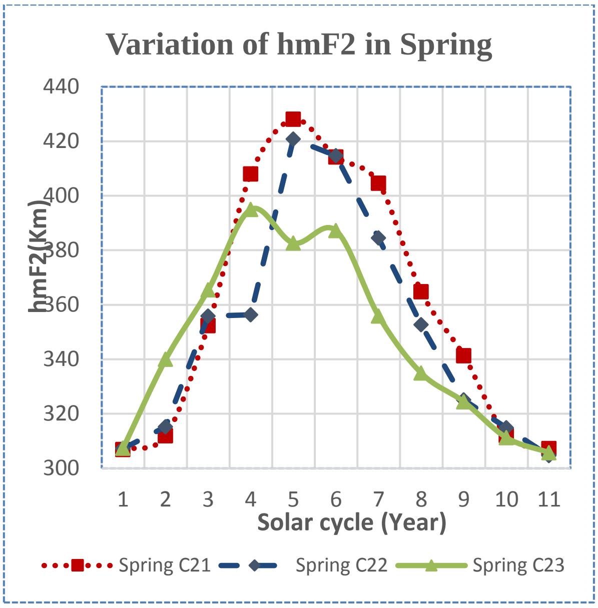


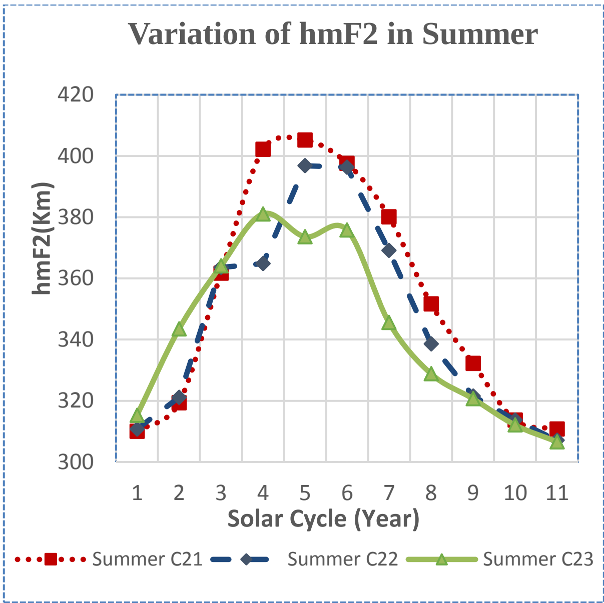
Figure 1: Profiles of hmF2 in Spring, Summer, Autun and Winter from 1976 to 2007

Figure 1 illustrates the seasonal variation of hmF2 over 32 years corresponding to three solar cycles. Figure 2 presents a comparative study of the evolution of the seasonal virtual height as a function of the solar cycle.

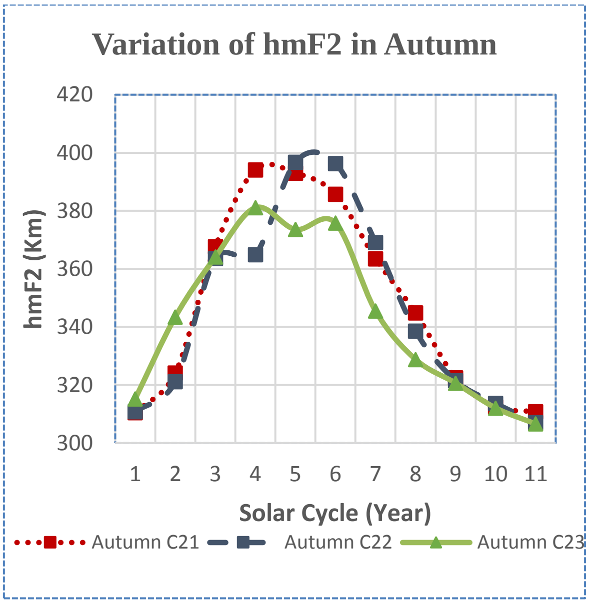
The morphological analysis shows that the profiles of the height of the F2 region of the ionosphere for each of the four seasons during the three solar cycles depend on the time, and therefore on the degree of ionization of the F2 region of the ionosphere. The seasonal profiles (spring, summer, autumn and winter) of the height of the F2 region of the ionosphere show the same variability. All profiles show a virtual maximum height at the maximum of the cycle phase and a trough at the minimum of the phase. It is observed, firstly a profile of the virtual height in winter higher than that of the three seasons (spring, summer and autumn) during the three cycles. Then, the profile of autumn is lower than that of summer and spring except at the phase minimum and at the rising phase during each solar cycle. Finally, the profile of hmF2 in spring is higher than that of summer except at the phase minimum and the rising phase during each solar cycle. The study of the variability of the height of the F2 region of the ionosphere by the IRI model at the Ouagadougou station shows that this parameter depends on the solar cycle phase. The profiles show minimum values at the minimum of solar phase and maximum at the maximum of solar phase. During the ascending and descending phase of the solar cycle respectively, the virtual height profiles each show an increasing and decreasing trend, and therefore related to sunspot activity. This study also highlights reduced virtual height profiles from one cycle to the next. The height profiles of the F2 region in winter obtained over the three solar cycles indicate an overall shrinkage. All four panels in Figure 2 show a morphological analysis identical to that in Figure 1.



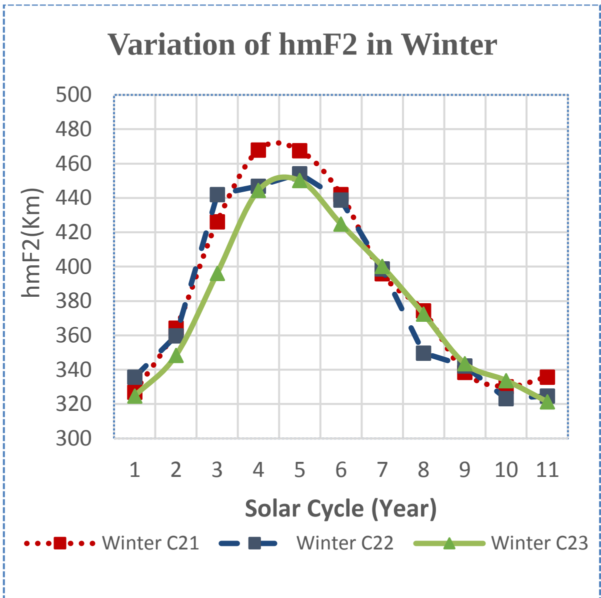
Panel a. Variation of the virtual height during the spring according to the solar cycle.



Panel b. Variation of the virtual height during the summer according to the solar cycle.



Panel c. Variation of the virtual height during the autumn according to the solar cycle.



Panel d. Variation of virtual height during winter as a function of the solar cycle.

Figure 2: Seasonal hmF2 profiles as a function of the solar cycle

Figure 3 shows the profiles of the virtual height drop between winter and spring, between winter and summer, and between winter and autumn from 1976 to 2007.

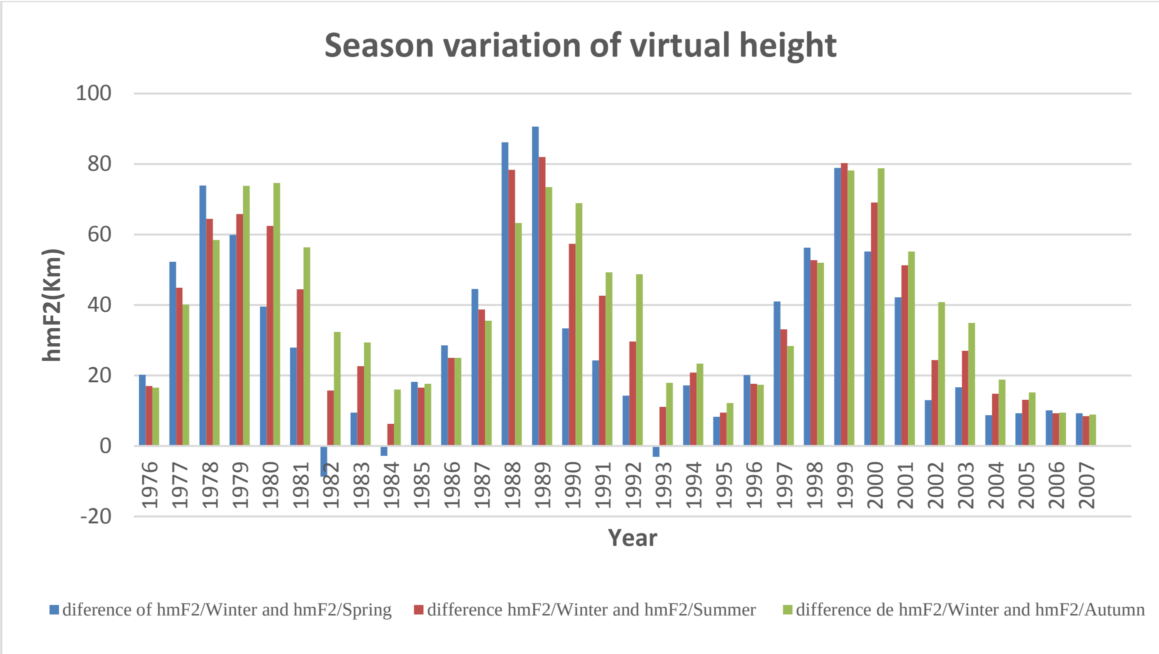


Figure 3: Profiles of the variation of hmF2 between the four seasons from 1976 to 2007

Figure 3, discusses the variation of the virtual height drop between winter and spring, between winter and summer, and between winter and fall during three solar cycles. The observation in Figure 3 shows that the height drop of the F2 region of the ionosphere between winter and the other three seasons is strongly related to the solar cycle activity. All curves show a maximum virtual height drop at the phase maximum and minimum at the phase minimum between winter and the other three seasons. During the ascending phase, the height drop of the F2 region increases and decreases during the descending phase of the solar cycle.

Table 2: Virtual height difference at maximum cycle phase

	Maximum			
	Spring	**Summer**	**Autumn**	**Winter**
CH_{hmF2} (C1-C2)	7,24	8,404	7,784	13,444
CH_{hmF2} (C2-C3)	25,8	15,724	13,936	4,024
CH_{hmF2} (C1-C2)	33,04	24,128	21,72	17,468

Table 2 shows that at the phase maximum of the solar cycle, for each of the four seasons, the virtual height shrinks from one solar cycle to the next. A variation of the order of 4 Km at the minimum of shrinkage of the height of the region F2 of the ionosphere between a maximum of phase and the following one.

4. Conclusion

This study allowed us to evaluate the variability of the height of the F2 region of the ionosphere during periods of very quiet geomagnetic activity during solar cycles 21, 22 and 23 at the Ouagadougou station. The study allowed to plot the seasonal profiles of the virtual height. The IRI model in its 2016 version was used to investigate the ionosphere. This study presented the seasonal profiles of hmF2 as a function of three solar cycles. Examination of the seasonal profiles of hmF2 variability over the solar cycle highlights three characteristic zones strongly related to the solar cycle activity. The study also shows that the IRI model exhibits variability in F2 region height as a function of time, season, phase, and cycle activity. The seasonal profiles of hmF2 show the same pattern. In this work, the winter anomaly is seen during all three cycles. We also observe the semi-annual anomaly. It allowed us to evaluate the shrinkage of the height of the F2 region of the ionosphere between one phase maximum and the next. This drop has a minimum value of 4 Km.

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