CORONAL LINE INTENSITY AS AN INTEGRATED INDEX OF SOLAR ACTIVITY

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Abstract. The relation between coronal green line intensity and high-speed streams of solar wind emitted by coronal holes or by loop structures of the corona is studied. As well as these exclusive regions of coronal radiative emission, other factors of solar activity have been taken into account in this relation, such as proton events, sunspot number, faculae, and solar magnetic fields.

Although the investigated time period (1964–1974) is very short, because of lack of data, we attempted to define the intensity of the coronal green line as an integrated index of the solar activity which can express all the photospheric and coronal phenomena of the Sun. The contraction of the low-density coronal-hole regions and the presence of bright loops during solar maximum provide a theoretical explanation of the above-mentioned relation.

1. Introduction

Several authors have reported that the change in solar modulation of the coronal line intensity at 5303 Å are associated with changes in the characteristics of the solar wind and the magnetic field which it carried into the interplanetary space over the 11-year solar activity cycle. Indeed, Simpson and Wang (1967) remarked that the solar coronal emission at 5303 Å is the observable parameter in the corona closely associated with the long-term changes in the solar wind parameters. Later, the same authors (Simpson and Wang, 1970) proved that the coronal temperature determines the coronal line intensity such as originates from a $2P_{3/2} - 2P_{1/2}$ Fe XIV transition. As far as known the coronal temperature also controls the coronal expansion leading to the solar wind in space. Thus a close association may exist between the green line intensity and the solar wind characteristics responsible for modulation.

Indeed, Waldmeier (1971) investigating the behaviour of the coronal line at 5303 Å found and described regions where this line was especially weak. These regions are the well-known 'coronal holes' which are long-lived regions of low density and temperature and occur in weak, open, diverging, and unipolar magnetic field regions (Zirker, 1977). As the green coronal line becomes weaker by decreasing density and temperature, the coronal holes are a good index for the intensity changes. Waldmeier (1981) studied the extension of the polar coronal holes for four solar cycles (1940–1978), using the observations of the coronal line at 5303 Å.

Furthermore, the coronal streams and especially the 'loop structures' show a complex

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magnetic structure, including closed field zones, which affects coronal electronic density and temperature (Priest, 1978). For this reason Poulain (1981) took into account the loop structure characteristics in order to compute the intensity of the 5303 Å emission line.

In this paper the high-speed solar wind streams emitted by coronal holes (Nolte *et al.*, 1976) and those associated with active regions (loop structures) with respect to the coronal green line intensity, have been studied. This results from the fact that periods of enhanced solar wind speed which are often observed in the solar wind velocity data, have been associated with these two regions (Iucci *et al.*, 1979; Lindblad and Lundstedt, 1981). These regions are characterized by entirely different features and are the only responsible regions of coronal radiative emission (Vaiana and Rosner, 1978).

As remarkable differences have been found between the interplanetary parameters characterizing the streams of these two different regions (Iucci *et al.*, 1979), the green line intensity variations should be different for the two kinds of streams. Elsewhere, Venkatesan *et al.* (1982) have noted differences in the effects of the above-mentioned two types of fast solar-wind streams on cosmic-ray intensity and Mavromichalaki *et al.* (1988) have noted a similar kind of behaviour on geomagnetic activity.

The essential purpose of this report is to further investigate the relation of the green line emission with the solar and interplanetary parameters and especially with the high-speed streams of solar-wind which escape from the corona. Coronal data (5303 Å) from the Pic-du-Midi Observatory have been systematically observed until the year 1974. As the solar wind speed began to be measured by space probes and Earth-orbiting spacecraft from 1962, we study here the time period from 1964 to 1974.

2. Data

Measurements of the absolute intensity of the coronal emission line 5303 Å were taken from the Pic-du-Midi Observatory for the time period 1964–1974. We note that these measurements have been obtained by a classical coronograph of Lyot-type for all heliolongitudes around the solar limb with a resolution of 5° and at a distance of about 40″ until 2″ from the Sun's edge. The unit of the measured intensity of this line is 10^{-6} times the intensity at a width of 1 Å wavelength (Rozelot and Fulconis, 1983; Dollfus, 1983). Two half-year (semestrial) values were used for every year. The half-yearly mean values at each position angle were calculated from the daily measurements of the intensities. So the total intensity of the coronal emission line 5303 Å for all helio-longitudes (0°–360°) has been used for our calculations. The corresponding curves of each half-year for the period 1964–1973 are presented in Figure 1. Zero points of the curves are at the north pole of the Sun. We believe that the intensity of this line is practically uniform over all longitudes ± 60° around the solar meridian and reaches 10–15 absolute coronal units. At the beginning of the solar cycle the activity starts at longitudes of 50°–120°, then it grows rapidly and forms two very well-expressed peaks in the cycle maxima. The brightness in this period is about ten times higher than that in the solar minima (Sýkora, 1980).

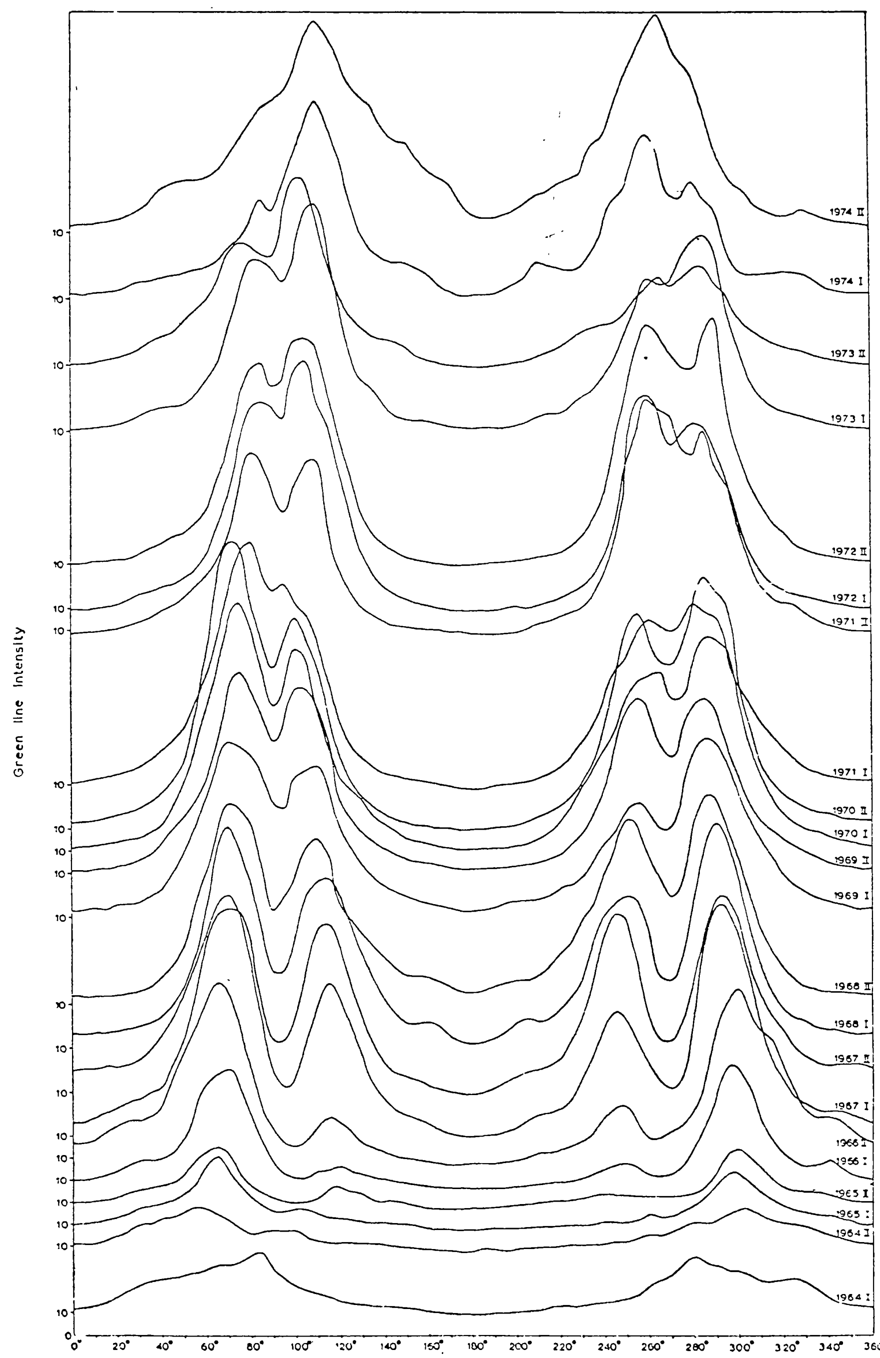

Fig. 1. Longitudinal distribution of the corona green line intensity for the period 1964 I–1974 II.

These basic data are homogeneous and continuous from 1964 to 1974. In order to study their reliability we have compared them with other homogeneous values of the green line intensity which Rušín (1980) gave by use of Rybanský's theory (Rybanský, 1975; Rušín and Rybanský, 1975; Rušín *et al.*, 1979). These values are considered to be more useful than those from the Pic-du-Midi Observatory (Table I), because they are derived from the comprehensive measurements of all coronal observatories. When we

TABLE I

Semi-annual values of green line intensity measured at Pic-du-Midi $I_{\text{Pic}}^{\text{obs}}$, obtained by Rybanský's theory $I_{\text{Ryb}}^{\text{obs}}$ and calculated by relation (a1) $I_{\text{Pic}}^{\text{Ryb}}$

1965	I	15.4	254.8	18.07	−2.67
	II	14.6	251.2	14.69	−0.09
1966	I	19.7	409.5	20.58	−0.88
	II	30.6	652.4	29.26	1.34
1967	I	43.9	962.5	39.61	4.29
	II	43.0	1011.5	39.21	13.79
1968	I	44.8	1151.8	43.14	−1.66
	II	45.2	1117.2	41.38	−3.82
1969	I	39.1	1081.4	40.50	1.40
	II	39.7	998.3	38.69	−1.01
1970	I	45.1	1110.7	45.71	0.61
	II	47.7	1186.0	53.18	5.48
1971	I	41.1	691.6	34.75	6.35
	II	37.6	639.9	37.42	0.18
1972	I	40.1	704.8	49.99	9.89
	II	43.6	504.4	45.85	−2.25

compare these values with the corresponding ones from the Pic-du-Midi we find that the values of Pic-du-Midi $I_{\text{Pic}}^{\text{Ryb}}$ can be computed from the Rybanský measurements $I_{\text{Ryb}}^{\text{obs}}$ by the relation

$$I_{\text{Pic}}^{\text{Ryb}} = I_{\text{Ryb}}^{\text{obs}}(11 + 16\sin(\pi/16)t)^{-1}, \quad t = 0, 1, \ldots, 16. \tag{1}$$

The standard deviation between observed values of Pic-du-Midi $I_{\text{Pic}}^{\text{obs}}$ and those calculated by the relation (1) $I_{\text{Pic}}^{\text{Ryb}}$ for the time period 1965–1972 is $\sigma = \pm 3.1$. The intensity variation of the Pic-du-Midi values (relation (1)) differs very little from the observed ones from Pic-du-Midi Observatory as presented in Figure 2. Thus, the reliability of the Pic-du-Midi values is shown and the ratio of these values to those of Rybanský is dependent only on the time.

In this work we have also used semi-annual values of the number of the most important proton events N_p measured in polar caps (Shapley *et al.*, 1979) for the same time period. The values of the sunspot number R_z for the calculation of the index $I_a(R)$, which is a successful approximation of the area index I_a as Xanthakis and Poulakos (1978) have shown, are taken from the tables of the *IAU Quarterly Bulletin on Solar Activity*.

For a more accurate estimation of the green line intensity the number of high-speed solar wind streams recorded near the Earth is also used. These data are taken from the catalog of Lindblad and Lundstedt (1981). This catalog is based on data compilation by J. King available through the National Space Science Data Center (King, 1977).

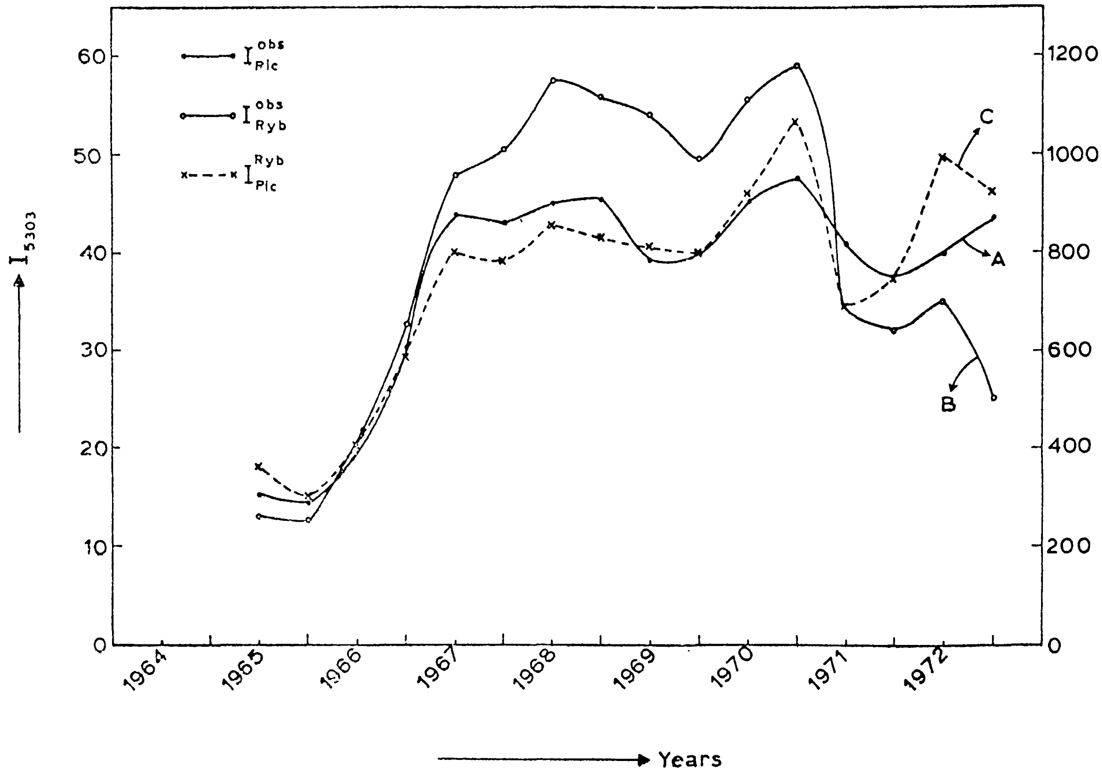

Fig. 2. The good agreement between the Pic-du-Midi observed values of green line intensity (curve A) and those obtained by relation (1) (curve C) using the Rybanský's values (curve B) is shown here for the period 1964–1972.

3. High-Speed Solar Wind Streams

Generally, a high-speed plasma stream (HSPS) is characterized by a large increase in the solar wind velocity lasting for several days. However, in searching for streams various definitions of the HSPS have been given. For example, Intrilligator (1977) defines a high-speed stream as one having a rapidly rising increase in solar wind speed and a peak velocity greater than or equal to 450 km s^{-1}. Broussard *et al.* (1978) define a high-speed stream as a period in which the solar wind speed is greater than, or equal to, 500 km s^{-1} average per day. Iucci *et al.* (1979) define a HSPS as a stream where the difference between the maximum daily mean speed and the mean value between the speeds immediately preceding and following the stream is greater than, or equal to, 100 km s^{-1} and the total duration of the stream greater than two days. According to Lindblad and Lundstedt (1981), a possible HSPS is that in which the difference between a smallest 3-hr velocity value for a given day and the largest 3-hr value for the following day is greater than, or equal to, 100 km s^{-1}. These last definitions are more adequate for the purpose of solar-terrestrial studies, because they emphasize the velocity gradient of a high-velocity stream and not the maximum velocity.

As mentioned above, the high-speed plasma streams are of two basic types: coronal hole streams and loop structure streams with different properties. The first one is a long-lasting HSPS emitted by coronal holes consistent with a solar wind from a quiet solar region with a unipolar diverging magnetic field. The second one, characterized by lower solar wind speed, seems to be associated with strong active regions emitting solar flares accompanied by type IV radio emission and producing Forbush decrease in the Earth (Iucci *et al.*, 1979).

TABLE II

Semi-annual values of green line intensity measured $I_{\mathrm{Pic}}^{\mathrm{obs}}$ and calculated $I_{\mathrm{Pic}}^{\mathrm{Cal}}$ by relation (2). The number of loop structures and coronal hole streams is also given.

		S	H	$I_{\mathrm{Pic}}^{\mathrm{obs}}$	$I_{\mathrm{Pic}}^{\mathrm{Cal}}$
1964	I	0	4	18.9	15.9
	II	0	7	15.1	12.8
1965	I	0	13	15.4	16.9
	II	1	11	14.6	14.1
1966	I	2	6	19.7	19.7
	II	4	3	30.6	29.2
1967	I	8	7	43.9	43.8
	II	6	13	43.0	45.0
1968	I	4	19	44.8	44.4
	II	2	8	45.2	43.9
1969	I	8	8	39.1	39.8
	II	7	13	39.7	40.4
1970	I	8	9	45.1	45.1
	II	7	12	47.7	45.6
1971	I	8	14	41.1	41.6
	II	0	13	37.6	36.0
1972	I	5	11	40.1	39.0

The number of these two kinds of streams are given separately in Table II for the time period studied here. It is interesting to note that the number of active region streams during sunspot maximum is large, while their number during sunspot minimum is almost equal to zero. The opposite picture for the number of coronal hole streams is not so clear, as coronal holes wax and wane during the sunspot cycle. Nevertheless, the flattening of the total number of streams at total maximum (see Figure 4) may be attributed to the contraction and disappearance of these low-density region and the presence of bright loops and streams.

4. Computations and Results

Many authors (Rušín *et al.*, 1979; Sýkora, 1980) have remarked that many problems are encountered in the study of the relations between coronal emission and other manifestations of solar activity. This is not only due to imperfect observations of the emission corona and particularly to the spatial distribution of the individual corona structures in the vicinity of the solar limb, but there are also other factors which have recently been discovered, such as the existence of two maxima in the course of the cycle (Gnevyshev, 1967), etc.

In the attempt to overcome these difficulties we think it useful to develop a formula which can predict the time variations of the green line intensity as a function of solar parameters such as the number of sunspots and faculae well represented by the index $I_a(R)$, the number of proton events N_p, the loop structures and coronal holes well represented by the number of the fast solar-wind streams. For this we study the variations of green line intensity with respect to the above-mentioned solar parameters for the time period 1964–1974 and we give the following relation for the green line intensity I_{5303}:

$$I_{5303} = C + 0.155(1 + \sqrt{N_p})I_a(R) + P(t) + K(S + H - 17.3)\,, \tag{2}$$

where C is a constant with values equal to 12 for the years of solar minimum and equal to 17 for the other years of the solar cycle; N_p, the number of proton events; $I_a(R)$, the solar activity index (Xanthakis *et al.*, 1978); $P(t)$, a three-year periodic term which has the same phase for the ascendant branches of solar activity and inverse phase for the descendent branches; S, the number of high-speed streams related to the loop structure sola regions; H, the number of high-speed streams emitted by coronal holes; and K, a constant with the following values: $K_1 = 0.8$ for the years 1967 II–1970 II (solar maximum); $K_2 = 0.1$ for the years 1964 I–1967 I, 1971 I–1972 II (solar minimum and remaining years).

It is remarked that the constant K has maximum values during the years where the term $P(t)$ has appeared.

The first three terms of the relation (2) have also been discussed in a previous work (Xanthakis *et al.*, 1982). The introduction of the last term into the relation (2) provides a good agreement between the values of this term and the residuals between observed $I_{\rm Pic}^{\rm obs}$, and calculated by the previous work $I_{\rm Pic}^{\rm Cal}$, values of the green line intensity, as appeared in Figure 3.

The values of the green line intensity $I_{\rm Pic}^{\rm obs}$ observed at the Pic-du-Midi Observatory and those ones calculated by the relation (2) $I_{\rm Pic}^{\rm Cal}$ are given in Table II and presented in Figure 4. The standard deviation between observed and calculated values of green line intensity is $\sigma = \pm 1.9$. It is worth noting that the corresponding standard deviation between values observed and calculated, by relation (4) of the previous work, was $\sigma = \pm 2.5$ (Xanthakis *et al.*, 1982).

Attention should be drawn to the fact that the curve of the total number of high-speed solar wind streams follows the curve of green line intensity over the 11-yr solar cycle 20 (Figure 4). If we take into account only the number of streams with velocity smaller than 500 km s^{-1} (catalogue by Broussard *et al.*, 1978) and greater than 100 km s^{-1}, the standard deviation become $\sigma = \pm 1.48$. Remaining streams with velocity ≥ 500 km s^{-1}

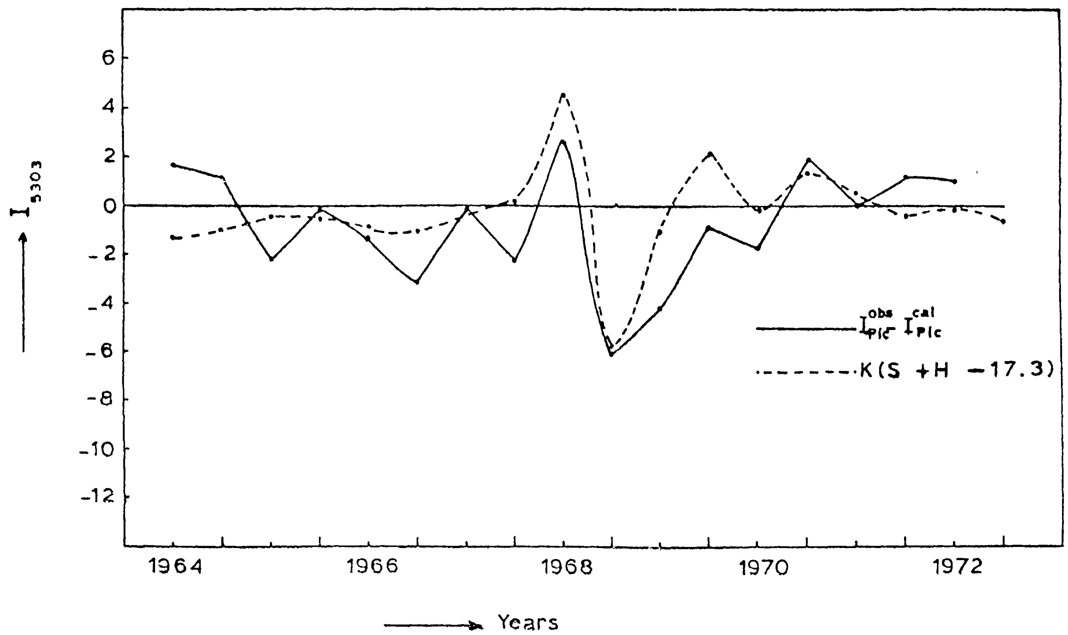

Fig. 3. The values of the term $K(S + H - 17.3)$ and the differences between the values of $I^{\text{obs}}_{\text{Pic}}$ and those of $I^{\text{Cal}}_{\text{Pic}}$ calculated by relation (4) of the previous work have the same training.

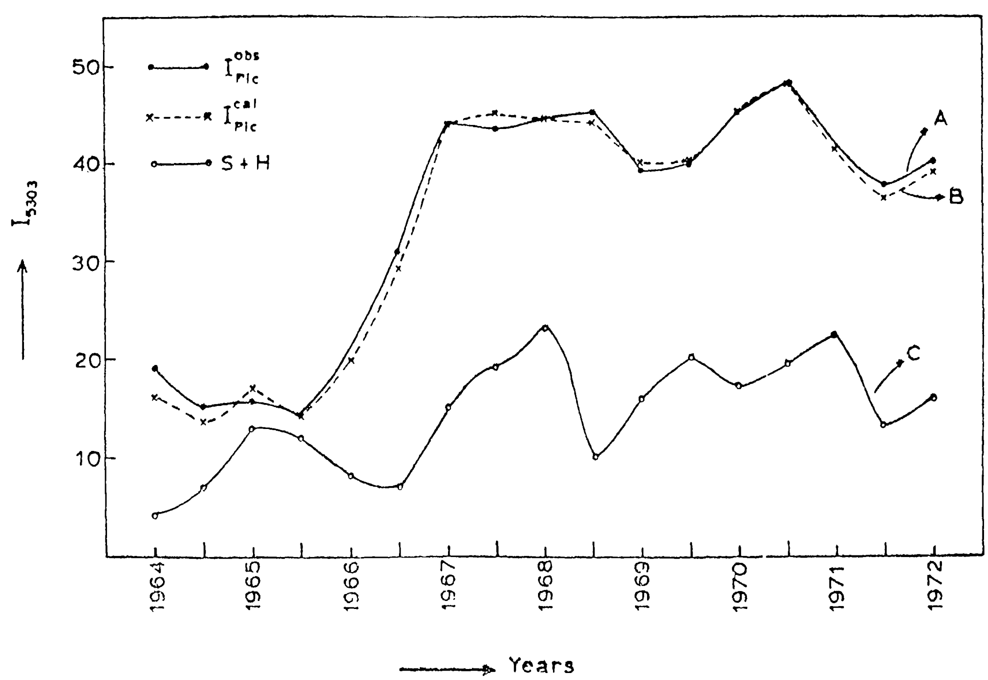

Fig. 4. Semi-annual values of the green line intensity measured by Pic-du-Midi, $I^{\text{obs}}_{\text{Pic}}$ and calculated by relation (2), $I^{\text{Cal}}_{\text{Pic}}$, are presented here. The total number of solar wind fast streams $(S + H)$ show almost the same feature with the green line intensity through the sunspot cycle 20.

were found to be associated with coronal holes at less than 40° latitude and have no association with streams at the Earth according to Broussard *et al.* (1978).

5. Theoretical Justification

If we accept that the electron density N of the solar corona is homogeneous (Billings, 1966) the green line intensity I_{5303} for a given observed line xx can be computed by the relation

$$I_{5303} = \int_{-\infty}^{+\infty} A(Te) N_e^{1+a} \, \mathrm{d}x \,, \tag{3}$$

where $A(Te)$ is a distribution function corresponding to the electron temperature and a is a coefficient with values between 0.5 and 1 in corona region (Dollfus, 1971). These values of a are close to 1 for regions where collisional effects (i.e., loop structures and coronal holes) are predominant and close to 0.5 if radiative effects are important (Zirker, 1971; Pottasch, 1963).

However, more and more observations tend to prove that if the corona seems to be globally homogeneous it is locally very heterogeneous. Allen (1973) and Leroy and Trellis (1974) give the values of a coronal irregularity factor. Altschuler and Newkirk (1969) and Rust and Roy (1971) in their reconstruction of coronal magnetic fields, compute loop-shaped field lines above the active centers. Recently, Vaiana and Rosner (1978) suggested that only the loop structures and coronal holes are the exclusive responsible regions of coronal radiative emission. Likewise, Priest (1978) pointed out that closed structures are often seen to consist of distinct magnetic loops in quiet regions and inside active regions.

These assumptions led different authors, i.e., Poulain (1981) to give a numerical simulation of the I_{5303} line corona intensity using the following relation for the electron density N_e at a point of the corona with a loop stream

$$N_e = N_0 \, e^{-ap^2} e^{-k(2+h)} \,, \tag{4}$$

where h is the height of the point; p, the distance from the axis of the flux-tube; a, a parameter which depends on the thickness of the stream; N_0, the density of the quiet Sun; and k, a constant.

In order to express the green line intensity for non-homogeneous corona such as regions of coronal holes and loop structures we have accepted the following assumptions:

(a) The electron density of the corona is proportional to the solar magnetic field. However, also the production of solar flares and fast solar wind streams which originate from coronal holes and loop structrures are proportional to the magnetic fields. So, the following relations can be adopted:

$$N_e = (N_p + H + S) N_e(t) \tag{5}$$

and

$$\Delta N_e = N_e - \overline{N}_e = (N_p + H + S)\Delta N_e(t)\,, \tag{6}$$

where $N_e(t)$ is a function of time; $\overline{N}_e$, the mean electron density of the corona; and $\Delta N_e(t) \approx \overline{N}_e$.

(b) The function $A(Te)$ can be given by the expression

$$A(Te) = I_a(T)F(Te)\,, \tag{7}$$

where $F(Te)$ is a function of the electron temperature (Xanthakis *et al.*, 1982).

With the aid of the relations (6) and (7) Equation (2) becomes

$$I_{5303} = \int_{-\infty}^{+\infty} I_a(R)F(Te)\overline{N}_e^{1+a}(1 + N_p + H + S)^{1+a}\,\mathrm{d}x\,, \tag{8}$$

which is an analytical expression of the intensity at 5303 Å with the indices N_p, $I_a(R)$, S, and H. If the above polynominal is developed in series and we take into account only the first terms the variation of I_{5303} ($\Delta I_{5303} = I_{5303} - I_0$) is given by the expression

$$I_{5303} = I_0 + (1 + a)I_a(R)\,(1 + N_p^a + S^a + H^a) \int_{-\infty}^{+\infty} \Delta F(Te)\overline{N}_e^{1+a}\,\mathrm{d}x - $$
$$- aI_a(R) \int_{-\infty}^{+\infty} \Delta F(Te)\overline{N}_e^{1+a}\,\mathrm{d}x + P_1(t)\,, \tag{9}$$

where I_0 is the intensity of green line during the quiet Sun and $P_1(t)$ are the other terms of the polynomial with exponent smaller than a.

If we take into account that $a = 1$ for coronal holes and loop structures (Drago, 1980; Poulain, 1981) and $a = 0.5$ for the rest of the corona (Dollfus, 1971; Xanthakis *et al.*, 1982), we find according to our previous work that

$$I_{5303} = C + 0.155(1 + \sqrt{N_p})I_a(R) + P(t) +$$
$$+ 2I_a(R)S \int_{-\infty}^{+\infty} \Delta F(Te)\overline{N}_e^2\,\mathrm{d}x +$$
$$+ 2I_a(R)H \int_{-\infty}^{+\infty} \Delta F(Te)\overline{N}_e^2\,\mathrm{d}x +$$
$$- 2I_a(R) \int_{-\infty}^{+\infty} \Delta F(Te)\overline{N}_e^2\,\mathrm{d}x + p_1(t)\,, \tag{10}$$

If we identify this equation with the relation (2) we find that

$$K = 2I_a(R) \int_{-\infty}^{+\infty} \Delta F(Te)\overline{N}_e^2 \, dx \,. \tag{11}$$

We can also estimate the order of magnitude of the term $p_1(t)$ by the relation

$$p_1(t) = -16.3 \text{ K} \,. \tag{12}$$

As we can see in relation (4)

$$\overline{N}_e^2 = N_0^2 B \,, \tag{13}$$

where B is a function depending only on the geometry of loop structures for a given time period. We can also admit for the coronal holes (Drago, 1980) that

$$\overline{N}_e^2 = N_0^2/D \,; \tag{14}$$

where D is a function depending only on the coronal hole size.

We separate the loop structures and the coronal holes into two types: those which appear at a solar maximum and those which appear at a solar minimum and remaining years. Thus identifying the relation (10) with the last term of the relation (2) we obtain for the time period of maximum the equation

$$2I_a(R)S_{\max} \int_{-\infty}^{+\infty} \Delta F(Te)N_0^2 B_{\max} \, dx + \\ + 2I_a(R)H_{\max} \int_{-\infty}^{+\infty} \Delta F(Te)N_0^2/D_{\max} \, dx = K_1(S + H) \,; \tag{15}$$

and for the time period of minimum,

$$2I_a(R)S_{\min} \int_{-\infty}^{+\infty} \Delta F(Te)N_0^2 B_{\min} \, dx + \\ + 2I_a(R)H_{\min} \int_{-\infty}^{+\infty} \Delta F(Te)N_0^2/D_{\min} \, dx = K_2(S + H) \,. \tag{16}$$

From the relations (15) and (16) we obtain

$$B_{\max}/B_{\min} = D_{\min}/D\text{S}_{\max} = K_1/K_2 = 8 \,. \tag{17}$$

This means that the number and the characteristics of the streams of the solar active regions emitting solar flares at the solar maximum are much stronger than those of the other phases of the solar cycle. Conversely, the size of the coronal holes which appear at solar maximum is very small, while the coronal hole size at the solar minimum and other years is large.

Indeed many authors have observed the same from spacecraft observations. Broussard *et al.* (1978) found that using the X-ray and *XUV* solar images obtained from rockets over the period 1965–1974 the polar coronal holes, prominent at solar minimum, decreased in areas as solar activity increased. They were also small or absent at maximum phase. Sheeley (1980) indicated that at sunspot minimum when the polar fields are strong, the polar holes should be relatively large and symmetric. Near the sunspot maximum, when the polar fields weaken and reverse, the polar holes should contrast and disappear. Broussard *et al.* (1978), Hundhausen *et al.* (1980) have showed that the ratio of coronal hole size during sunspot minimum to the corresponding size during sunspot maximum is almost equal to eight.

Also the presence of bright loops and streams during sunspot maximum gives large and wide streams recorded near the Earth.

6. Conclusions

The study of high-speed solar wind streams with respect to the coronal intensity at 5303 Å during the solar cycle 20 led us to define a new integrated index of the solar activity.

According to our new relation (2) the coronal intensity at 5303 Å becomes an index of coronal activity with four variables: proton events N_p, solar index $I_a(R)$, loop streams S, and coronal-hole streams H. In this way, the coronal intensity expresses almost all the photospheric and coronal phenomena which occur in the Sun. It is a more realistic solar indicator than the sunspot number because it has a much higher correlation with phenomena of interplanetary space and geomagnetic indices.

Another interesting point of this relation is that the green line intensity presents a 3-yr period expressed by the term $P(t)$. Quasi-biennual periodicities of the green line intensity in the main range of 20–33 months have also been observed in the Lomnický stit data of this line (Apostolov, 1988), while Ozguç and Ocer (1987) have observed in the same data periods of 2.5, 3.5, 5, and 14.5 yr. We also note that the green line intensity of the Pic-du-Midi Observatory appears north–south and east–west asymmetries with peaks of 11 months and 12 months and 7.5 yr, respectively (Tritakis *et al.*, 1988).

Moreover, it is concluded here that the size of coronal holes is small during sunspot maximum in contrast to the loop streams which are large. This may be attributed to the contraction and disappearance f the low-density coronal-hole regions and to the presence of bright loops near sunspot maximum. At any rate the contribution of the number of streams to the numerical value of green line intensity is not so important as several workers have assumed (Xanthakis *et al.*, 1980).

Certainly, the investigated time period is still very short to be able to draw general conclusions about the relation of the coronal emission and different variations which were observed in the solar activity. We note here that unfortunately the relation between the green line intensity observed by the Pic-du-Midi Observatory and that one simulated by Rybanský data (expression (1)) is nonlinear as one would expect in order to extend this work in the next solar cycle. As is known, Rybanský *et al.* (1988) in order to compute the coronal index have used data from four observatories located at different places and measured at different days during the year. It means that probably there is not an homogeneity in the technics of these two observations. In the future, we believe that most suitable available Fe XIV 5303 Å coronal observations would be useful in the study of the large-scale solar magnetic fields and their associated coronal holes and also the sporadic occurrence of loop structures introducing transient and long-term variations into the solar wind streams at the Earth.

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References

Allen, C. W.: 1973, *Astrophysics Quantities*, 3rd ed., Athlone Press, London.

Altschuler, M. D. and Newkirk, G.: 1969, *Solar Phys.* **9**, 131.

Apostolov, E.: 1988, *Bull. Astron. Inst. Czech.* **39**, 243.

Billings, D. E.: 1966, *A Guide to the Solar Corona,* Academic Press, New York.

Broussard, R. M., Sheeley, N. R., Jr., Tousey, R., and Underwood, J. H.: 1978, *Solar Phys.* **56**, 161.

Dollfus, A.: 1971, in C. J. Macris (ed.), *Physics of Solar Corona*, D. Reidel Publ. Co., Dordrecht, Holland, p. 97.

Dollfus, A.: 1983, *L'Astronomie* **97**, 107.

Drago, F. C.: 1980, *Solar Phys.* **65**, 237.

Gnevyshev, M. N.: 1967, *Solar Phys.* **51**, 175.

Hundhausen, A. J., Sime, D. G., Hansen, R. T., and Hansen, S. F.: 1980, *Science* **207**, 761.

Intrilligator, D.: 1977, in M. Shea *et al.* (eds.), *Study of Travelling Interplanetary Phenomena,* D. Reidel Publ. Co., Dordrecht, Holland, p. 195.

Iucci, N., Parisi, M., Storini, M., and Villoresi, G.: 1979, *Nuovo Cimento* **2C**, 4, 421.

King, J.: 1977, *Interplan Medium Data Book,* NSSDC/WDC-A Greenbelt, Maryland.

Leroy, J. L. and Trellis, M.: 1974, *Astron. Astrophys.* **35**, 289.

Lindblad, B. A. and Lundstedt, H.: 1981, *Solar Phys.* **74**, 197.

Mavromichalaki, H., Vassilaki, A., and Marmatsouri, L.: 1988, *Solar Phys.* **115**, 345.

Nolte, J. T., Krieger, A. S., Timothy, A. F., Gold, R. E., Roelof, E. C., Vaiana, G. S., Lazarus, A. J., Sullivan, J. D., and McIntosh, P. S.: 1976, *Solar Phys.* **46**, 303.

Ozguç, A. and Ocer, C.: 1987, *Solar Phys.* **134**, 141.

Pottasch, S. R.: 1963, *Astrophys. J.* **137**, 945.

Poulain, P.: 1981, *Solar Phys.* **70**, 229.

Priest, E. R.: 1978, *Solar Phys.* **58**, 57.

Rozelot, J. P. and Fulconis, M.: 1983, *Solar Phys.* **84**, 77.

Rušín, V.: 1979, *Bull. Astron. Inst. Czech.* **31**, 9.

Rušín, V. and Rybanský, M.: 1975, *Bull. Astron. Inst. Czech.* **26**, 160.

Rušín, V., Rybanský, M., and Scheirich, L.: 1979, *Solar Phys.* **61**, 301.

Rust, D. M. and Roy, J. R.: 1971, in R. Howard (ed.), 'Solar Magnetic Fields', *IAU Symp.* **43**, 569.

Rybanský, M.: 1975, *Bull. Astron. Inst. Czech.* **31**, 9.

Rybanský, M., Rušín, V., and Dzifáková, E.: 1988, *Bull. Astron. Inst. Czech.* **39**, 106.

Shapley, A. H., Ellyett, C. D., and Kroehl, H. N.: 1979, *Solar-Terrestrial Physics and Meteorology*, Working Document III.

Sheeley, N. R., Jr.: 1980, *Solar Phys.* **65**, 229.

Simpson, J. A. and Wang, J. R.: 1967, *Astrophys. J.* **149**, 173.

Simpson, J. A. and Wang, J. R.: 1970, *Astrophys. J.* **161**, 265.
Sýkora, J.: 1980, in M. Dryer and E. Tandberg-Hanssen (eds.), *Solar and Interplanetary Dynamics*, p. 87.
Tritakis, V. P., Mavromichalaki, H., and Petropoulos, B.: 1988, *Solar Phys.* **115**, 367.
Vaiana, G. S. and Rosner, R.: 1978, *Ann. Rev. Astron. Astrophys.* **16**, 393.
Venkatesan, D., Shukla, A. K., and Agrawal, S. P.: 1982, *Solar Phys.* **81**, 375.
Waldmeier, M.: 1971, in C. J. Macris (ed.), *Physics of Solar Corona*, D. Reidel Publ. Co., Dordrecht, Holland, p. 1300.
Waldmeier, M.: 1981, *Solar Phys.* **70**, 251.
Xanthakis, J. and Poulakos, C.: 1978, *Praktica Acad. Athens* **53**, 286.
Xanthakis, J., Petropoulos, B., and Mavromichalaki, H.: 1980, in *Sun and Climate International Conference*, CNES, p. 101.
Xanthakis, J., Petropoulos, B., and Mavromichalaki, H.: 1982, *Solar Phys.* **76**, 181.
Zirker, J.: 1977, *Coronal Holes and High-Speed Wind Streams*, Colorado Associated Univ. Press, Boulder, Colorado.
Zirker, J. B.: 1971, in C. J. Macris (ed.), *Physics of Solar Corona*, D. Reidel Publ. Co., Dordrecht, Holland, p. 140.