Hindawi
International Journal of Geophysics
Volume 2023, Article ID 4405266, 7 pages
https://doi.org/10.1155/2023/4405266

Research Article

New Analysis of the Seasonal Variation of the Critical Frequencies foF2 by a Proposed Formula of the Power of Solar Radiation

Segda Abdoul-kader, Gnabahou Doua Allain, and Gyebre Aristide

Laboratory of Analytical Chemistry of Space and Energy Physics (LACAPSE) UFR-ST, Université Norbert ZONGO, BP 376 Koudougou, Burkina Faso

Correspondence should be addressed to Gnabahou Doua Allain; gnabahou@yahoo.fr

Received 15 May 2023; Revised 19 August 2023; Accepted 14 October 2023; Published 20 November 2023

Academic Editor: Stelios M. Potirakis

The present article is a new analysis of the seasonal variation of the critical frequencies foF2 by establishing a formula as a tool. Thus, from the formula of the power of solar radiation proposed, by its two components, one the power linked to the angles of attack of the solar rays and the other the power imparted to the Earth-Sun distance, we will understand the asymmetries foF2 peaks at the equinoxes and the various winter and semiannual anomalies. By the power component imparted to the contribution of sunspots, we will understand the reversal of the maximum peak during the growth and waning phase of the solar cycle. Finally, by the power component linked to the transport mechanism and the reinforcement by the solar wind of the ionization, we will understand the why of the noninversion of the maximum of the peaks.

1. Introduction

This paper is an approach that takes into account results from in situ measurements of the solar cycle 21 of the Ouagadougou and Dakar stations and the solar cycle 20 of the Djibouti station. The long-term objective is to find a formula for the temporal variation of the solar radiation power $P_S(t)$ and the critical frequencies foF2(t) which on the one hand would reproduce as well as possible the variations of the critical frequencies given by in situ measurements and on the other hand would be able to explain the main characteristics [1, 2]. To do this, this article will first present the curves of the in situ measurements of the stations of Ouagadoudou, Dakar, and Djibouti and the curves resulting from the proposed formula of $P_S(t)$. The second step in the discussion will be to show the process of elaboration of the solar radiation power $P_S(t)$ and by ricochet foF2(t).

2. Data

The data used are from the station of Ouagadougou (latitude 12.5° N, longitude 358.5° E) and Dakar (latitude 14.8° N, longitude 342.6° E) of solar cycle 21 during the period from 1975 to 1984 [3] and the Djibouti station (latitude 11.5° N, longitude 42.8° E) of solar cycle 20 during the period from 1964 to 1974 [3]. If for Djibouti we have considered the solar cycle 20, it is because all the data of the solar cycle 21 of this station are not available.

3. Materials and Methods

The Excel 2010 software is the "hardware" used to build the different curves. The method consists of using the data of the in situ measurements to build the graphs and in a second time to establish the formula of the power of the solar radiation and also to obtain graphs. After that observed profiles, we proceed to comments or explanations to justify the validity of the formula for the variations in the power of solar radiation that we have proposed.

4. Discussion

The proposed formula of $P_S(t)$ would be based on the observation (Figure 1) of variations in the powers of solar radiation $P_\alpha(t)$, $P_d(t)$, and $P_a(t)$ (Figure 1). These different

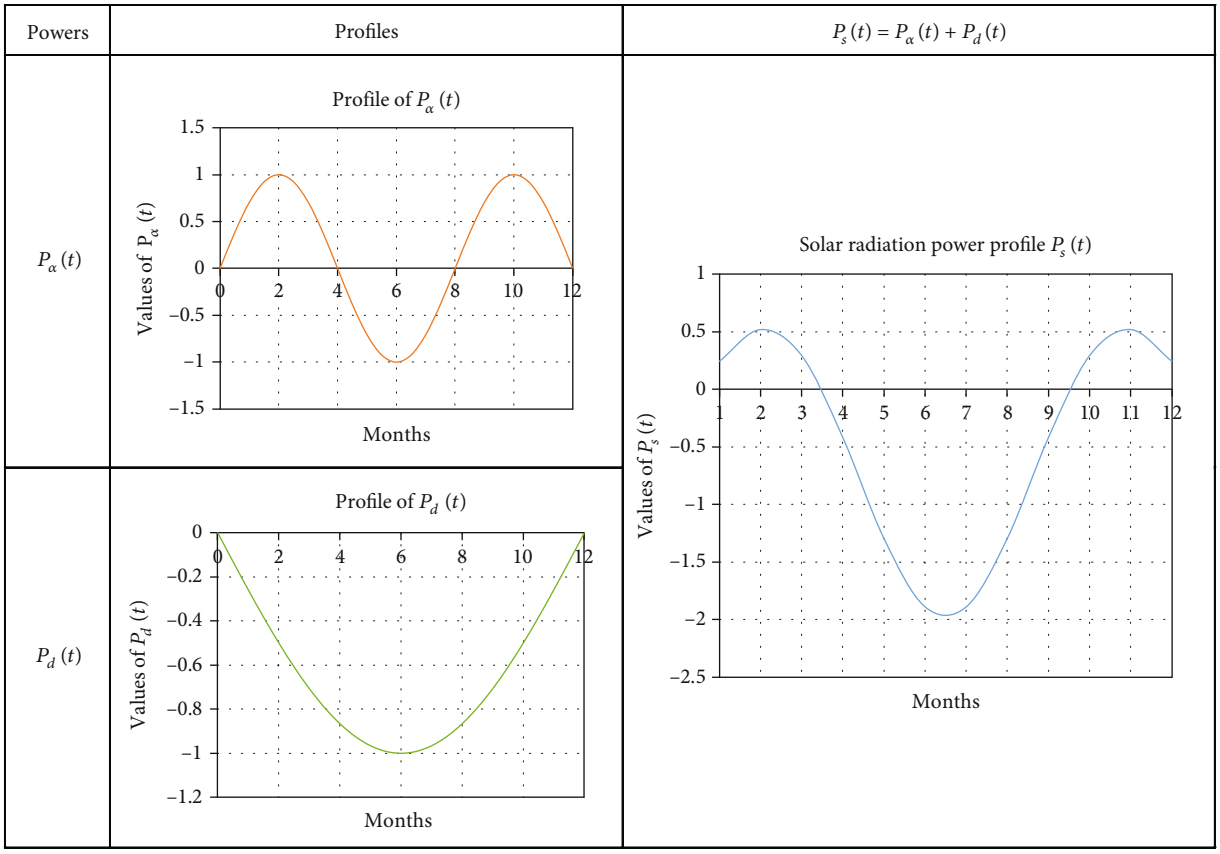

Figure 1: Variation curves of the solar radiation powers.

powers have been used in our previous articles [4, 5] to explain the different characteristics observed in the seasonal variation of foF2. Thus, as a brief reminder in order to be better understood, $P_\alpha(t)$ is the part of the power induced by the variation of the angles, $P_\mathrm{d}(t)$ induced by the variation of the distance of the Earth from the Sun, and finally $P_\mathrm{a}(t)$ the part of the power which represents the contribution of sunspots.

The decor or context being planted or clarified the proposed formula of the power of solar radiation which reproduces the main characteristics given by the curves of the in situ measurements of the monthly average variability of the critical frequencies foF2 or seasonal is

$$P_\mathrm{S}(t) = 2P_{\alpha 0} \sin\left(\frac{2\pi}{3} f_\alpha t\right) \cos\left(\frac{4\pi}{3} f_\alpha t\right), \tag{1}$$

where $P_{\alpha 0}$ and f_α would represent the amplitude and the frequency of the variation of $P_\alpha(t)$, respectively. These parameters represent amplitude and frequency, respectively. The alpha index designates that of the solar power imparted to the angles of incidence on the ionosphere. The formula proposed for this purpose which reproduces this variation observed during the year is of the following form:

$$P_\alpha(t) = P_{\alpha 0} \sin\left(\frac{2\pi}{T_\alpha} t\right) \text{ or } P_\alpha(t) = P_{\alpha 0} \sin\left(2\pi . f_\alpha t\right), \tag{2}$$

where T_α is the period of $P_\alpha(t)$ which would be eight (08) months because an alternation is counted as half a period. If we add to this power of the solar radiation $P_\alpha(t)$, the power of the solar radiation related to the distance Earth-Sun present only one negative alternation is thus of the form:

$$P_\mathrm{d}(t) = -P_{\mathrm{d}0} \sin\left(\frac{2\pi}{T_\mathrm{d}} t\right) \text{ or } P_\mathrm{d}(t) = P_{\mathrm{d}0} \cos\left(\frac{2\pi}{T_\mathrm{d}} t + \frac{\pi}{2}\right). \tag{3}$$

By considering $P_{\alpha 0}$ is equal to $P_{\mathrm{d}0}$, we arrive at the formula for $P_\mathrm{S}(t)$ given by equation (1) whose graphic representation is given in Figure 1. For this purpose of simulation representation, $P_{\alpha 0}$ is taken as 1 because any other value assigned to them will not modify the pace or the profile of the variation $P_\mathrm{S}(t)$. We will obtain an enlarged or reduced form of $P_\mathrm{S}(t)$ just like an image that we can enlarge or reduce. This established power $P_\mathrm{S}(t)$ would oscillate around an almost constant average value $P_\mathrm{S}(\varphi, \Phi)$ linked to the geographical position of the station such as its latitude φ and its longitude Φ. Thus, the profile of solar radiation linked to latitude φ at longitude Φ of the station and at time t is given by the following formula:

$$P_\mathrm{S}(\varphi, \Phi, t) = P_\mathrm{S}(\varphi, \Phi) + P_\mathrm{S}(t). \tag{4}$$

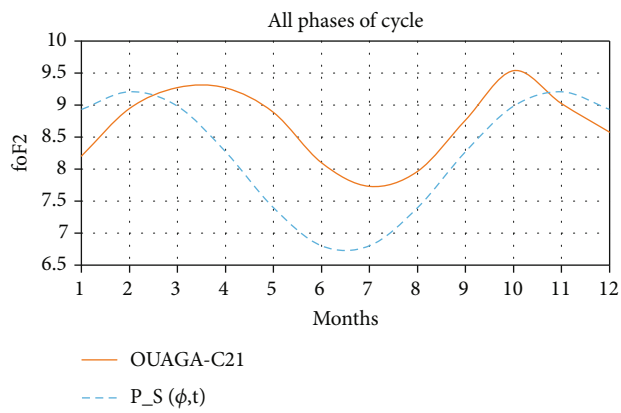

Figure 2: Profile of the in situ measurements of the Ouagadougou station and profile of the solar radiation power.

It is thus the effect of this power $P_S(\varphi, \Phi)$ linked to the station if it is not zero that allows on the one hand to keep the profile given by $P_S(t)$ and on the other hand to no longer observe the negative values that would be given by the only representation of $P_S(t)$ that would rather mean that $P_S(t)$ would oscillate around an average value $P_S(\varphi, \Phi) = 0$. For example, if we consider the Ouagadougou station and then oscillate $P_S(t)$ around this average value given by the set of values, we obtain the following graph (Figure 2).

Thus, we see a near agreement in the variation of the two curves. Indeed, while the peaks reflecting the equinoctial asymmetry are observed for the in situ measurements in the months of March and October of 9.27 MHz and 9.53 MHz, respectively, those given by the simulation of $P_S(\varphi, \Phi, t)$ are observed in the months of February and November of 9.21 and 9.22, respectively. Also, the lowest minimum is observed in the month of July both for in situ measurements of critical frequencies at 7.73 MHz and that given by the power of solar radiation at 6.80. The concordances observed with the Ouagadougou station are also observed if we consider the Dakar or Djibouti stations as shown in Figures 3(a) and 3(d). Thus, if the proposed formula reproduces the main characteristics as possible, would it also be able to reproduce the effects of sunspots on the variation of critical frequencies? Or, taking into account the very good correlation cycle of the sunspots and variation of the critical frequencies [6], one observes the strong tendency to the inversion of the maximum of peak during the phases of growth and decrease of the cycle of the sunspots.

Indeed, this problem was solved by starting from the fact that the sunspots would bring a supplement or an addition of power $P_a(t)$ to that $P_S(t)$ (1.1) which we named for this purpose clean power $P_0(t)$. Thus, the temporal variation of the power of the solar radiation is given by the following expression:

$$P_S(t) = P_0(t) + P_a(t). \tag{5}$$

Also, to mark for the same year the increasing contribution by the sunspots from January to December during the phase of growth of the solar cycle of a solar power supplement, the proposed formula whose pace is given in Figure 4:

$$P_a(t) = P_{a0} \sin\left(\frac{2\pi}{T_a} t\right). \tag{6}$$

And also, to mark for the same year the decreasing contribution by the sunspots from January to December during the phase of decrease of the solar cycle of a solar power supplement, the proposed formula whose pace is given to Figure 4:

$$P_a(t) = P_{a0} \cos\left(\frac{2\pi}{T_a} t\right), \tag{7}$$

where P_{a0} and T_a are counted as half an alternation, respectively, the amplitude and period of the additional power. The expected effects follow. Indeed and for example, if we consider the station of Dakar during the phase of growth of the minimum to the maximum of phase we obtain by also making oscillate $P_s(t)$ around the average value considered as $P_S(\varphi, \Phi)$ given by the set of values, we obtain the following graph (Figure 5).

We also notice a quasiconcordant reproduction of the curve of variation of critical frequencies of the in situ measurements of the Dakar station to that given by the simulation of $P_S(\varphi, \Phi, t)$. The equinox peaks are observed at the same period in February and October but at even higher amplitudes of 9.68 MHz and 10.27 MHz, respectively, for the in situ measurements and 9.59 and 9.94, respectively, for those given by the simulation of $P_S(\varphi, \Phi, t)$. However, the lowest minimum is observed in July for the in situ measurements of critical frequencies at 7.36 MHz while that given by the simulation of the power of solar radiation at 7.31 in June. The concordances observed with the station of Dakar are also observed if we consider the stations of Ouagadougou or Djibouti as shown in Figures 3(b) and 3(e). For the decrease relating to the periods of the maximum of phase until the end of the phase of decrease, one notices by taking, for example, the station of Ouagadougou on the one hand a quasiconcordance from the point of view

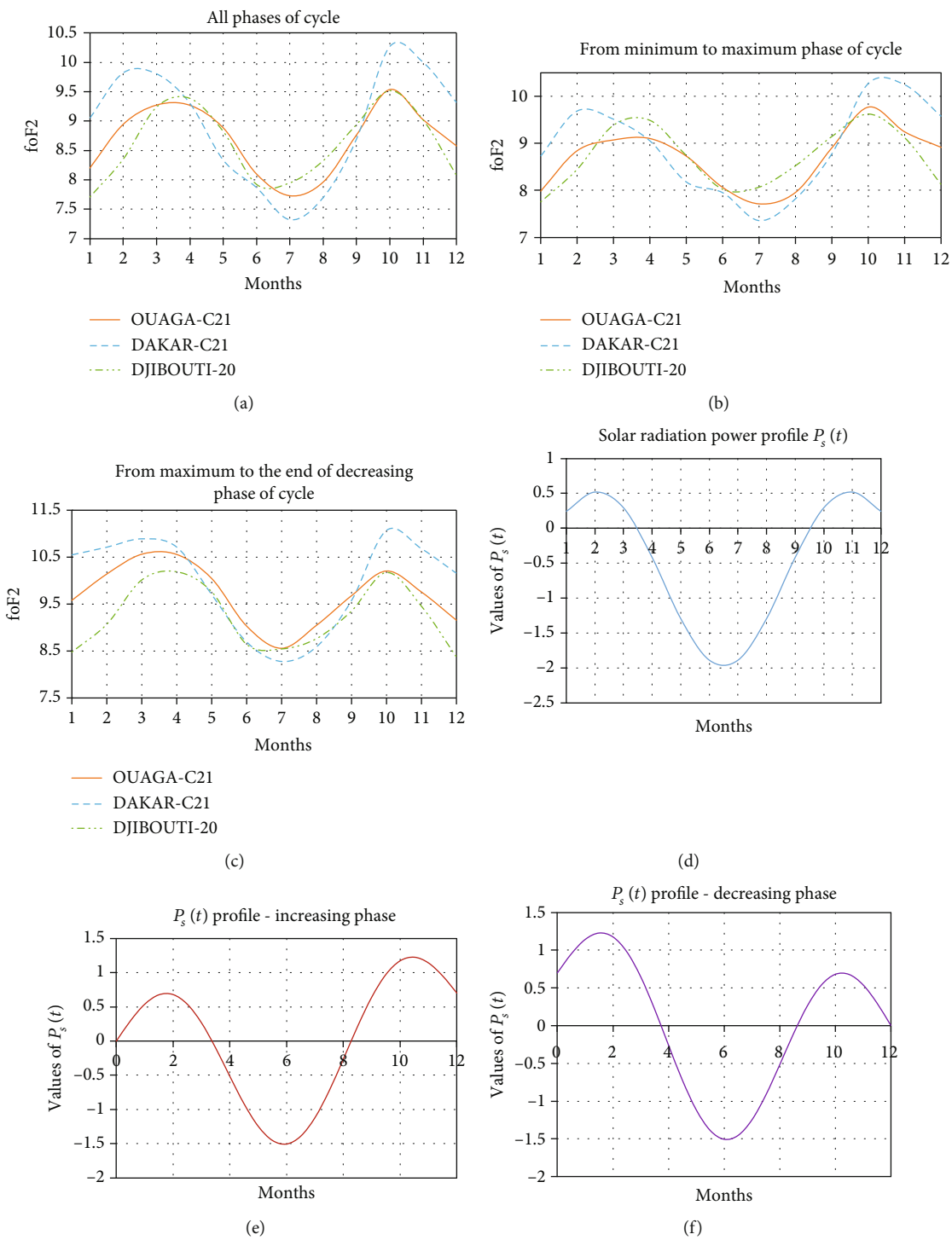

Figure 3: Graphical comparison of in situ measurements and solar radiation profile.

profile with the power of the solar radiation and on the other hand the effects of sunspots during this phase of decay as the following graph (Figure 6).

The amplitudes are large, and we note an inversion of the period of the peak maximum. Indeed, during the phase of growth of the minimum to the maximum of phase, the peaks of the equinoxes were observed in April at 9.10 MHz and in October at 9.77 MHz, whereas during the phase of decline, the peaks of the equinoxes are recorded in March at 10.56 MHz and 10.20 MHz in October. It is the same with the simulation of the solar radiation power where we note an inversion of the period of the maximum of peak. The month of February recorded the highest peak during the decay phase while it was recorded in November during the growth

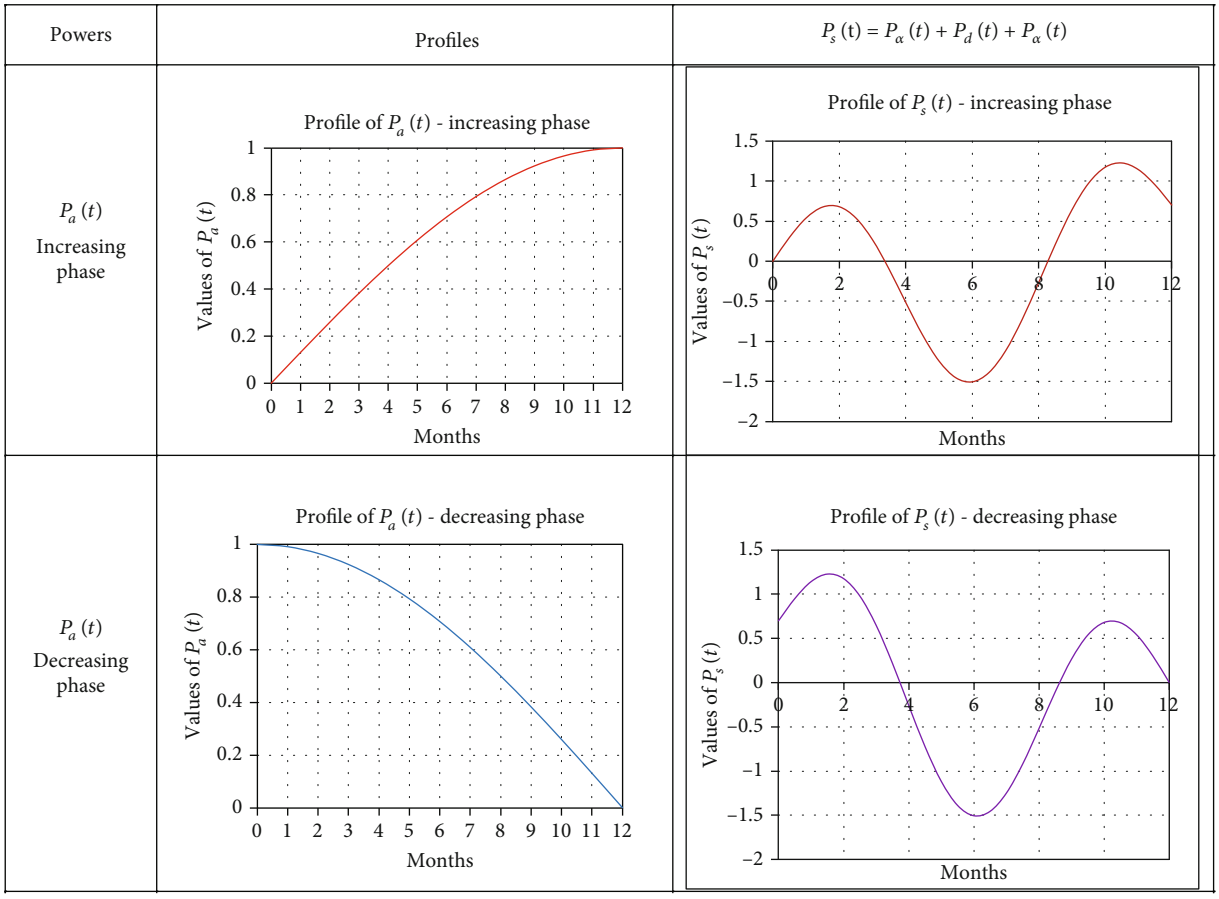

Figure 4: Effect of sunspots.

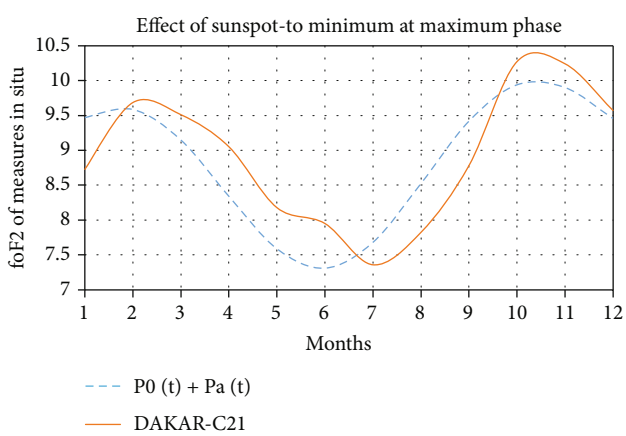

Figure 5: Profile of the in situ measurements of the Dakar station and profile of the solar radiation power.

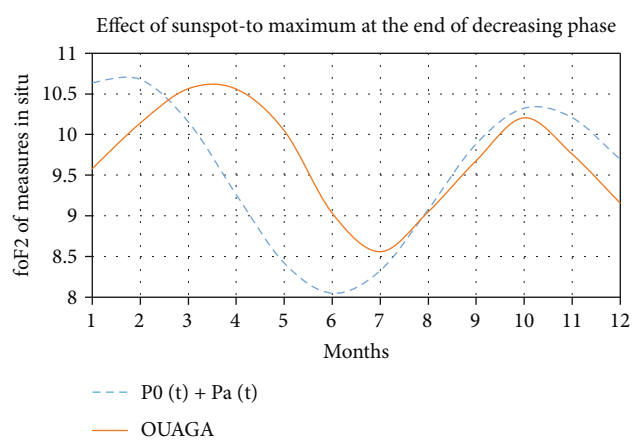

Figure 6: Profile of the in situ measurements of the Ouagadougou station and profile of the solar radiation power during the decay phase.

phase. However, we consider the Djibouti station, where $P_s(t)$ has also been oscillated around the average value considered as $P_S(\varphi, \Phi)$ given by all the values in the figures of the following graph (Figure 7).

We note to this effect a quasiconcordance even if it is not very pronounced given the fact that the peaks observed during the equinoxes for the in situ measurements of the station of Djibouti are almost identical to 10.19 MHz in April against 10.17 in October while it is not the case with the simulation of the power of solar radiation or the difference is much more noticeable. It could be observed for the Dakar station (Figures 3(c) and 3(f)) that even if there was no inversion of the period of the maximum peak, the gap between the two peaks is strongly reduced showing this strong propensity to peak inversion. It is therefore appropriate to recognize that

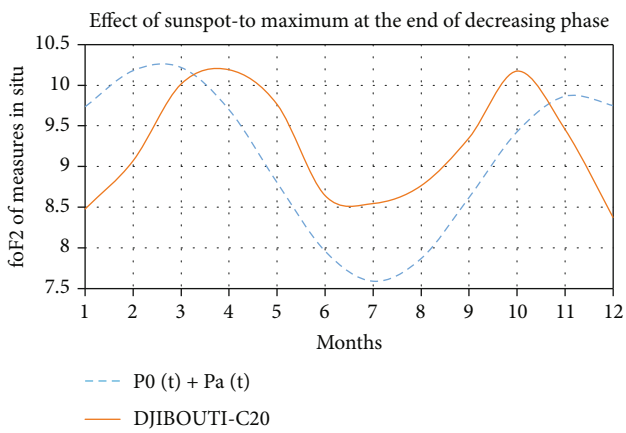

Figure 7: Profile of the in situ measurements of the Djibouti station and profile of the solar radiation power.

the inversions announced by the sunspots of the maximum peak in favor of the autumn peak during the growth phase and in favor of the spring peak during the waning phase of the solar cycle are not always effective.

If so, how can we justify the noninversion of the peaks observed both at the Dakar station and at the Djibouti station during the phase of the decrease in the solar cycle?

This noninversion observed despite the contribution by the sunspots of a supplement of power in the solar radiation could be attributed to multiple combinations of factors. In particular the strong preponderance in this period of the transport to another location of a part of the ions produced electrons, and even neutrals. Everything then happens as if the power of solar radiation $P_s(t)$ mainly responsible for production was amputated or reduced by part of its power which we will name for this purpose $P_{tp}(t)$ linked to this phenomenon. The formula for the power of solar radiation $P_s(t)$ becomes

$$P_S(t) = P_0(t) + P_a(t) - P_{tp}(t). \tag{8}$$

We could also justify this noninversion to a reinforcement at the peak of the autumn equinox by the solar wind or solar flares of ionization by an additional power $P_{vt}(t)$ linked to the winds or flares which prevails on $P_{tp}(t)$; hence, $(P_{vt}(t) - P_{tp}(t) > 0)$. This was not the case at the peak of the vernal equinox, where the power $P_{tp}(t)$ prevails over the power $P_{vt}(t)$; hence, $(P_{vt}(t) - P_{tp}(t) < 0)$. The formula for the power of solar radiation $P_s(t)$ becomes

$$P_S(t) = P_0(t) + P_a(t) + P_{vt}(t) - P_{tp}(t). \tag{9}$$

Thus, justify why at this phase of decline the inversion was not effective as expected. The same analysis could be carried out in the growth phase. In such a case, the power $P_{vt}(t)$ prevails over $P_{tp}(t)$ at the peak of the spring equinox and $P_{tp}(t)$ prevails over the power $P_{vt}(t)$ at the peak of the autumn equinox.

Finally, the formula proposed on the power of solar radiation strongly responds to it both in terms of the profile, therefore of the main characteristics, and the effects of sunspots, the transport mechanism, and the reinforcement by solar winds. The proposed formula is therefore a powerful tool for analyzing. Taking into account good solar irradiant correlation and variation of the critical frequencies foF2 [6], we deduce that the formula of the temporal variation of the critical frequencies is as follows:

$$\text{foF2}(t) = 2f_{\alpha 0} \sin\left(\frac{2\pi}{3} f_\alpha t\right) \cos\left(\frac{4\pi}{3} f_\alpha t\right) + f_a. \tag{10}$$

5. Conclusion

At the end of this study, the formula proposed on the power of solar radiation inducing the variation of critical frequencies, to really say simple, is adapted. This formula is not only mathematical because it takes into account physical realities such as the Earth-Sun distance, the effects of sunspots, the transport mechanism, and the winds and solar flares and geographical position. Finally, the formula could strongly contribute to bringing a rational explanation both to the problem of the diurnal profiles of the critical frequencies foF2 and to that of the geomagnetic anomaly or equatorial anomaly.

Data Availability

The data of the in situ measurements were made available to us by the National School of Telecommunications of Brittany.

Disclosure

The research was carried out within the framework of our scientific productions such as articles.

Conflicts of Interest

We declare that there is no conflict of interest regarding the publication of this article.

References

[1] H. Huang and K. Cheng, "Solar cycle variations of the equatorial ionospheric anomaly in total electron content in the Asian region," *Journal of Geophysical Research*, vol. 101, no. A11, pp. 24513–24520, 1996.

[2] H. Rishbeth, I. C. F. Muller-Wodarg, L. Zou et al., "Annual and semiannual variations in the ionospheric F2- layer. II. Physical discussion," *Annales Geophysicae*, vol. 18, no. 8, pp. 945–956, 2000.

[3] A. Gnabahou, *Long-Term Variability and Variation of the Ionosphere in the African Equatorial Region, [Ph.D. thesis]*, University of Ouagadogou, Ouagadougou Burkina Faso, 2014.

[4] Segda, "Contribution to the Resolution of the Semi-Annual Anomaly Anomaly Observed in the Intertropical Zone Using the fof2 Critical Frequencies Extracted during the Shock Activities of Shocks of Solar Cycles 21 and 22 at the Station of Ouagadougou and by Iri-2012, Annales, July 2022," Université Joseph Ki-ZERBO, 2022.

[5] G. Segda and Kaboré, "Contribution to the explanation of the semi-annual anomaly observed in the intertropical zone using the critical frequencies fof2 extracted during the sunspot cycles 20, 21 and 22 at the ouagadougou station," *Internationnal Journal Of Advanced Research*, vol. 11, no. 2, pp. 412–417, 2023.

[6] J. P. Legrand and P. A. Simon, "Solar and geomagnetic activity: a review for geophysicists. Part 1. The contributions to geomagnetic activity of shock waves and of solar wind," *Annals of Geophysics*, vol. 7, pp. 565–578, 1989.