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RESEARCH ARTICLE

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

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Abstract

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The objective of this paper is to bring a mathematical resolution to the semi-annual anomaly of the critical frequencies foF2 which presents itself as a sinusoid.Thus, we posit two postulates about the average and monthly power of the solar radiation $P_s(t)$which would induce the semi-annualanomaly.This power result of the power caused by the angle of attack of the sun's rays$P_\alpha(t)$ and that imparted to the Earth-Solar distance $P_d(t)$variable due to the fact that the orbit of the Earth is elliptical. Thus the monthly variations of the critical frequencies foF2 can be explained in these terms:If the critical frequencies foF2 are increasing from the solstices to the equinox peaks it is thus respectively because the power $P_s(t)$is increasing on the sole effect of the power $P_\alpha(t)$with respect to from the winter solstice to the peak of the spring equinox and on the combined effects of the two powers $P_\alpha(t)$and $P_d(t)$which are all increasing for what from the summer solstice to the peak of the autumn equinox. If the critical frequencies foF2 are decreasing from the peaks of the equinoxes to the solstices it is thus respectively because the power $P_s(t)$is decreasing on the combined effects of $P_\alpha(t)$and $P_d(t)$which are all decreasing with respect to the spring equinox to summer solstice peak and on the sole effect of the power $P_\alpha(t)$ with respect to the fall equinox to winter solstice peak.Finally the winter anomaly, the semi-annual anomaly and the equinoctial asymmetry would be explained according to the in-phase or out-of-phase outcome of the two powers $P_\alpha(t)$and $P_d(t)$at peaks or solstices.

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Introduction:-

The ionosphere is a thin electrified layer of the atmosphere stratified itself during the day into several other sub-layers E, F1, F2 and D, each with particular properties. Among these layers, the F2 layer is particularly important in telecommunications.By its capacity according to its electronic density to reflect the waves, it makes it possible to cross certain immediate obstacles and also for a given minimal frequency or threshold called critical frequency foF2 it can let itself cross for satellites and allows a communication of longer distance.How do these critical foF2 frequencies vary, especially monthly or seasonally? What are the tangible elements to take into account in order to

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pose the problem mathematically? These are some of the questions whose answers will allow us to better understand this issue. To do so, the study will be articulated on two axes.The first will consist from the critical frequencies foF2 extracted during the solar cycles 20, 21 and 22 to build the curves of monthly variability of the critical frequencies foF2, the second to the discussion including an observation, an analysis and of the interpretation which will be the base of the resolution.

Data

The data are the Measures in situ of the critical frequencies foF2 from the Ouagadougou station. They are extracted during the solar cycles 20 (from 1966 to 1976), 21 (from 1976 to 1986) and 22 (from 1986 to 1996)

Materials:-

The material used is the Excel-2010 software. It has allowed us on the one hand to proceed through its pivot table to the monthly compilation of the critical frequencies foF2 and thus to obtain average values.

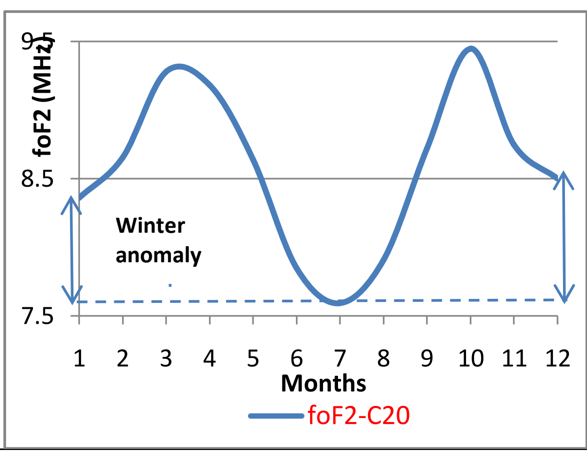
Methodology:-

The methodology of analysis consisted from the observation of the constancy of the sinusoidal shape of the semi-annual anomaly(Huang and al, 1996) to deduce the variation of the average and monthly power of the solar radiation $P_s(t)$received by a point at the external surface of the layer F2 of the ionosphere and which would induce the semi-annual anomaly. And this for considering the good correlation (Legrand and al, 1989)existing of the Solar irradiance and the variation of the critical frequencies foF2. Thus the average and monthly power of solar radiation $P_s(t)$is increasing if its 1st derivative with respect to monthly time is positive otherwise if $\frac{dP_s(t)}{dt} > 0$and decreasing if this one is negative otherwise if $\frac{dP_s(t)}{dt} < 0$. The variation of the average and monthly power of the solar radiation imparted to the distance Earth-Sun $P_d(t)$for its part is part of two principles that are: The more the Earth moves away from the Sun the more the power $P_d(t)$decreases and we deduce then that it is decreasing otherwise $\frac{dP_d(t)}{dt} < 0$. Also the closer the Earth gets to the Sun the more the power $P_d(t)$increases and we then infer that it is increasing otherwise $\frac{dP_d(t)}{dt} > 0$. Finally, knowing the variation of the average and monthly power of solar radiation $P_s(t)$and that imparted to the Earth-Sun distance $P_d(t)$we then deduce the variation of the power occasioned by the angle of attack α of the sun's rays $P_\alpha(t)$. Thus, the variation of $P_\alpha(t)$should justify the variation of $P_s(t)$.From this fact with regard to the variation of $P_d(t)$we deduce that for a given period where the two powers $P_\alpha(t)$and $P_d(t)$are out of phase, i.e. one increasing and the other decreasing the variation in absolute value of $P_\alpha(t)$always prevails on that in absolute value of the power $P_d(t)$that is to say then $\left|\frac{dP_\alpha(t)}{dt}\right| > \left|\frac{dP_d(t)}{dt}\right|$.

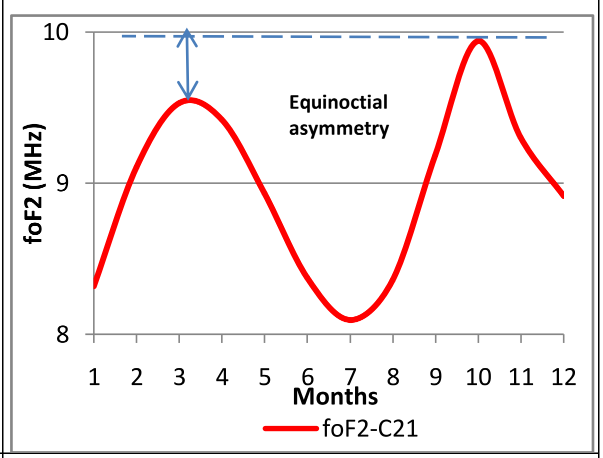
Results:-

Figure 1:- Curves of monthly variations of critical frequencies foF2 (solar cycles 20, 21 and 22).

a



b



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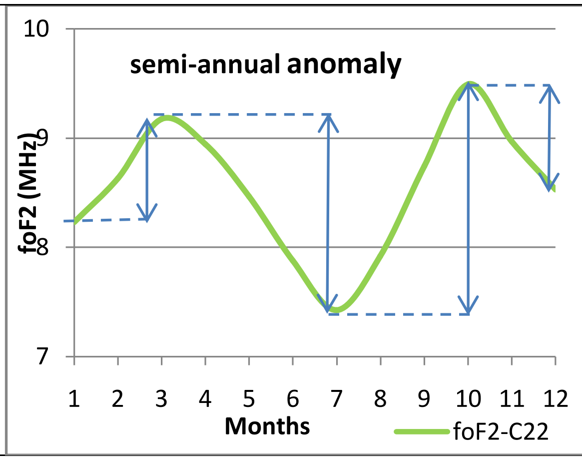

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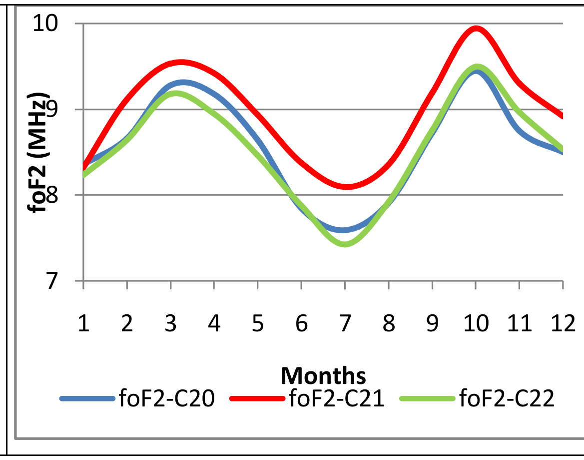

Discussion:-

The various observed graphs present curves of monthly variability of the critical frequencies foF2 of the cycles of the solar spots 20, 21 and 22These curves are derived from in situ measurements at the Ouagadougou station (12.5 N, 358.5E) and are almost in phase with a lowest minimum observed in summer, particularly in July, of 7.593 MHz for solar cycle 20, 8.095 MHz for solar cycle 21 and 7.425 MHz for solar cycle 22 (figure 1) and respectively panel a, b and c. This lowest minimum separates on both sides two peaks of different amplitudes.

The first of the peaks observed in spring in March for all curves is less pronounced than the second peak observed for all curves in fall in October. It is for the month of March of 9.278 MHz, 9.529 MHz and 9.177 MHz respectively for cycles 20, 21 and 22. On the other hand for the most pronounced peak, it is observed in October with amplitudes of 9.446 MHz, 9.941 MHz and 9.492 MHz respectively for cycles 20, 21 and 22.

This irregularity in amplitude of critical frequencies foF2 throughout the year is called semi-annual anomaly in reference to the maximum values observed at equinoxes and minimum at solstices. For example for cycle 22, figure 1 panel c we have : (winter solstice we have in December 8.531 MHz or in January 8.232 MHz while spring equinox in March we have 9.177 MHz) or (summer solstice in July we have 7.425 MHz while fall equinox we have 9.492 MHz).

It can also be called winter or seasonal anomaly in reference to the values of critical frequencies foF2 higher in winter than those observed in summer. For example for cycle 20, figure 1 panel a we have: (winter solstice we have in December 8.500 MHz or in January 8.359 MHz while at summer solstice in July we have 7.593 MHz).

Finally we can call it equinoctial asymmetry curves in reference to the difference in amplitude of the spring and autumn peaks. For example for cycle 21, figure 1 panel b we have: (spring peak in March we have 9.529 MHz while the fall peak in October we have 9.941 MHz).

This irregularity in amplitude of the critical frequencies foF2 shows that the profile of the various curves of monthly variability would be rather strongly dependent on its period or season of extraction. The month of October would correspond to a maximum ionization of the year of the F2 layer of the ionosphere, the month of July to its minimum ionization. The other months have an ionization between these two extremes with that of April or March even higher than the other remaining months because corresponding to the second peak of amplitude of the highest critical frequencies foF2. Thus the following interpretation follows as a proposal for resolution or mathematical explanation of the semi-annual anomaly:

Ouagadougou being located in the intertropical zone the duration of illumination varies little during the year. The observed irregularity of the ionization throughout the year would thus be impartial to the energy received thus to the average and monthly power of Solar radiation $P_s(t)$received by a point of the F2 layer of the ionosphere. This radiation power would itself depend on the angle of attack αat the ionosphere of the Solar rays and also for the same angle the Earth-Sun distance. We can therefore postulate a priori with regard to the constancy of the sinusoidal shape of the semi-annual anomaly and tangible elements such as on the one hand the orbit of the Earth which is an ellipse where the Sun occupies one of the foci and on the other hand the North-South obliquity of the axis of rotation inclined by 23°26' with respect to the normal to the plane of the ecliptic that :

The average and monthly power of the Sun's radiation received by a point at the outer surface of the F2 layer of the ionosphere and which would induce the semi-annual anomaly is the resultant of the power $P_\alpha(t)$caused by the angles of attack α of the Sun's rays on the ionosphere and that $P_d(t)$induced at the Earth-Sun distance. From this we can posit that

$$P_S(t) = P_\alpha(t) + P_d(t)) \quad \textbf{(eq.1)}$$

with a view to finding an explanation for this semi-annual anomaly of critical frequencies foF2.

Thus from the winter solstice on December 22 to the summer solstice on June 21 or from the closest position to the Sun called perihelion on January 4 to the farthest position called aphelion on July 4 the Earth moves away from the Sun and the angle of attack α undergoes a variation. It would move closer to the vertical from the winter solstice to the spring equinox to reach its maximum approach in March or April. The radiated power $P_\alpha(t)$would increase greatly compared to the decrease of that $P_d(t)$induced by the distance of the Earth from the Sun so that $\left|\frac{dP_\alpha(t)}{dt}\right| > \left|\frac{dP_d(t)}{dt}\right|$|to allow us to have also a variation of the average and monthly increasing power ie. to say $\frac{dP_s(t)}{dt} > 0$. We can then note that (Table 1, line 2):

$$\frac{dP_S(t)}{dt} = \frac{dP_\alpha(t)}{dt} + \frac{dP_d(t)}{dt} > 0 \quad \textbf{(eq.2)}$$

The ionization during this period grows only on the sole effect of $P_\alpha(t)$to reach the first peak in April or March or depending on the periods in winter or spring.

From March to July corresponding to the aphelion at the farthest position of the Earth from the Sun the angle of attack α would deviate more and more from the vertical and the power $P_\alpha(t)$decreases in the same way always that of $P_d(t)$to cause the decrease of $P_s(t)$.The relation $\left|\frac{dP_\alpha(t)}{dt}\right| > \left|\frac{dP_d(t)}{dt}\right|$is no longer necessary in this case to obtain the decay of$P_s(t)$ or $\frac{dP_s(t)}{dt} < 0$because the two powers $P_\alpha(t)$and $P_d(t)$are in phase and all decreasing. Thus $\frac{dP_\alpha(t)}{dt} < 0$and $\frac{dP_d(t)}{dt} < 0$then we can note that (Table 1, line 3):

$$\frac{dP_S(t)}{dt} = \frac{dP_\alpha(t)}{dt} + \frac{dP_d(t)}{dt} < 0 \quad \textbf{(eq.3)}$$

Ionization during this period decreases to reach its lowest minimum of the year in July or at the summer solstice on June 21 due to the two combined and decreasing effects of the two powers $P_\alpha(t)$and $P_d(t)$.

From summer solstice to winter solstice or from aphelion to perihelion the Earth gets closer and closer to the Sun. The power$P_d(t)$imparted to the Earth-Sun distance during this period is always increasing or $\frac{dP_d(t)}{dt} > 0$.This is not the case for $P_\alpha(t)$or depending on the period it should be increasing or decreasing in order to justify the growth or not of the average and monthly power of $P_s(t)$.

Thus from July to the autumnal equinox in particular in October the angle of attack α would approach the vertical again to reach its maximum approach in October. The power $P_\alpha(t)$is increasing as well as that $P_d(t)$to obtain an average and monthly power$P_s(t)$increasing. In such a case the relation$\left|\frac{dP_\alpha(t)}{dt}\right| > \left|\frac{dP_d(t)}{dt}\right|$is no longer needed to obtain the growth of$P_s(t)$or $\frac{dP_s(t)}{dt} > 0$because the two powers $P_\alpha(t)$and $P_d(t)$are in phase and all increasing. We can then note that(Table 1, line 4):

$$\frac{dP_S(t)}{dt} = \frac{dP_\alpha(t)}{dt} + \frac{dP_d(t)}{dt} > 0 \quad \textbf{(éq.4)}$$

The two combined and increasing effects of $P_\alpha(t)$and $P_d(t)$induce more and more increasing ionization to reach the maximum ionization peak of the year in October.

From October through the winter solstice in December to perihelion in January the Earth continues its approach to the Sun and the angle of attack α would again deviate from the vertical. The radiated power $P_\alpha(t)$ would decrease greatly compared to the growth of that $P_d(t)$ induced by the Earth's approach to the Sun such that $\left|\frac{dP_\alpha(t)}{dt}\right| > \left|\frac{dP_d(t)}{dt}\right|$ to allow us to have also a variation of the average and monthly radiated power decreasing $P_s(t)$ that is to say $\frac{dP_s(t)}{dt} < 0$.We can then note that (Table 1, line 5):

$$\frac{dP_s(t)}{dt} = \frac{dP_\alpha(t)}{dt} + \frac{dP_d(t)}{dt} < 0 \textbf{(eq.5)}.$$

This explains the observed decrease of ionization from October to December.

If the autumn peak in October is the more pronounced than the spring peak thus justifying the equinoctial asymmetry and concomitantly its greater stability it is because the two powers $P_\alpha(t)$and $P_d(t)$lead to this peak in phases. They are all increasing. This is not the case for the second peak observed in spring in April or March because $P_\alpha(t)$and $P_d(t)$end up there in phase shifts. $P_\alpha(t)$is increasing while $P_d(t)$is decreasing.

If therefore the minimum observed at the winter solstice has a higher amplitude than that in summer July or at the summer solstice thus justifying the winter anomaly it is therefore because $P_\alpha(t)$and $P_d(t)$are out of phase. $P_\alpha(t)$ends up in December in decay and $P_d(t)$ ends up there in growth.On the other hand, at the summer solstice $P_\alpha(t)$and $P_d(t)$end up there in phases. $P_\alpha(t)$and$P_d(t)$are all decreasing.

Maximum values of critical frequencies foF2 at equinoxes and minimum values of critical frequencies foF2 at solstices justifying the semi-annual anomaly would be explained by the only effect of the power $P_\alpha(t)$. At the solstices the power $P_\alpha(t)$ always decreases while at the equinoxes the power $P_\alpha(t)$ always increases.

Conclusion:-

At the end of this article, the mathematical milestones set starting from the constancy of the sinusoidal shape and tangible elements such as the elliptical orbit of the Earth around the Sun and the North-South obliquity of the rotation axis have allowed us a mathematical and effective resolution of the semi-annual anomaly, or winter anomaly. The average and monthly power $P_s(t)$of Solar radiation received by a point at the outer surface of the F2 layer and which would induce the semi-annual or winter anomaly or even the equinoctial asymmetry is of the form $P_s(t) = P_\alpha(t)+ P_d(t)$.The power $P_\alpha(t)$varying according to the angle of attack of the Sun's rays on the F2 layer and that $P_d(t)$varying because of the elliptical orbit of the Earth. Starting from that a table of variation of these two powers allowed to justify the fundamental characteristics of the anomaly. With the variation table thus established, our next articles will allow us to proceed to the mathematical formalization. Monthly expressions of the variation of the two powers $P_\alpha(t)$and $P_d(t)$ will be established there and consequently that of the average and monthly power$P_s(t)$. Once that $P_s(t)$established one will deduce from it by ricochet and that for held of the good correlation Solar irradiance and variation of the critical frequencies foF2 the expression of the monthly variation.

Table 1:- Summary table of the variations in the powers $P_\alpha(t)$, $P_d(t)$ of $P_s(t)$responsible for the semi-annual anomaly.

Seasonal variation	$P_\alpha(t)$	$P_d(t)$	$P_\alpha(t)$et$P_d(t)$	$\frac{dP_s(t)}{dt}$	Ionization in	Peak or Minimum
Winter Solstice to Spring Equinox (March)	$\frac{dP_\alpha(t)}{dt} > 0$	$\frac{dP_d(t)}{dt} < 0$	Dephasingor out of phase	$\frac{dP_s(t)}{dt}$has the meaning 1st derivative of the power $P_s(t)$with respect to monthly time	Increasing	**March peak** Less pronounced than October because $P_\alpha(t)$and$P_d(t)$are out of phase
	$\left\|\frac{dP_\alpha(t)}{dt}\right\| > \left\|\frac{dP_d(t)}{dt}\right\|$			$\frac{dP_s(t)}{dt} = \frac{dP_\alpha(t)}{dt} + \frac{dP_d(t)}{dt} > 0$		

Spring equinox (March) to Summer Solstice (July)	$\frac{dP_\alpha(t)}{dt} < 0$	$\frac{dP_d(t)}{dt} < 0$	Phase	$\frac{dP_s(t)}{dt} = \frac{dP_\alpha(t)}{dt} + \frac{dP_d(t)}{dt} < 0$	Decreasing	**Minimum of July** Lower minimum because$P_\alpha(t)$and$P_d(t)$are in phase
Summer Solstice (July) to the equinox autumn (October)	$\frac{dP_\alpha(t)}{dt} > 0$	$\frac{dP_d(t)}{dt} > 0$	Phase	$\frac{dP_s(t)}{dt} = \frac{dP_\alpha(t)}{dt} + \frac{dP_d(t)}{dt} > 0$	Increasing	**October peak** The most pronounced of the year because $P_\alpha(t)$and$P_d(t)$are in phase
the equinox autumn (October) to Winter Solstice (December)	$\frac{dP_\alpha(t)}{dt} < 0$ $\left\|\frac{dP_\alpha(t)}{dt}\right\| > \left\|\frac{dP_d(t)}{dt}\right\|$	$\frac{dP_d(t)}{dt} > 0$	Dephasingor out of phase	$\frac{dP_s(t)}{dt} = \frac{dP_\alpha(t)}{dt} + \frac{dP_d(t)}{dt} < 0$	Decreasing	**December minimum** More elevated than that of July because$P_\alpha(t)$and$P_d(t)$are out of phase

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