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ΑΣΤΡΟΝΟΜΙΑ.— **«On a Relation between the Indices of Solar Activity in the Photosphere and the Corona»** *, *by John Xanthakis* **.

Abstract

In the first part of this paper a new index of solar activity in the photosphere is introduced i.e. the areas index I_α defined with the help of the relation $I_\alpha = \frac{1}{2}[\sqrt{A} + \sqrt{f}]$, where A and f are the total areas of the sunspots and faculae respectively corrected for foreshortening. The variation of this index is then compared to the variation of the corresponding mean annual values of the intensity of the coronal line 5303 Å observed in the Pic-du-Midi Observatory (1947 - 1964) on one hand, and the variation of the semi-annual values of the intensity of the solar radio-emission in the frequency range 1000 MHz $\leqslant f <$ 10000 MHz (1955 - 1964) on the other hand.

In the second part a relation of the form:

$$S_\odot = S_o + K\,(1 + \sqrt{10^{-2} I_F})\, I_\alpha$$

is proposed, where $S_\odot$ represents the intensity of the solar radio-emission

* ΙΩΑΝΝΟΥ ΞΑΝΘΑΚΗ, **Σχέσεις μεταξὺ τῶν δεικτῶν τῆς ἡλιακῆς δραστηριότητος εἰς τὴν φωτοσφαῖραν καὶ τὸ ἡλιακὸν στέμμα.**

** Prof. Dr. John Xanthakis, Research Center for Astronomy and Applied Mathematics, Academy of Athens.

in the frequency range 1000 MHz $\leqslant f <$ 10000 MHz, I_F is the index of solar flares and K is a constant.

In the third part a relation of the form:

$$I_{5303} = I_o + K\,(1 + \sqrt{N_{PF}})\,I_\alpha$$

is proposed, where I_{5303} is the mean intensity of the coronal line 5303 Å in each quarter of the years 1954 - 1964, N_{PF} is the number of proton flares in each quarter of the years 1957 - 1964 and K is a constant.

Finally the quarterly values of the number N_{PCA} of the PCA's have been compared to the corresponding values of the number N_{PF} of proton flares and a relalion of the form:

$$N_{PCA} = K\,\frac{I_{5303}}{I_\alpha}\,N_{PF}$$

has been found. Parameter K is equal to 0.9 for all the quarters of the years considered here, except for the fourth quarter of the years 1956 - 60 for which the values of K show a variation of the form $K = 1 - 0.75 \sin \frac{\pi}{6} t$.

1. Introduction

The main phenomena characterizing the variation of solar activity within each sunspot cycle are the sunspots and faculae. For this reason the principal indices of solar activity used so far are the relative sunspot numbers R, as well as the areas of the sunspots A and the faculae f which are expressed in millionths of the visible solar hemisphere (10^{-6} ⊙). It has already been shown (Xanthakis, 1967) that the variation of the annual values of the indices R, A and f within each sunspot cycle and from cycle to cycle can be analytically expressed as a function of the time of rise T_R and certain periodic terms $G_{1,2}$ of relatively small amplitude. These relations, the physical explanation of which has not yet been found, are of the form:

$$[Z] = [Z_m] \cos^2 \frac{\pi}{2\Omega_{1,2}} t + G_{1,2} \qquad (1)$$

where $\Omega_1 = T_R$, $\Omega_2 = 11 - T_R$ for the years preceding and following the sunspot maximum respectively. Parameter t assumes the value t = 0 for the year of maximum and t = 1, 2, 3, ... for the first, second, third, ... year preceding or following the year of maximum.

In this equation [Z] represents the mean annual value of the indi-

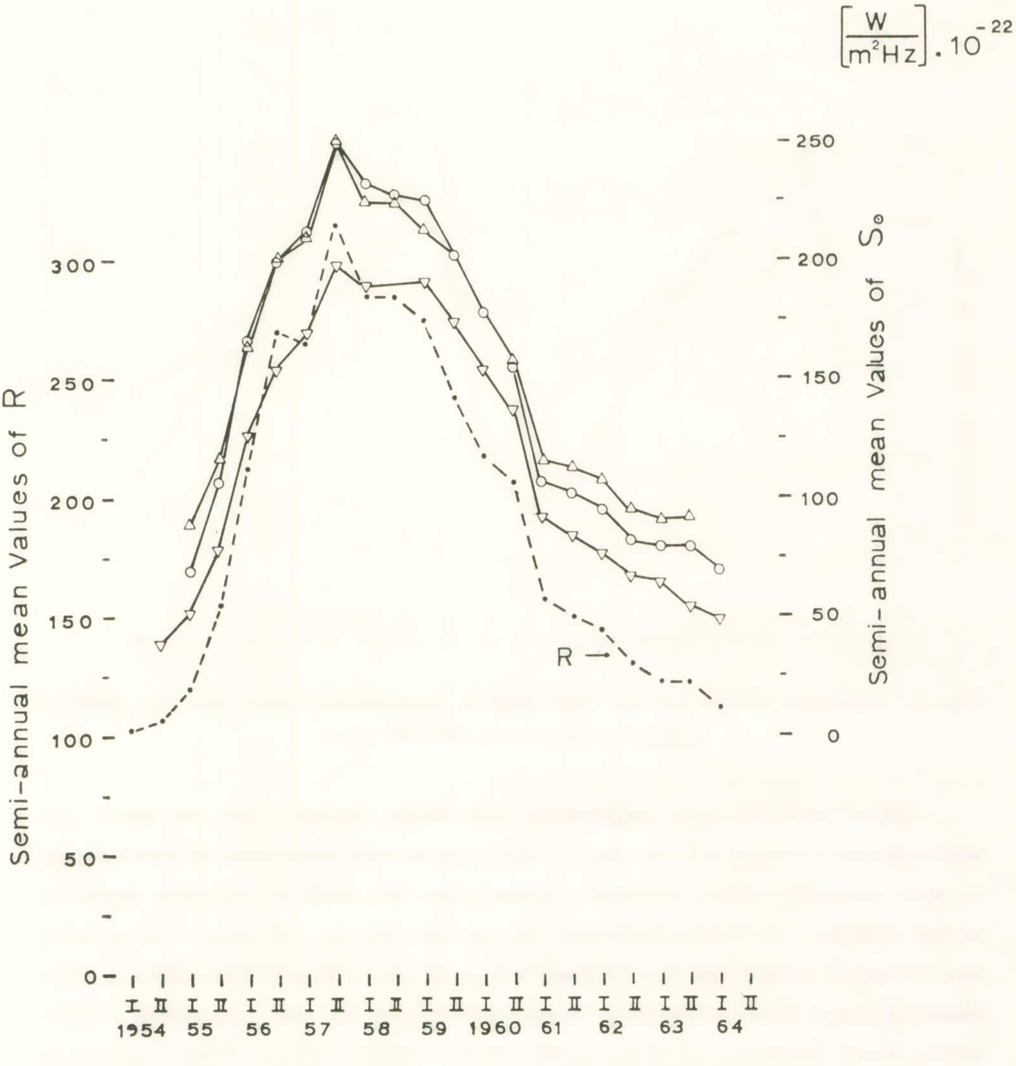

Fig. 1. Radio-emission of the Sun in the frequencies 1500 (▽▽▽) 2800 (ooo) and 3750 MHz (△△△) and the relative sunspot numbers R (dashed line). (O. Hachenberg, 1965).

ces R, A and f, while $[Z_m]$ represents the value of [Z] corresponding to the year of maximum solar activity $(t = 0)$. It should be noted that $[Z_m]$ is a linear function of the time of rise T_R in the case of the areas of the faculae, while in the case of the relative sunspot numbers R and the sunspot areas A the corresponding relation is of the second order.

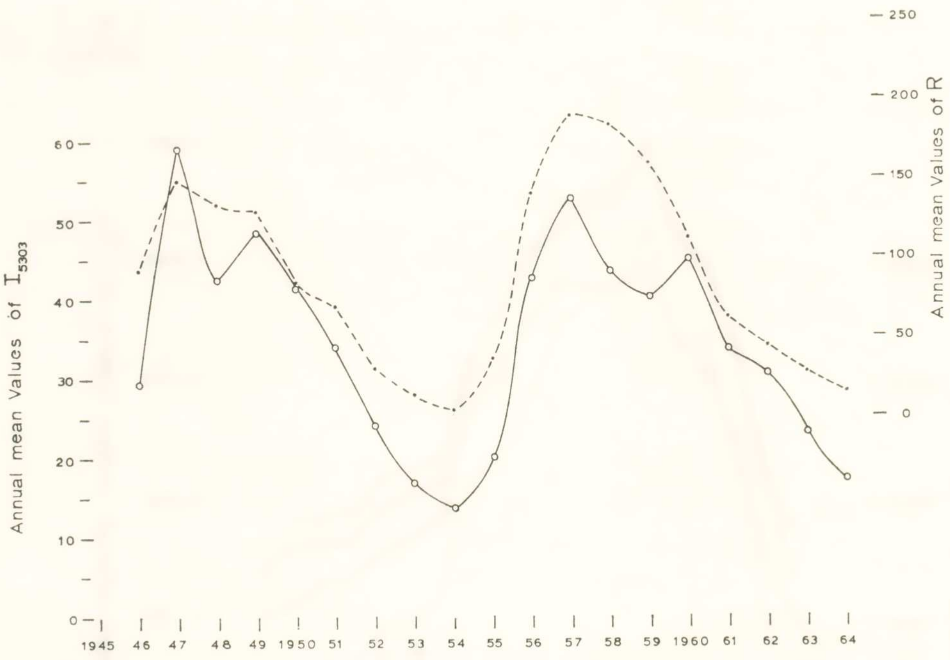

Fig. 2. Intensity of the coronal line 5303 Å (continuous line) and the relative sunspot numbers R (dashed line).

Solar activity also influences the solar corona and we have the well-known changes of the shape, brightness and structure of the corona, as well as some other related phenomena. As indices of solar activity in the corona the radio emission $S_\odot$ of the sun in different frequencies can be used, as well as the intensity I_{5303} of the coronal line 5303 Å. The observational data concerning these two indices $S_\odot$ and I_{5303} cover a relatively short interval of time equal to 2 - 3 solar cycles. Therefore, it is not possible to find analytical relations between $S_\odot$ or I_{5303} and the time of rise T_R analogous to the relation found in the case of the «photospheric» indices R, A and f (relation 1). The study of these indices $S_\odot$ and I_{5303}

carried out so far, has been, therefore, limited to a comparison of their variation to the variation of the corresponding values of the relative sunspot numbers R.

Thus, from Figure 1 we see that the variation of the semi-annual means of the radiation flux $S_{\odot}$ in the frequencies 3750 MHz ($\lambda = 8$ cm) 2800 MHz ($\lambda = 10.7$) and 1500 MHz ($\lambda = 20$ cm) observed at the Nagoya, Ottawa and the Heinrich Hertz Institut (Bonn) respectively, during the XIXth solar cycle (1954 - 1964), is very similar to the variation of the corresponding values of the relative sunspot numbers R (Hachenberg, 1965).

The intensity I_{5303} of the coronal line 5303 Å observed in Pic-du-Midi during the XVIIIth (1947 - 1954) and the XIXth solar cycle (1954 - 1964) also presents a variation similar to that of the relative sunspot numbers R (Figure 2). In this case, however, the correlation is sensibly lower than in the case of Figure 1. In fact, as noticed by Gentili di Giuseppe M. et al (1966): «Le nombre de Wolf a atteint en 1957 une valeur maximale plus élevée qu'en 1947, mais l'intensité maximale de la raie verte n'a pas suivi cette augmentation; elle a même été légèrement plus faible en 1957 qu' en 1947». Moreover, the curve of the annual mean values of the intensity I_{5303} in the XIXth solar cycle presents two maxima in 1957 and 1960 which are not present in the case of the curve of R. This fact is, as we shall see, of particular importance.

2. The Areas Index I_α

It is generally accepted today that the different phenomena in the solar photosphere as well as in the chromosphere and the corona that characterize the 11-year cycle of solar activity are direct or indirect results of the magnetic fields present in the solar active regions. These active regions are observed especially in the vicinity of the sunspots and faculae. It is, therefore, preferable for the comparative study of the long-time variation of the coronal indices $S_{\odot}$ and I_{5303} of solar activity to use, instead of the relative sunspot numbers R, the areas A and f of the sunspots and faculae respectively. It is true that the sunspot areas A are related in a rough approximation to the relative sunspot numbers R with the relation $A \sim 16R$, and, therefore, one could expect that any relation valid for the relative sunspot numbers will, as a rule, be valid for the sunspot areas as well.

The same is not true, however, in the case of the areas of faculae, the variation of which within each sunspot cycle and from cycle to cycle is different from that of the sunspot areas and the relative sunspot numbers (Xanthakis, 1967). In our opinion, the index that could express better one principal characteristic of an active region is the composite index of the areas I_α defined by the relation:

$$I_\alpha = \frac{1}{2}\left[\sqrt{A} + \sqrt{f}\right] \qquad (2)$$

where A and f are respectively the areas of sunspots and of faculae during the time interval considered. This index can be expressed as a function of the time of rise T_R with the help of the relation: (Xanthakis, in preparation)

$$I_\alpha = C\,(7 - T_R)\cos^{1/2}\frac{\pi}{2\Omega_{1,2}}\,t + G_{1,2} \qquad (3)$$

where t, $\Omega_{1,2}$ and $G_{1,2}$ have the same significance as in relation (1) and C is a constant.

3. The Solar Radio Emission $S_\odot$

A comparison of the variation of the areas index I_α with the variation of the index $S_\odot$ (semi-annual means) and I_{5303} (annual means) is given in Figures 3 and 4.

From these Figures we see that the indices $S_\odot$ and I_{5303} are more closely correlated with the areas index I_α than with the relative sunspot numbers R; this is especially valid for I_{5303} (Figure 4) for which the values of the correlation coefficients are respectively:

$$\text{cor coef. } I_{5303,\,R} = +0.87$$

$$\text{cor coef. } I_{5303,\,I\alpha} = +0.90$$

Moreover, and this is more significant, the ratio:

$$\frac{S_\odot - I_\alpha}{I_\alpha} = W$$

is very closely correlated with the flare index I_F defined by the relation, (Sawyer C., 1966)

$$I_F = \frac{7600}{T^*} \sum A_{\square}^2 \qquad (4)$$

where $A_{\square}$ is the apparent (measured or projected) area in square degrees,

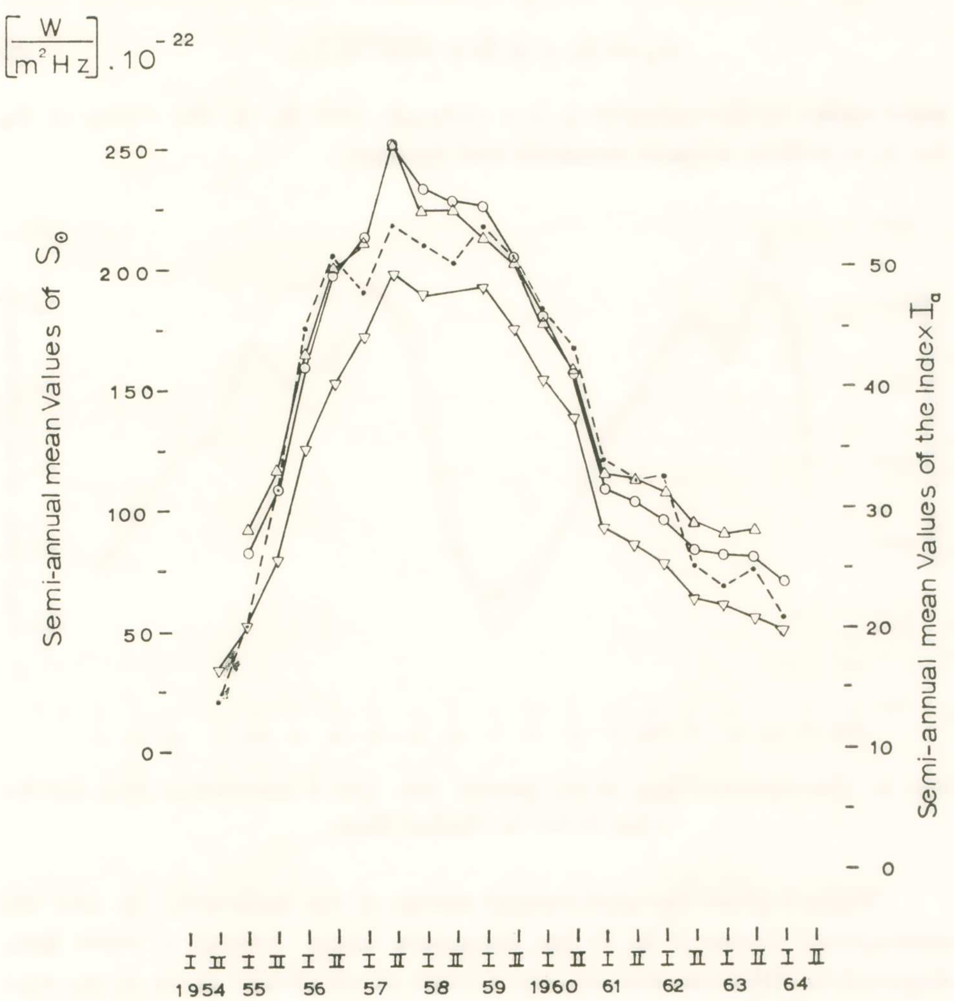

Fig. 3. Radio-emission of the Sun in the frequencies 1500 (▽▽▽) 2800 (ooo) and 3750 MHz (△△△) and the areas index I_α (dashed line).

given for each flare in the N.B.S. flare lists (numbers 17, 29 and 33 of this series). In fact as we see from Figure 5 the semi-annual means of the quantity $N = \frac{S_\odot - I_\alpha}{I_\alpha}$ vary in a highly similar way with the semi-annual values of the flare index $I_F = \frac{1}{6} \sum_1^6 I_F$ during the period 1956 I to 1962 I.

This fact shows that during this period a linear relation of the form:

$$S_\odot = S_o + K \left[1 + \sqrt{10^{-2} I_F}\right] I_\alpha \qquad (5)$$

must exist; in this relation K is a constant and S_o is the value of $S_\odot$ for $I_\alpha = 0$ (Sun without sunspots and faculae).

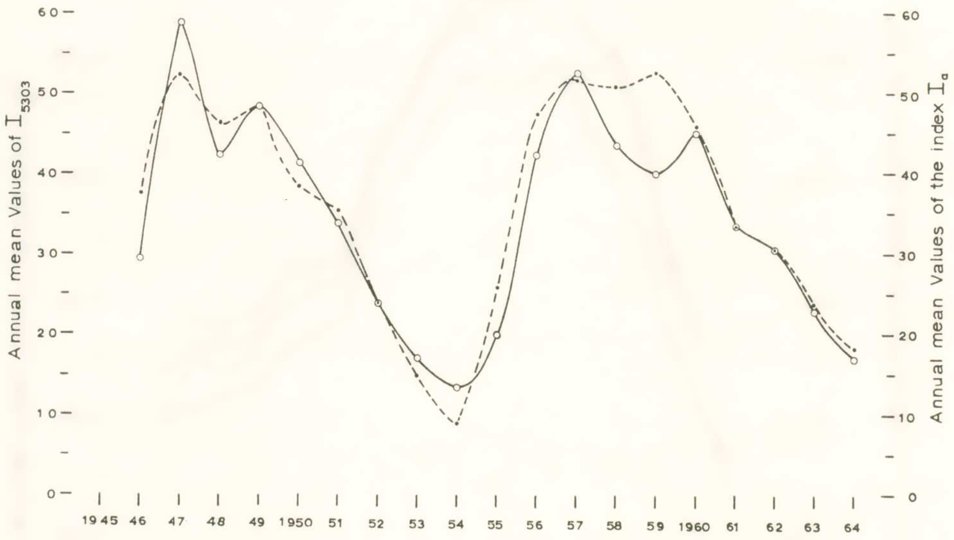

Fig. 4. The intensity I_{5303} of the coronal line 5303 Å (continuous line) and the areas index I_α (dashed line).

Table I gives the semi-annual means of the indices I_α, I_F and the semi-annual means of $S_\odot$ in the frequency range $1000 \leqslant f < 10000$ MHz observed in different stations, the initials of which are given in the first line of the Table. The values of the areas index I_α given in this table have been computed with the help of relation (2) and the values of the areas of sunspots and faculae published by the Greenwich Observatory (values corrected for foreshortening); the values of the flare index I_F have been taken from the table «The Daily Flare Index I_f for July 1955-

December 1961» given by Sawyer (1966). Finally, the semi-annual means of $S_{\odot}$ have been kindly put at our disposal by Prof. Dr. O. Hachenberg (Max-Planck-Institut für Radioastronomie, Bonn).

Computations based on the numerical data of Table I show that coefficient K assumes constant value, while the quantity S_o does not remain

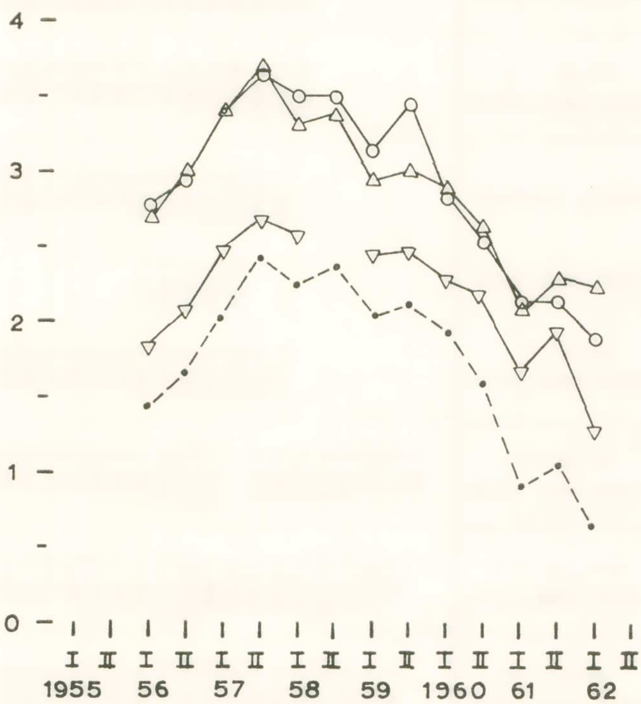

Fig. 5. Variation of the quantity $\sqrt{10^{-2} I_f}$ (dashed line) and of the ratio $\frac{S_{\odot} - I_{\alpha}}{I_{\alpha}}$ for the frequencies 1500 (▽▽▽), 2800 (ooo) and 3750 MHz (△△△).

constant during the different phases of the solar cycle but shows oscillations around a mean value i. e.:

$$S_o = C + A\,p(t)$$

where C and A are constants and p(t) is a periodic term. From Table II, which gives the values of K, C, A and p(t) we see that the amplitude A and the period of these oscillations depend on the frequency of the solar radio-emission considered.

TABLE I

Semi-Annual Mean Values of the Areas Index I_α, the Flare Index I_F and the Radiation Flux of the Sun for Different Frequencies.

Date		I_α	I_F	NAG 3750 MHz $\lambda = 8$ cm	OTT 2800 MHz $\lambda = 10.7$ cm	HHI 1500 MHz $\lambda = 20$ cm	NAG 2000 MHz $\lambda = 15$ cm	HHI 2000 MHz	Adopted Values	NAG 1000 MHz $\lambda = 30$ cm	NAG 9400 MHz $\lambda = 3.2$ cm	HHI 9400 MHz	Adopted Values
1954	II	14.0	(0)			39.1							
5	I	19.8	(11)	91.9	83.3	53.6							
	II	30.9	(48)	117.7	108.1	80.0							
6	I	44.4	210	164.5	167.5	126.2							
	II	51.1	267	(201.6)	(200.4)	153.7							
7	I	48.0	400 *	209.2	211.9	169.0				116.8	322.4	338.2	330.6
	II	53.7	600 *	250.1	250.6	198.4	186.7		186.7	132.0	346.9	345.4	346.9
8	I	51.9	504	223.7	232.8	189.4	167.9		167.9	126.3	336.7	339.4	339.4
	II	50.7	554	223.2	228.5		173.0	173.2	173.0	125.6	328.2	334.4	328.2
9	I	54.1	426	(213.2)	224.4	(188.4)	169.8	167.7	167.7	116.8	334.3	332.1	332.1
	II	50.0	446	(203.3)	(203.5)	(174.5)	145.9	152.7	152.7	109.0	313.2	308.3	313.2
1960	I	46.5	375	(178.2)	(177.9)	153.6	116.0	120.3	120.3	96.9	303.2	309.6	309.6
	II	43.3	253	158.5	154.4	138.4	108.3	105.7	105.7	84.1	302.6	294.4	294.4
1	I	34.2	84	115.2	107.4	92.1	75.1		75.1	56.4	264.1	264.4	264.1
	II	32.1	100	112.6	102.3	85.0	78.1		78.1	54.8	258.1	246.7	258.1
2	I	32.9	(43)	107.8	96.6	77.7	70.7		70.7	49.6	254.4	253.4	254.4
	II	25.0	(35)	94.3	83.2	67.7	58.7		58.7	41.3	245.1	240.4	245.1
3	I	23.7	(33)	91.8	81.0	65.9	56.3		56.3	40.2	244.4	240.3	242.3
	II	24.8	(16)	92.8	80.8	56.9	55.0		55.0	38.9	243.6	239.9	239.9
4	I	16.2	(43)		72.0	49.6							

* Smoothed Values by $\frac{a + 2b + c}{4}$.

T A B L E II

Values of the Parameters K, C, A and p(t) for Different Frequencies.

Frequency	K	C	A	p(t)	t = 0
HHI and NAG 9400 MHz	0.7	216.10^{-22} MHz	6	$\sin\frac{\pi}{8}(t+1)-\cos\pi t$	1957 I
» 3750 »	1.1	44 »	12	$\sin\frac{\pi}{8}(t+1)$	1954 I
OTT 2800 »	1.1	41 »	12	$\sin\frac{\pi}{8}(t-1)$	1954 I
HHI and NAG 2000 »	0.8	27 »	12	$\sin\frac{\pi}{8}\left(t-\frac{1}{2}\right)+\frac{1}{2}\sin\frac{\pi}{2}\left(t+\frac{1}{2}\right)$	1957 I
HHI 1500 »	0.95	27.5 »	3	$\sin\frac{\pi}{2}\left(t-\frac{1}{2}\right)$	1954 I
NAG 1000 »	0.6	17 »	9	$\sin^2\frac{\pi}{3}t$	1956 I

Figure 6 represents the observed values S_o (open circles) for each frequency ; they lie very close to the curve $S_o = C + Ap(t)$ (dashed line) with the help of the values of S_o and K given in Table II we can compute from relation (5) the values of the flare index I_F corresponding to

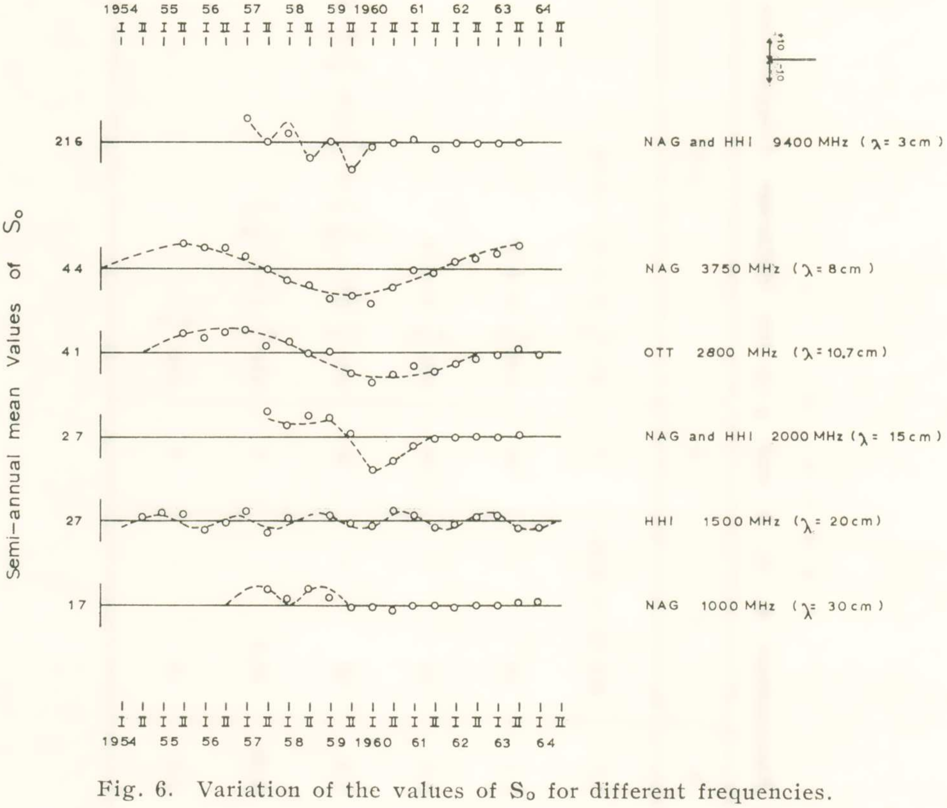

Fig. 6. Variation of the values of S_o for different frequencies.

each of the frequencies considered as function of the index I_α and the radiation flux $F_\odot$ given by the observations. The numerical results, together with the corresponding dispersion, are given in Table III. Figure 7 represents the values of I_F given by the observations (Table I, continuous line) and the ones (dashed line) computed with the help of relation :

$$\sqrt{I_F} = 10 \left[\frac{S_\odot - S_o}{K I_\alpha} - 1 \right] \tag{6}$$

Finaly, Figures 8 and 9 represent the observed values $S_\odot^{ob}$ (Table III)

T A B L E III

Values of the Flare Index I_F Computed with the Help of Relation (5).

Date		NAG 3750 MHz λ = 8 cm	OTT 2800 MHz λ = 10.7 cm	HHI 1500 MHz λ = 20 cm	NAG and HHI 2000 MHz λ = 15 cm	NAG 1000 MHz λ = 30 cm	NAG and HHI 9400 MHz λ = 3.2 cm	Mean	I_F (Observed)	Remarks
1954	II			0					[0]	Adopted Value
5	I			8					[8]	» »
	II	65	52	72				63 ± 8	48	
6	I	176	186	193				185 ± 7	210	
	II	273	252	243				256 ± 12	267	
7	I	416	410	414		413	440	419 ± 12	410*	Smoothed by $\frac{a+2b+c}{4}$
	II	618	577	571	630	660	605	610 ± 30	600*	» » »
8	I	496	508	538	486	515	449	499 ± 27	504	
	II	559	559		585	536	545	557 ± 14	554	
9	I	412	466	445	423	428	408	430 ± 17	426	
	II	458	445	458	458	438	450	451 ± 16	446	
1960	I	338	358	381	368	347	353	358 ± 14	375	
	II	251	267	269	259	250	253	258 ± 7	253	
1	I	103	112	85	85	84	103	95 ± 11	83	
	II	89	96	91	102	92	77	90 ± 8	100	
2	I	40	44	45	44	42	45	43 ± 4	[43]	Adopted Value
	II	27	29	33	39	38	44	35 ± 5	[35]	» »
3	I	31	28	37	31	36	34	33 ± 5	[33]	» »
	II	13	21	12	17	21	14	16 ± 4	[16]	» »
64	I		46	40				43 ± 3	[43]	» »

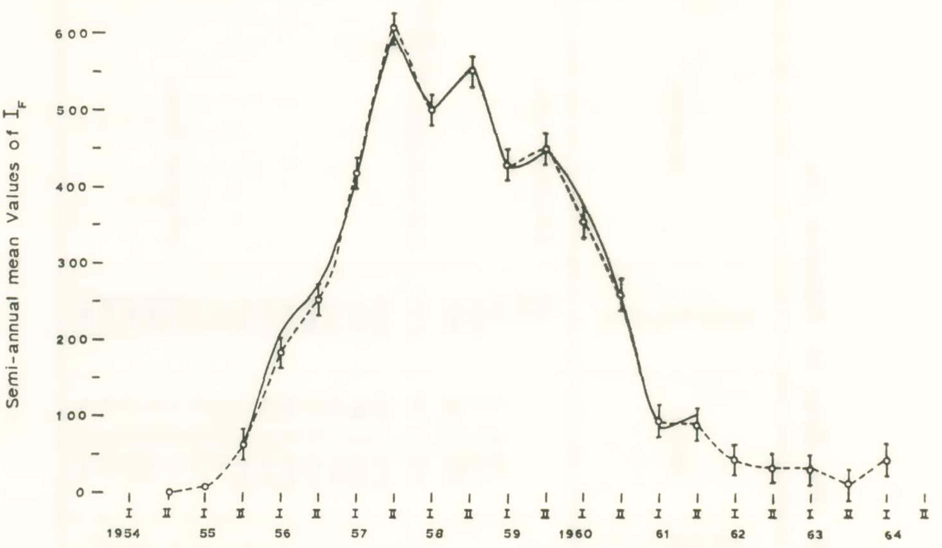

Fig. 7. The continuous line represents the values of the flare index I_f given by the observations, while the dashed line gives the mean value of I_f computed with the help of relation (6). Segments give the dispersion.

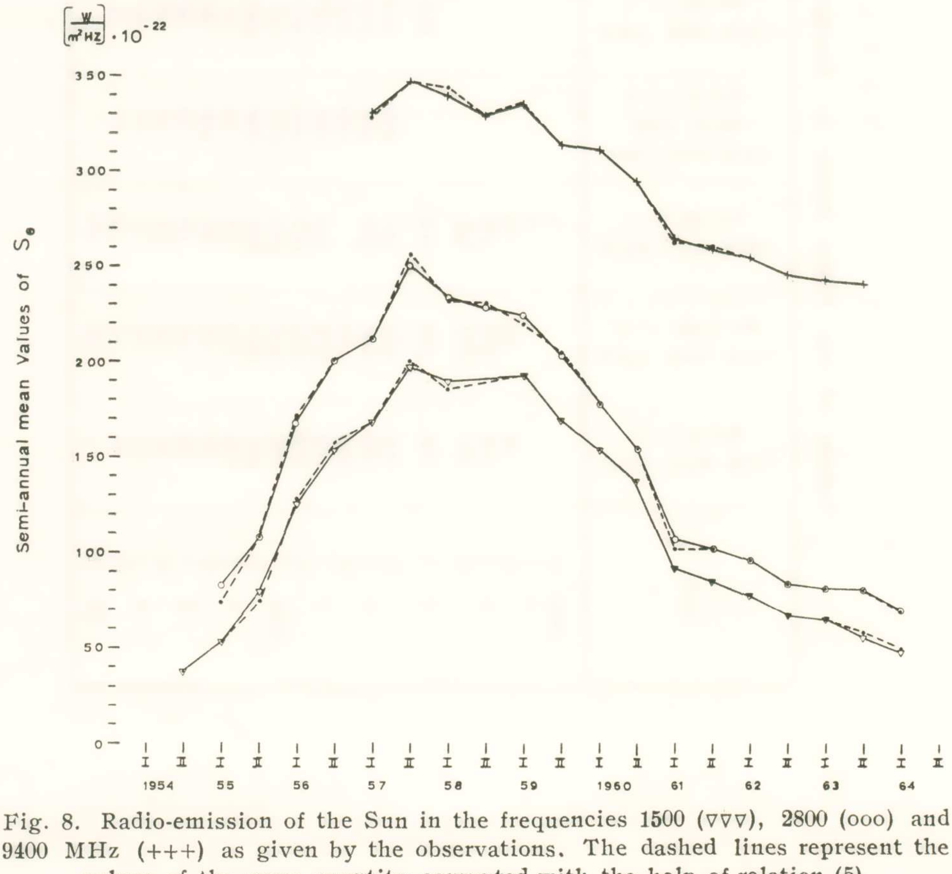

Fig. 8. Radio-emission of the Sun in the frequencies 1500 (▽▽▽), 2800 (ooo) and 9400 MHz (+++) as given by the observations. The dashed lines represent the values of the same quantity computed with the help of relation (5).

of the rediation flux $S_{\odot}$ (continuous lines) in the frequency range $1000 \leqslant f < 10000$ MHz as well as the values $S^{c}_{\odot}$ of the same quantities computed with the help of relation (5) (dashed lines). The values of the flare index I_F for the time interval 1954 II, 1955 I and 1962 I to 1964 I which are given in Table III are not included in Sawyer's table but

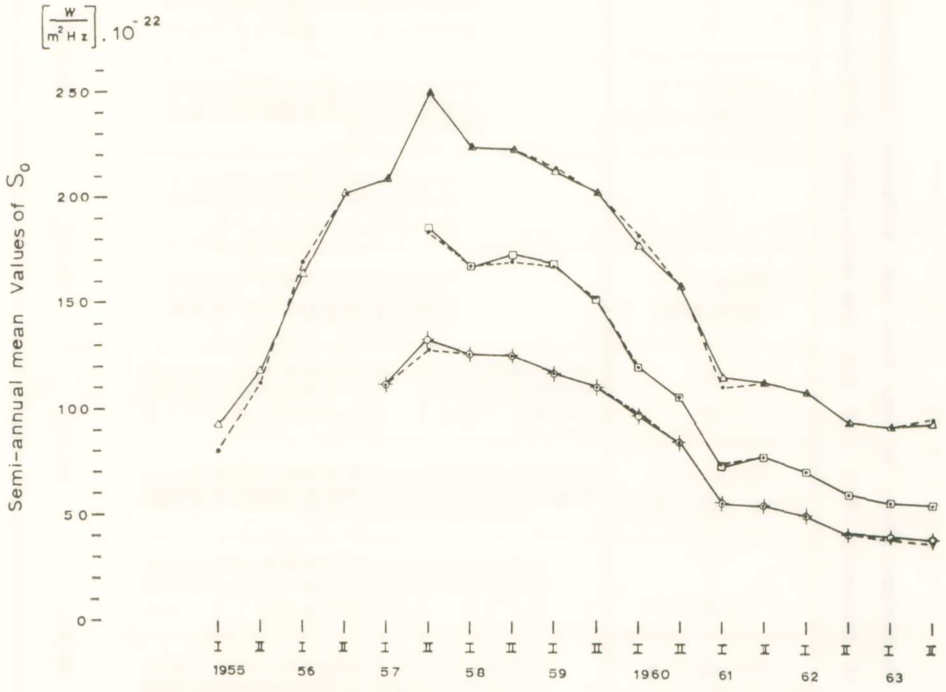

Fig. 9. Radio-emission of the Sun in the frequencies 3750 (ΔΔΔ), 2000 (□□□) and 1000 MHz (-ọ- -ọ- -ọ-) as given by the observations. The dashed lines represent the values of the same quantity computed with the help of relation (5).

have been computed with the help of relation (6). From Table IV, which gives the values $S^{c}_{\odot}$ computed with the help of relation (5) as well as the corresponding differences $S^{ob}_{\odot} - S^{c}_{\odot}$, we see that relation (5) gives the semi-annual mean values of the radiations flux $S_{\odot}$ in the frequency range considered with an accuracy $\left(1 - \frac{\sigma}{S_{\odot}}\right) 100\,\%$ of the order of 98 percent or even higher.

T A B L E IV

Values $S_{\odot}^{c}$ of the Radiation Flux of the Sun for Different Frequencies (Computed with the help of Relation (5)) and the Corresponding Differences $S_{\odot}^{o} - S_{\odot}^{c}$.

Date		NAG 3750 MHz λ = 8 cm	o − c	OTT 2800 MHz λ = 107 cm	o − c	HHI 1500 MHz λ = 20 cm	o − c	2000 MHz λ = 15 cm	o − c	NAG 1000 MHz λ = 30 cm	o − c	9400 MHz λ = 3,2 cm	o − c
1954	II					39.6	−0.5						
5	I					52.4	+1.2						
	II	113.5	+4.2	107.0	+1.1	74.1	+5.9						
6	I	170.7	−6.2	171.7	−4.2	128.7	−2.5						
	II	200.6	+1.0	201.1	−1.7	157.5	−3.8						
7	I	208.3	+0.9	211.8	+0.1	167.5	+1.5			111.6	+0.2	227.8	+2.5
	II	250.8	−0.7	256.3	−5.7	201.4	−3.0	184.0	+2.7	228.2	+3.8	345.7	+0.5
8	I	224.6	−0.9	230.8	+2.0	185.4	−3.0	168.6	−0.7	125.5	+0.8	344.1	−4.7
	II	222.5	+0.7	228.0	+0.5	192.1		169.9	+3.1	126.5	−1.2	329.0	−0.8
9	I	215.3	−2.1	218.8	+5.6	187.1	+1.3	168.4	−0.7	117.5	−0.7	333.7	−1.6
	II	204.3	−1.0	204.8	+1.3	174.2	+0.3	151.9	+0.4	111.0	−1.2	313.6	−0.4
1960	I	183.2	−5.0	180.2	−0.3	155.2	−1.6	121.0	−0.7	99.0	−2.1	311.6	−2.0
	II	158.9	−0.4	152.4	+2.0	136.2	+2.2	105.3	+0.4	84.3	+0.2	294.5	−0.1
1	I	111.3	+3.9	101.8	+5.6	91.9	+0.2	74.4	+0.7	56.2	+0.2	261.8	+2.4
	II	114.6	−2.0	103.1	−0.8	86.4	−1.4	78.4	−0.3	55.5	+0.7	260.9	−2.8
2	I	109.1	−1.3	96.9	−0.3	77.6	+0.1	71.0	−0.3	50.0	−0.4	254.5	−0.1
	II	95.4	−1.1	83.9	−0.7	66.6	−1.1	58.8	+0.7	41.4	−0.1	244.7	+0.4
3	I	91.8	0.0	81 7	−0.7	64.5	−1.9	56.6	0.0	39.2	+1.0	241.9	+0.4
	II	94.5	−1.7	79.5	+1.3	57.7	−0.8	55.0	0.0	38.0	+0.5	239.8	+0.1
64	I			69.7	+0.3	50.1	−0.9						
Precision $\left(1 - \frac{\sigma}{S_{\odot}}\right) 100\%$		98.3 %		98.0 %		98.0 %		98.7 %		98.4 %		99.4 %	

4. The Intensity of the Coronal line 5303 Å

It has been already mentioned that the intensity I_{5303} of the coronal line 5303 Å for the years 1946 to 1964 is more closely correlated to the areas index I_α than to the relative sunspot numbers R.

As the observation of Pic-du-Midi show a satisfactory homogeneity, it would be interesting to study the quarterly values of the coronal index I_{5303} instead of the annual ones. These values, which were kindly put at our disposal by Prof. J. Rösch and J. L. Leroy of the Pic-du-Midi Observatory, as well as the corresponding values of the areas index I_α, are given in Table V for the time interval 1947 II to 1964 IV.

As in the case of $S_\odot$, in this case, too, the variation of the quarterly values of the ratio:

$$\frac{I_{5303} - I_\alpha}{I_\alpha} = W$$

does not seem to be random. Rather there appears a strong correlation with the variation of the proton flare number N_{PF}, the values of which for the time interval 1955 I to 1964 IV, based on Table I of Švestka and Olmr (1966), are given in Table VI. This remark led us to attempt to find a relation of the form:

$$I_{5303} = I_o + K\left[1 + \sqrt{N_{PF}}\right] I_\alpha\,, \qquad (7)$$

where K is a constant and I_o is the intensity of the coronal line 5303 Å for the sun without sunspots and faculae ($I_\alpha = 0$). Using the available observational data, concerning the time interval 1957 III to 1964 IV for which the values of N_{PF} are more or less well-known, we can compute with the help of relation (7) the corresponding values of K and I_o. These computations show that coefficient K assumes a constant value $K = 0.165$, while the value of I_o varies in a different way for the different quarters of the year. In fact, while the values of I_o for the first, second and fourth quarter of each year vary slightly around the mean value $I_o = 14.0$ the values of I_o for the third quarter of the years 1956 - 1960 show a considerable variation which can be represented by the relation:

$$I_o = 14\left[1 - \sin\frac{2\pi}{6}\left(t - {}^1/_2\right)\right] \qquad (8)$$

where $t = 0$ for date 1956 III and $t = 4$ for 1960 III.

T A B L E V

Quarterly Values of the Intensity I_{5303} of the Coronal Line 5303 Å Observed in Pic-du-Midi and the Corresponding Values of the Areas Index I_α for the Time Interval 1954 - 1964.

Year	Quarter of the Year								Year	
	I		II		III		IV			
	I_{5303}	I_α	I_{5303}	I_α	I_{5303}	I_α	I_{5303}	I_α	I_{5303}	I_α
1954	11.5	8.2	13.6	3.9	8.7	8.1	16.5	12.5	13.8	8.8
5	16.4	16.2	26.4	21.5	16.2	27.2	20.2	35.3	19.8	25.8
6	37.4	44.1	37.5	44.6	43.7	49.2	51.5	53.0	42.5	47.8
7	54.1	46.8	53.2	51.3	50.9	52.4	52.4	56.7	52.7	51.5
8	48.4	52.0	39.6	51.6	39.0	51.9	46.8	47.7	43.3	51.0
9	40.7	52.5	42.6	47.5	37.5	51.5	39.9	48.4	40.2	52.8
1960	42.3	48.3	52.5	45.6	44.2	45.9	40.2	39.2	44.8	45.8
1	30.7*	33.0	32.8	34.7	38.4	36.0	24.7	26.9	31.6	33.1
2	22.5	33.3	30.0	32.4	24.8	26.9	24.5	23.0	25.5	29.9
3	20.4	20.6	23.0	28.2	29.4	25.5	21.7	20.3	22.8	24.2
64	20.6	18.6	17.1	15.2	15.3	11.6	15.0	11.5	17.1	18.6

* This value is reduced by 7.7 units.

TABLE VI

Quarterly Values of the Proton Flare Number N_{PF}.

Year	Quarter of the Year			
	I	II	III	IV
1955	0	0 (6)	0	0
6	5	0 (5)	1 (3)	5 (11)
7	2 (17)	8 (13)	18	8
8	7	4	11	8
9	5	6	9	4
1960	7	17	4	11
1	1 (3)	3	10	1
2	2	5	2	1
3	1	1	7	2
4	1	0	0	0
Total	31	44	62	40

This curious behavior of I_o is shown by Figure 10 in which the open curcles represent the values of I_o in the first, second and fourth quarters and the symbol -ǫ- the ones in the third quarter of the years 1956 - 1960.

It is difficult to admit that these changes of I_o during the summer months July, August, September, are due to observational errors which bias the value of I_{5303} only during this period of the year. Therefore, it seems that this variations is probably due to a periodic variation of the proton flare number N_{PF} during the summer months of the years of higher solar activity, which variation does not follow the variation of I_{5303}. As Švestka (1968) has already noticed the flare number, type IV bursts, magnetic crochets, polar-cap absorptions and great magnetic storms, show a yearly period, characterized by a striking deficiency of flare activity in the winter months. From the last line of Table VI, which gives the sum $\sum N_{PF}$ of the proton flare numbers N_{PF} corresponding to each of the four quarters of the year, for the time interval 1955 - 64, we see that this sum is about 50 percent higher for the third quarter of the year than for the remaining three quarters. Especially during the time interval 1956 - 60 during which solar activity assumed the highest values from all the values corresponding to the XIXth sunspot cycle, quantity N_{PF} shows during the third quarter of the year a variation which is clearly opposite to the variation of the corresponding

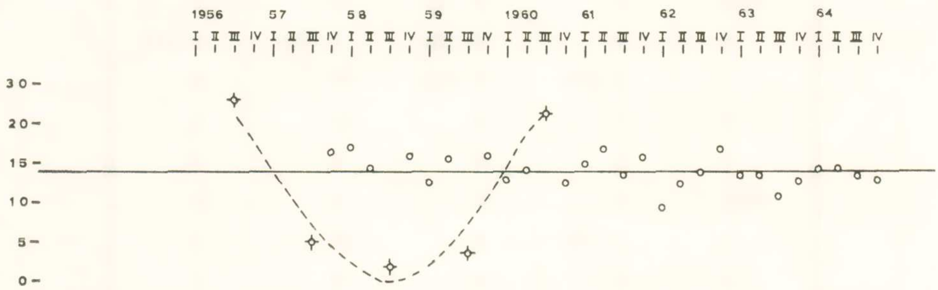

Fig. 10. Variation of the quantity S_o during the time interval 1956 III - 1964 IV. Symbol correspond to the third quarter of the years 1956 to 1960.

values of the quantity I_o (Figure 11c), while for the first, second and fourth quarter the values of N_{PF} and I_o remain fairly constant (Figures 11a and 11b).

Any attempt to explain this phenomenon seems to be very premature yet, before we are sure that this phenomenon is in fact, always present during the same season of the year, i.e. during the time interval between the summer solstice and the autumn equinox.

If we assume that relation (7) is valid during the entire duration of the XIXth sunspot cycle, then, from the observed values of I_{5303} and the areas index I_α, we can compute the values of N_{PF} for each quarter of the year of the time interval 1954 to 1964 with the help of relation:

$$\sqrt{N_{PF}} = \frac{I_{5303} - I_o}{K\, I_\alpha} - 1$$

where K is constant (K = 0.165) and $I_o = 14.0$ for all the quarters of the years 1954 - 1964, but the third quarter of the years 1956 to 1960 for which

$$I_o = 14 \left\{ 1 - \sin \frac{2\pi}{6} (t - 1/2) \right\}$$

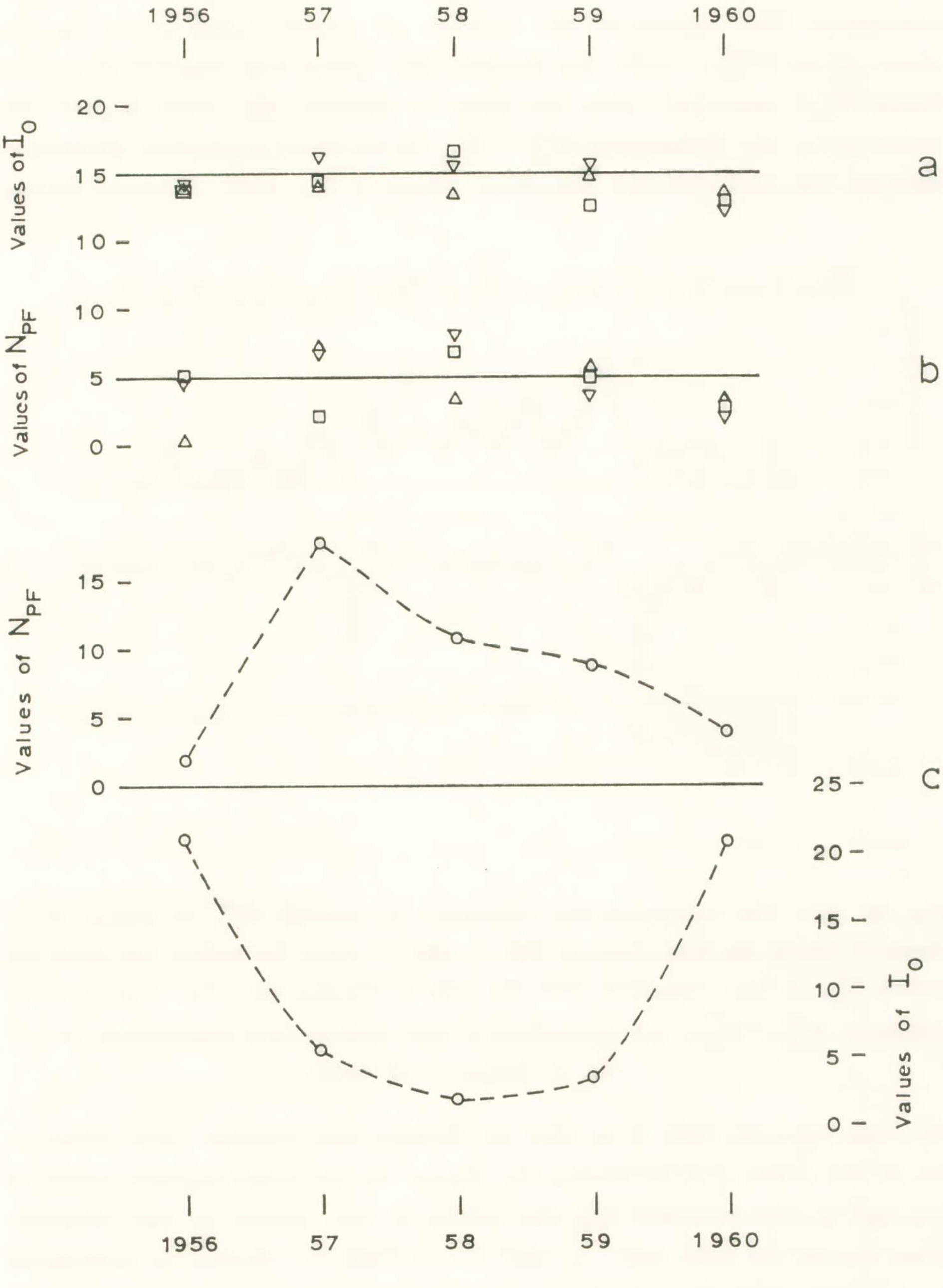

Fig. 11. Variation of the quantity I_o and the proton flare number N_{PF} corresponding to the first (□□□), second (△△△), third (ooo) and fourth (▽▽▽) quarter of the years 1956 - 1960.

The numerical results are represented by Figure 12a, where the continuous line represents the number of proton flares given by the observations (N^{ob}_{PF}), while the dashed line gives the number of proton flares (N^{c}_{PF}) computed with the help of relation (9). From Figure 12b which gives the differences $N^{ob}_{PF} - N^{c}_{PF}$ we see that the greatest difference between the observed and computed values of N_{PF} were observed during

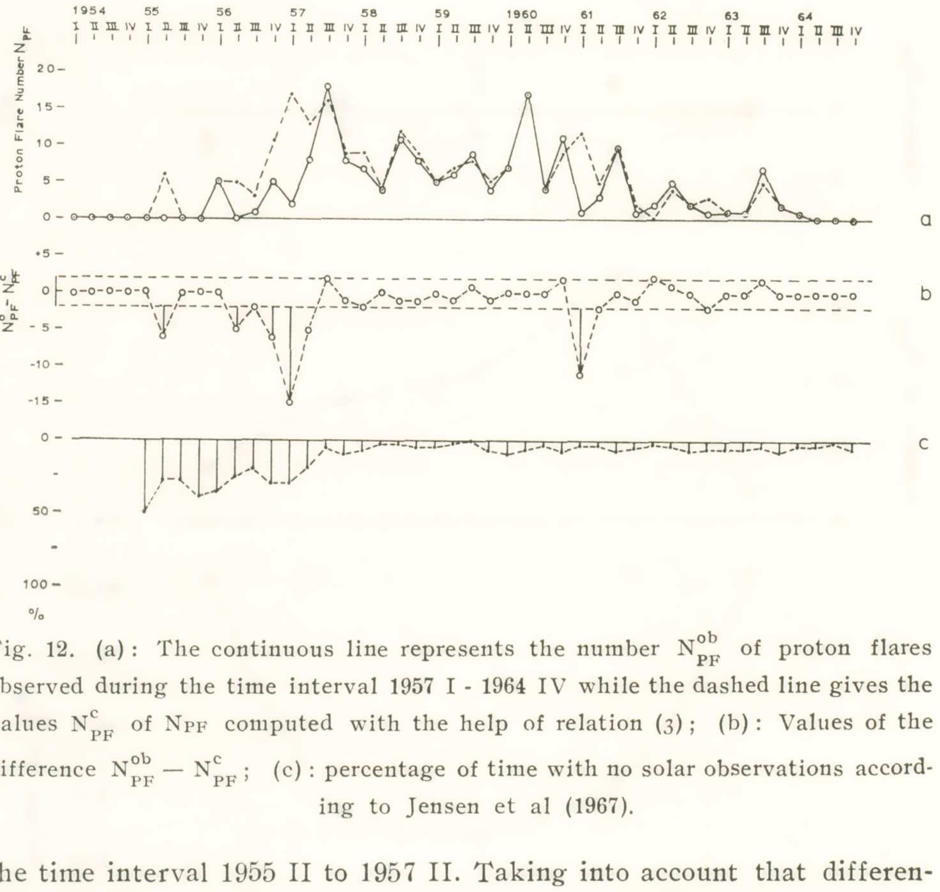

Fig. 12. (a): The continuous line represents the number N^{ob}_{PF} of proton flares observed during the time interval 1957 I - 1964 IV while the dashed line gives the values N^{c}_{PF} of N_{PF} computed with the help of relation (3); (b): Values of the difference $N^{ob}_{PF} - N^{c}_{PF}$; (c): percentage of time with no solar observations according to Jensen et al (1967).

the time interval 1955 II to 1957 II. Taking into account that differences of the order ± 2 lie within the limits of the observational errors of I_{5303} and I_{α}, we conclude that the values of N_{PF}, given by the observations during the time interval 1957 III to 1964 IV, should be considered as accurate, with the only exception of the first quarter of the year 1961 for which the value $N^{ob}_{PF} = 1$ given by the observations differs sensibly from the value $N^{c}_{PF} = 12$ computed with the help of relation (9).

As far as the time interval before 1957 III is concerned, the great discrepancies found, especially the one corresponding to the first quarter of 1957, should be attributed mainly to the incomplete observations of the proton flares, the actual number of which was during this time interval probably twice as high as the values given in Table VI. This hypothesis is also supported by the fact that during the same time interval we have, according to Jensen et al (1967) the greatest percentage of time during which the sun was not observed (Figure 12c). The same is not, however, valid for the first quarter of 1961 during which the percentage of time with no solar observations is very low, of the order of 3 percent; therefore, it is very improbable that such a great number of proton flares (about 10 proton flares) could have escaped observation. It is, nevertheless, possible that a small number of proton flares escaped observation, as we can conclude from the fact that during the same time interval (1961 I) 3 polar-cap absorption events and 3 geomagnetic storms have been recorded, as shown in Hakura's (1968) Table I. Considering that, as we shall see in the next chapter, these two phenomena are closely correlated with the proton flares, we come to the conclusion that a total of 3 - 4 proton flares have probably been omitted. On the other hand, we can assume that the value of I_{5303}, corresponding to the same time interval (1961 I) is in error by 20% i.e. is equal to $I_{5303} = 30.7$ instead of $I_{5303} = 38.4$. If we admit these corrected values i.e. $N_{PF} = 4$ and $I_{5303} = 30.7$, then the difference, which is shown in Figure 12b with an asterisk, no longer exists.

Table VII gives in the first line of each year the values I^{c}_{5303} of the intensity of the coronal line 5303 Å computed with the help of relation (7), where the values of N_{PF} have been taken from Table VI (based on the Table I of Švestka and Olmr 1966) for the time interval 1957 III to 1963 IV. For the time interval 1955 I to 1957 II we have accepted the values of N_{PF} computed with the help of relation (9); these last values of I^{c}_{5303} were written in Table VII in brackets.

The second line of each year in Table VII gives the values of the differences $I^{ob}_{5303} - I^{c}_{5303}$. From the values of these differences, and taking into account the corrections proposed for the observational data corresponding to 1961 I, we conclude that relation (9) represents the observed

TABLE VII

Values I^{c}_{5303} of the Intensity of the Coronal line 5303 Å Computed with the Help of Relation (7) and the Corresponding Differences $I^{ob}_{5303} - I^{c}_{5303}$

Year	Quarter of the Year			
	I	II	III	IV
1954				16.8
				— 0.3
1955	[16.7]	[26.2]	[18.5]	[19.8]
	— 0.3	+ 0.2	— 2.3	+ 0.4
1956	[37.5]	[37.5]	[43.2]	[51.8]
	— 0.1	0.0	+ 0.5	— 0.3
1957	[53.6]	[52.9]	52.3	49.8
	+ 0.5	+ 0.3	— 1.4	+ 2.6
1958	45.3	39.3	37.0	44.3
	+ 3.1	+ 0.3	+ 2.0	+ 1.9
1959	42.0	41.0	41.0	38.0
	— 1.3	+ 1.6	— 3.5	+ 1.9
1960	43.4	52.5	43.7	41.9
	— 1.1	0.0	+ 0.5	— 1 7
1961	30.3	29.8	38.7	22.9
	— 0.4	+ 3.0	— 0.3	+ 1.8
1962	27.2	31.3	24.7	21.6
	— 4.7	— 1.3	+ 0.1	+ 2.9
1963	20.8	23.3	29.5	22.1
	— 0.4	— 0.3	— 2.9	— 0.9
1964	20.1	16.5	15.9	15.9
	+ 0.8	+ 0.6	— 0.6	— 0.9

values of I_{5303} in a very satisfactory way, the value of the accuracy $\left(1 - \frac{\sigma}{\bar{I}_{5303}}\right) 100\,\%$ corresponding to the time interval 1957 III to 1964 IV being equal to 95.3 percent.

In Figure 13 the continuous line represents the quarterly values of I_{5303} given by the observation of Pic-du-Midi and the dashed line

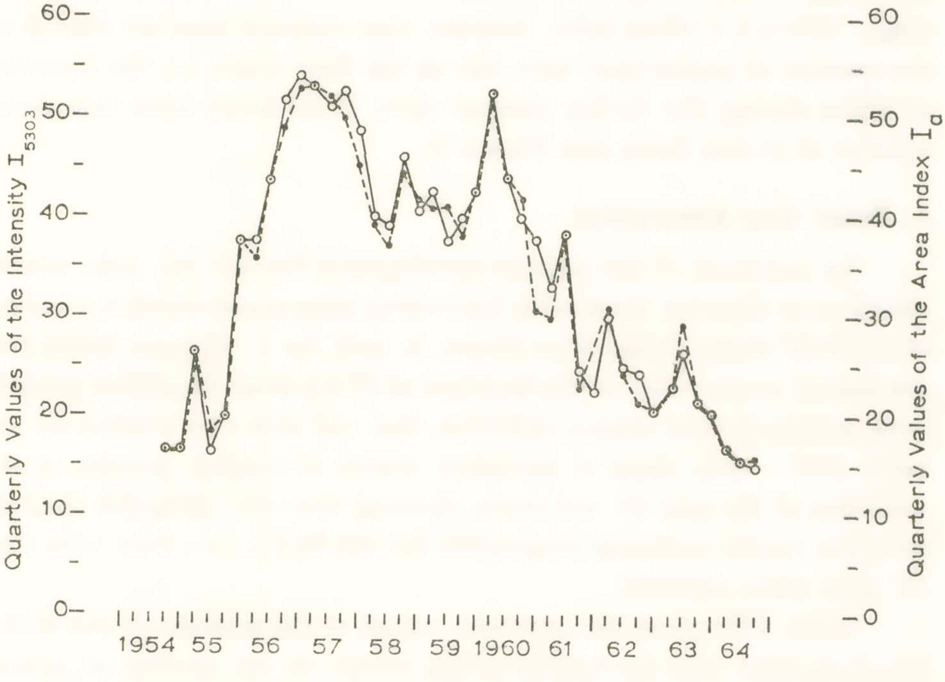

Fig. 13. The continuous line represents the values of I_{5303} given by the observations of Pic-du-Midi for each quarter of the years 1954 - 1964, while the dashed line gives the values of the same quantity computed with the help of relation (7).

the values of the same quantity computed with the help of relation (7) Table VII.

This relation (7) between I_{5303}, I_α and N_{PF} explains why the variation of the intensity of the coronal line 5303 Å presents, as shown in Figure 4 and already noticed by Gnevyshev - Krivsky (1966) and other investigators, two maxima during the XIXth sunspot cycle. In fact, during this cycle the areas index I_α presents a flat maximum (1957 - 1960), which is not the case for the relative sunspot numbers R. On the other hand, N_{PF} presents two principal maxima, one during the third quarter of 1957 ($N_{PF} = 18$) and another during the second quarter of 1960 ($N_{PF} = 17$). As, according to relation (7), the values of I_{5303} appear to depend on the product $N_{PF} . I_{\alpha}$, it is to be expected that the curve representing the variation of I_{5303} should show two distinct maxima, one during 1957 and another in 1960. The same is not, however, observed in the case of the intensities $S_{\odot}$ of the radio-emission in the frequency range $1000 \leqslant f < 10000$ MHz, because this emission does not depend on the number of proton flare only, but on the flare index I_F, the variation of which during the XIXth sunspot cycle is different from that of the number of proton flares (see Figure 7).

5. Polar Cap Absorption

An extension of the present investigation beyond the solar corona allows us to discover some other interesting phenomena which are worthy of a special study. It has been shown, in fact, by Y. Hakura (1968) that the annual mean values of the numbers of PCA's (total identified ground-level events of solar cosmic radiation, fast and slow type events) for the years 1956 - 1965, show a variation which is roughly parallel to the variation of the type IV outbursts, showing that the principal cause of the solar cosmic radiation responsible for the PCA's is a flare with type IV solar radio outburst.

Table VIII gives the quarterly values of the number of the PCA's (N_{PCA}) together with the corresponding values of the number of proton flares (N_{PF}). The values of N_{PCA} have been taken from the table of Hakura (1968), while the values of N_{PF} are from the table of Švestka and Olmr (1966). At first sight one gets the impression that not only the annual but also the quarterly values of N_{PCA} and N_{PF} vary in a roughly parallel way. If, however, we study more closely the values of the ratio N_{PCA}/N_{PF} for those quarters of the year for which the numbers of PCA's and of proton flares are $\geqslant 4$, we find out that the ratio N_{PCA}/N_{PF} does not remain constant, but decreases from 1957 I when this ratio was approximately equal to 1, until 1958 III when it was equal to 0.6, and then increases and assumes again the value 1 around the end of the sunspot cycle (1963 III). This means that N_{PCA} does not depend only upon N_{PF} but upon some other factors too, which in some way determine

T A B L E VIII

Quarterly Values of the PCA's (N_{PCA}) and Proton Flares (N_{PF}) and the Corresponding Values of the Ratios N_{PCA} / N_{PF}, I_{5303} / I_{α} for the Time Interval 1956 I to 1963 IV.

Date		N_{PCA}	N_{PF}	N_{PCA} / N_{PF}	I_{5303} / I_{α}	Date		N_{PCA}	N_{PF}	N_{PCA} / N_{PF}	I_{5303} / I_{α}
1956	I	2	5			1960	I	4	7	0.57	0.88
	II	3	5	0.60	0.85		II	13	17	0.76	1.05
	III	2	1		0.88		III	4	4	1.00	0.96
	IV	3	5	0.60	0.97		IV	8	11	0.73	1.03
1957	I	3	2		1.15	1961	I	3	3		0.86
	II	8	8	1.00	1.02		II	2	3		0.95
	III	14	18	0.78	0.97		III	10	10	1.00	1.07
	IV	3	8	0.28	0.92		IV	1	1		0.92
1958	I	5	7	0.71	0.93	1962	I	2	2		0.69
	II	3	4	0.75	0.77		II	0	5		0.94
	III	8	11	0.73	0.76		III	0	2		0.92
	IV	0	8	0	0.97		IV	1	1		1.07
1959	I	2	5	0.40	0.77	1963	I	1	1		1.00
	II	5	6	0.83	0.89		II	2	1		0.85
	III	5	9	0.56	0.72		III	7	7	1.00	1.04
	IV	2	4	0.50	0.97		IV	2	2		1.07

the physical conditions in the interplanetary space, through which the influence of proton flares on the PCA's is exerted.

The physical conditions in the interplanetary space are controlled by the combined action of many factors which have their origin in the Sun. Solar winds, magnetic fields, importance and position of the active

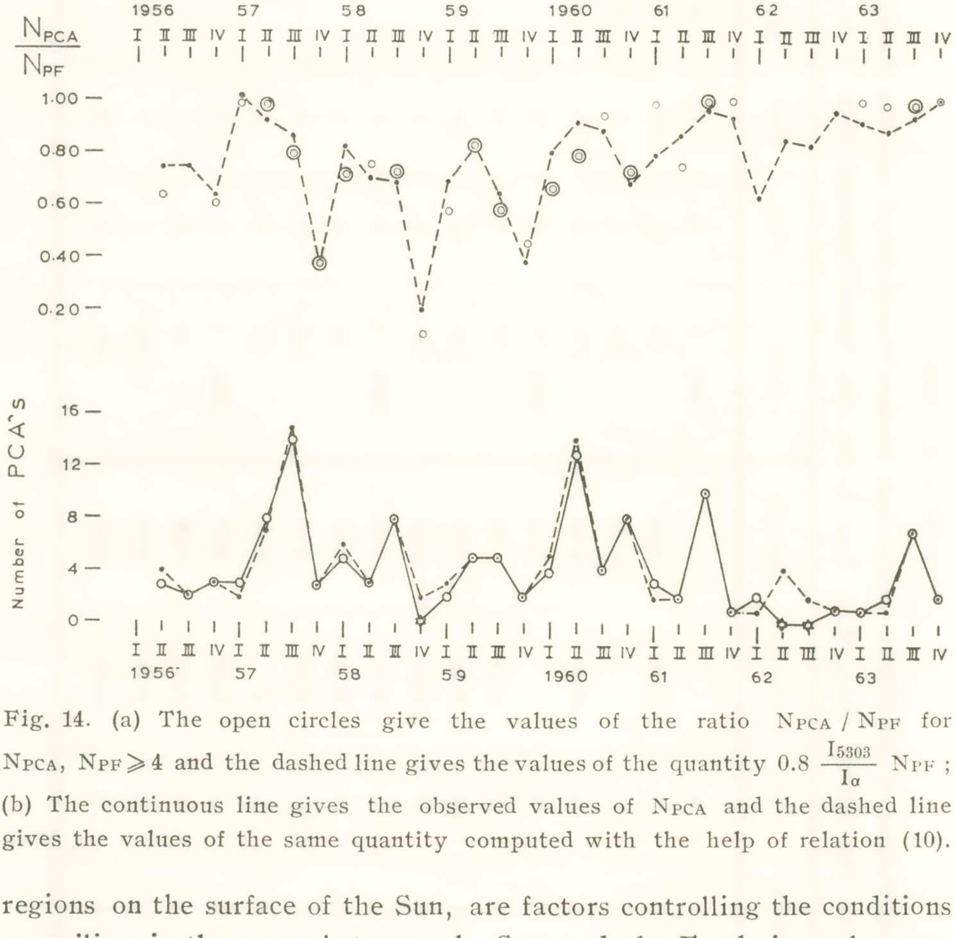

Fig. 14. (a) The open circles give the values of the ratio N_{PCA} / N_{PF} for $N_{PCA}, N_{PF} \geqslant 4$ and the dashed line gives the values of the quantity $0.8 \frac{I_{5303}}{I_{\alpha}} N_{PF}$; (b) The continuous line gives the observed values of N_{PCA} and the dashed line gives the values of the same quantity computed with the help of relation (10).

regions on the surface of the Sun, are factors controlling the conditions prevailing in the space between the Sun and the Earth in such a way that the influence of the corpuscular radiation accompanying proton flares on the PCA's is sometimes stronger and other times weaker or eclapsed. In general, the most significant out of these factors seems to be the solar activity in the photosphere and the corona, which can be expressed with the help of the areas index I_{α} and the intensity I_{5303} of the coronal line 5303 Å respectively.

Table VIII shows indeed the values of the ratio N_{PCA}/N_{PF} for N_{PCA} and $N_{PF} \geqslant 4$ during the time interval 1957 I to 1963 IV vary in a similar way with the corresponding values of the ratio I_{5303}/I_{α} with the exception of the fourth quarter of each year. In fact, if we consider the ratio:

$$\frac{N_{PCA}}{N_{PF}} : \frac{I_{5303}}{I_{\alpha}} = K$$

we find out that the values of K for N_{PCA} and $N_{PF} \geqslant 4$ vary slightly around the mean value $K = 0.9$ in the first, second and third quarter of each year. In the fourth quarter, on the contrary, the values of K show a considerable periodic variation with a half-period equal to 6 years, which can be represented by the relation:

$$K = 1 - 0.7 \sin \frac{\pi}{6} t$$

where $t = 0$ for 1955 IV and $t = 6$ for 1961 IV. These results are shown in Figure 14a in which the double circles represent the values of the ratio N_{PCA}/N_{PF} for N_{PCA} and $N_{PF} \geqslant 4$ and the circles the values of the same ratio for N_{PCA} and N_{PF} smaller than 4 but greater than 1. The dashed line represents the values of the quantity

$$K \cdot \frac{I_{5303}}{I_{\alpha}}$$

where $K = 0.9$ for the first second and third quarter of each year and

$$K = 1 - 0.7 \sin \frac{\pi}{6} t \ (t = 0 \text{ for } 1955 \text{ IV}, \ t = 6 \text{ for } 1961 \text{ IV})$$

for the fourth quarter of the years 1955 to 1961.

Therefore, one can conclude that the number N_{PCA} of PCA's is related, in a first approximation, with the number N_{PF} of proton flares with a relation of the form:

$$N_{PCA} \simeq K \frac{I_{5303}}{I_{\alpha}} N_{PF} \qquad (10)$$

where K assumes the above mentioned values.

In Figure 14b the continuous line represents for each quarter of the years 1957 - 1964 the value N^{ob}_{PCA}, given by the observations (Table VIII), while the dashed line gives the corresponding values (N^{c}_{PCA}) of this quantity computed with the help of relation (10). It is worth mentioning that, with the exception of the three cases corresponding to 1958 IV, 1962 II and 1962 III, the differences $N^{ob}_{PCA} - N^{c}_{PCA}$ are absolutely smaller than 1 and can therefore be attributed to the influence of observational errors, especially those eorresponding to I_{5303} or to N_{PCA}.

From the Table VIII it follows also, that the sum ΣN_{PCA} for each quarter of the year within the period 1956 I - 1963 IV reaches its greatest value during the third quarter ($\Sigma N_{PCA} = 50$), as in the case of proton flares, and it takes its smallest value during the fourth quarter ($\Sigma N_{PCA} = 20$), where the large periodic variation of K is also observed.

General Conclusions

From the above discussion we conclude that the relative sunspot numbers are not the most suitable index for the study of the coronal phenomena related to solar activity. These phenomena are, in fact, related with the activity regions of the photosphere; it is, therefore, more natural to use in their study as a basic index of solar activity in the level of the photosphere, instead of the relative sunspot numbers another index which is more closely correlated to the activity centers. The index used in the present study i. e. the areas index defined by the relation:

$$I_\alpha = \frac{1}{2} [\sqrt{A} + \sqrt{f}]$$

can be considered, in some way, as an index characterizing the size of the activity centers. The existing observational data show on the other hand that the coronal phenomena which are related to solar activity and especially the solar radio-emissions and the intensity of the coronal line 5303 Å, depend also on some other factors which are located above the photosphere, for example flares, filaments etc. It is, therefore, necessary to take into account these factors too, in any attempt to find an analytical expression of the variation of the coronal phenomena during the sunspot cycle.

Relations (5) and (7) given above represent in a very satisfactory way the evolution of the intensity of the coronal line 5303 Å and the solar radio-emissions in the frequency range $1000 \leqslant f < 10000$ MHz. It is worth mentioning that relations (5) and (7) are of the same form i.e.

$$Z = Z_o + K(1 + W)\, I_\alpha\,, \quad K = C^{te}$$

where Z represents the intensity of the coronal line 5303 Å or the solar radio-emission in the frequency range $1000 \leqslant f < 10000$ MHz during the different phases of the sunspot cycle and Z_o gives the value of the same quantities during the phase of the «quiet» Sun (Sun free of sunspots and faculae). Term W depends on the number N_{PF} of proton flares in the case of the intensity of the coronal line 5303 Å and on the flare index I_F in the case of the solar radio-emission i.e.

$$W = \sqrt{N_{PF}}\,, \qquad W = \sqrt{10^{-2}\, I_F}$$

respectively.

From the above relation we get:

$$W = \frac{Z - Z_o}{K I_\alpha} - 1$$

This relation leads to the conclusion that the flare index I_F and the number of proton flares N_{PF} assume great values when the intensity of the radio-emission of the sun or the intensity of the coronal line 5303 Å assume high values as compared with the corresponding values of the areas index I_α. Thus, in the case of the proton flares their number N_{PF} is greater if the intensity of the coronal line 5303 Å is high as compared with the areas of the sunspot and faculae during the corresponding time interval. The same is valid for the number N_{PCA} of the PCA's.

It would be very interesting to extend this present study to the current sunspot cycle too.

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ΠΕΡΙΛΗΨΙΣ

Εἰς τὸ πρῶτον μέρος τῆς παρούσης ἐργασίας εἰσάγεται εἷς νέος δείκτης τῆς ἡλιακῆς δραστηριότητος εἰς τὴν ἡλιακὴν φωτοσφαῖραν, ἤτοι ὁ δείκτης I_α, ὅστις ὡρίσθη τῇ βοηθείᾳ τῆς σχέσεως $I_\alpha = {}^1/_2 \left[\sqrt{A} + \sqrt{f}\right]$, ἔνθα A καὶ f εἶναι ἀντιστοίχως τὰ ὁλικὰ ἐμβαδὰ τῶν ἡλιακῶν κηλίδων καὶ πυρσῶν τὰ παρεχόμενα ὑπὸ τῶν παρατηρήσεων τοῦ Ἀστεροσκοπείου τοῦ Greenwich. Ἡ μεταβολὴ τοῦ δείκτου I_α συγκρίνεται ἀφ' ἑνὸς μὲν πρὸς τὴν μεταβολὴν τῶν μέσων ἐτησίων τιμῶν τῆς ἐντάσεως τῆς πρασίνης γραμμῆς λ 5303 Å τῆς ἡλιακῆς φωτοσφαίρας, ἥτις παρετηρήθη εἰς τὸ Ἀστεροσκοπεῖον Pic-du-Midi μεταξὺ 1947-1964, ἀφ' ἑτέρου δὲ πρὸς τὴν μεταβολὴν τῶν ἑξαμηνιαίων τιμῶν τῆς ἐντάσεως τῶν ἡλιακῶν ραδιοεκπομπῶν εἰς τὸ διάστημα συχνοτήτων 1000 MHz $\leqslant f <$ 10000 MHz (1955-1964).

Εἰς τὸ δεύτερον μέρος προτείνεται μία σχέσις τῆς μορφῆς:

$$S_\odot = S_o + K\left(1 + \sqrt{10^{-2} I_F}\right) I_\alpha$$

ἔνθα $S_{\odot}$ εἶναι ἡ ἔντασις τῶν ἡλιακῶν ῥαδιοεκπομπῶν εἰς τὸ διάστημα συχνοτήτων $1000\ \mathrm{MHz} \leqslant f < 10000\ \mathrm{MHz}$, I_F εἶναι ὁ δείκτης τῶν ἡλιακῶν ἐκλάμψεων καὶ K μία σταθερά.

Εἰς τὸ τρίτον μέρος προτείνεται μία σχέσις τῆς μορφῆς:

$$I_{5303} = I_o + K\,(1 + \sqrt{N_{PF}})\,I_\alpha$$

ἔνθα I_{5303} εἶναι ἡ μέση ἔντασις τῆς γραμμῆς λ 5303, ἡ ἀντιστοιχοῦσα εἰς ἕκαστον τετράμηνον τῆς περιόδου 1954 - 1964, ἔνθα N_{PF} εἶναι ὁ ἀριθμὸς τῶν ἡλιακῶν ἐκλάμψεων πρωτονίων δι' ἕκαστον τετράμηνον τῆς περιόδου 1957 - 1964 καὶ K εἶναι μία σταθερά.

Τέλος, ἐκ τῆς συγκρίσεως τοῦ πλήθους τῶν PCA μὲ τὰς ἀντιστοίχους τιμὰς τοῦ πλήθους τῶν ἡλιακῶν ἐκλάμψεων πρωτονίων N_{PF}, ἀνευρέθη μία σχέσις τῆς μορφῆς $N_{PCA} = K \frac{I_{5303}}{I_\alpha} N_{PF}$. Ὁ συντελεστὴς K εἶναι ἴσος πρὸς 0.9 διὰ τὸ πρῶτον, δεύτερον καὶ τρίτον τετράμηνον ἑκάστου ἔτους. Μόνον κατὰ τὸ τέταρτον τρίμηνον τῶν ἐτῶν 1955 - 1961 λαμβάνει τὰς τιμάς:

$$K = 1 - 0.7 \sin \frac{\pi}{6} t, \quad (t = 0 \quad 1955\ \mathrm{IV}, \quad t = 6, \quad 1961\ \mathrm{IV}).$$