A POSSIBLE E-W ASYMMETRY OF THE CORONAL EMISSION LINE INTENSITIES AND K-CORONA BRIGHTNESS

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Abstract. The analysis of the daily measurements of the coronal green and red line intensities as well as the K-corona brightness, which have been collected by the Pic-du-Midi Observatory, for the time period 1944–1974, has revealed some very interesting features. North-South (N-S) asymmetries for all these coronal intensities are confirmed again for this time period. The main point of this analysis is a strong evidence of longitudinal distribution of the coronal intensities as derived from the data record. In our effort to confirm this asymmetry, we have examined the yearly and monthly distribution of the asymmetry coefficient in each solar quadrant showing that the northeast (NE) quadrant appears the most active of all. We have also examined the intensity ratios measured at the East and West solar limbs which is continuously greater than the unit.

A seasonal variation of this ratio has also been reported with a maximum during the winter period and a minimum during the summer period.

1. Introduction

The coronal intensity is a numerical expression of the total radiated energy in the coronal emission lines which are caused from highly ionized atoms. The most important of these lines in the visible wavelengths, are the green (Fe XIV, λ_{5303}Å) and the red (Fe X, λ_{6374}Å) lines which allow to observe the corona on the solar disk. Useful information about the intensity of these lines can be inferred by detailed observations of the electron density within coronal holes and dense coronal regions (Noëns and Leroy, 1981).

Several attempts have recently been made by many authors to explain possible asymmetries of the corona emission lines. A North-South asymmetry of the green line intensity which correlates negatively with the solar activity has been confirmed by Pathak (1972), Rusin (1980) and Tritakis *et al.*. (1988). However, Sýkora (1992) studying a longer period of this asymmetry (1943-1991) noticed that the above mentioned result does not appear very clear. On the other hand, a time variable asymmetry of the green line intensity between East and West solar limbs for the

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time period 1944–1974 has also been reported by Trellis (1960) and Tritakis *et al.* (1988). In this last work it is pointed out that the combination of a N-S and an E-W asymmetry makes the NE solar quadrant appear to be the most active of all in the 22-year period 1949–1971, while the combination of a S-N and an E-W asymmetry points to the SE quadrant as the most active in the period 1944–1948 and 1972–1974.

Moreover, Tyagun and Rybansky (1981) have shown that an E-W asymmetry is present in the green coronal line in the 20th solar cycle and in the red line intensity in the period 1969–1972. This asymmetry shows an annual variation which is positive in the first half of the year and negative in the second, it has also been noticed by Noëns *et al.* (1991). Xanthakis *et al.* (1991) have recently attempted to make the E-W phenomenon more evident; they also point out that this effect is real and free from observational or instrumental errors. It is noteworthy that Pajdušákova (1966) has studied E-W and N-S asymmetries using data of nine coronal Observatories revealing that the east-west asymmetry is rather slight. Sýkora (1971, 1980, 1992) has analysed the asymmetries of the semi-annual green corona data of various corona stations and has found the largest east-west asymmetry from the Pic-du-Midi and Norikura Observatories but they were opposite to one another. These results made Sýkora very skeptical about the physical reality of the E-W asymmetry since it could be introduced by position angle errors.

In this work we have tried to examine existing asymmetries of the green line intensity measured at the Pic-du-Midi Observatory for the period 1944–1974 in each solar quadrant separately, so that preferential suractive areas of the solar corona could be found. This research has been also extended to the study of possible asymmetries in the red line intensities as well as to the K-corona brightness during the same time period. Moreover, a strong evidence of longitudinal distribution of the green and the red emission line intensities and the K-corona brightness values during the complete data record has become apparent when we examine the intensity ratio measured on the East and the West solar limbs.

2. Selection of Data

In order to study possible enhancements of the emission lines in the four solar quadrants, daily measurements of the absolute intensity of the coronal emission lines at 5303 Å and 6374 Å as well as the brightness of the K-corona measured at Pic-du-Midi Observatory have been used. Patrol observations of the two emission lines were performed daily from 01/01/1947 to 31/12/1974 (3497 and 1348 observing days respectively) and the K-corona was measured from 01/01/1964 to 14/07/1976 (787 observing days). Two different instruments were used for these observations: a 20 cm spectrocoronagraph and a K-coronameter polarimeter. These measurements have been obtained for all heliocentric sectors around the solar limb with a resolution of 5° and a distance of about $40''$ to $2''$ from the Sun's edge. Our data are obtained in a polar coordinate system defined by the central meridian passage. The unit of the measured intensity of these lines is 10^{-6} times the intensity at a 1 Å wavelength width of the continuous photospheric spectrum. The uncertainty of each single measurement is about 1–2 × 10^{-6} B_0, where B_0 is the absolute photospheric brightness in the center of the solar disk. Since the east-west inequality within a zone ±60°, on both sides of the solar equator, has been calculated by 25 single measurements on each side of the solar disk and the calculation extents to a span of 20–30 years, the average error of each east-west inequality could be expected to $\pm 0.02 \times 10^{-6} B_0$ which is very small.

The detailed statistical comparison of Pic-du-Midi data with those of several other coronal observatories (Sýkora, 1971) has clearly shown that the Pic-du-Midi photometric scale overestimates the low intensities, a result which has been confirmed by Leroy and Trellis (1974) too. The detailed analysis of the green line intensity values made by Tritakis *et al.* (1988), pointed out that these data set is consistent to a homogeneous and free of trend time-series. A similar analysis which has been carried out in the present report has shown that the red line intensity as well as the K-corona values are homogeneous and reliable as well.

3. N-S and E-W Asymmetries

A common way to express asymmetries is the use of the coefficient which is defined by the relation

$$A = \frac{I_i - I_j}{I_i + I_j}, \qquad (1)$$

where in our case I_i, I_j are mean yearly or monthly values of the green line intensity in the i and j solar limbs or quadrants.

We have calculated day-by-day the north-south (N-S) and the east-west (E-W) asymmetry coefficients of all the coronal data of the Pic-du-Midi Observatory and some typical examples of these asymmetries are given in Figures 1, 2, 3 and 4. It is very interesting that in most of the cases (80% at least) the N-S and the E-W asymmetry coefficients are positive that is the North and the East Solar hemispheres appear more active than the South and the West, respectively. In Figure 5, the yearly values of the north-south (N-S) and the east-west (E-W) asymmetry coefficients for the time span 1944–1974 are depicted. From this figure it is apparent that the integrated green line intensity in the north solar hemisphere appears in general more intensive than in the south, while the maximum asymmetry of this coefficient appears in the year 1966. It is also confirmed that after the year 1971 the north-south asymmetry shows a tendency to turn to negative. An additional information of this figure is that the north-south asymmetry around the maxima of the cycles No 18,19 (years 1947, 1957) turns to be negative while the maximum of the cycles No 20 it is positive showing perhaps in this way a 22-years feature of the green line asymmetry in the epoches of maxima.

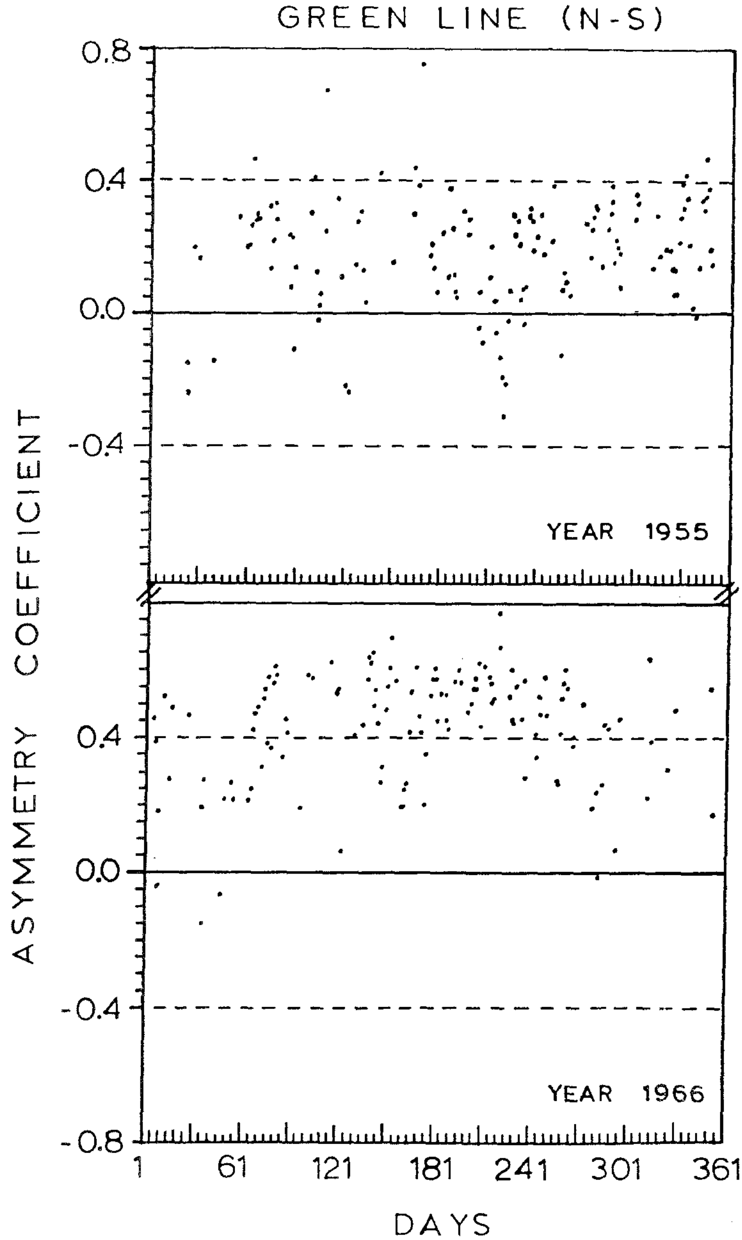

Fig. 1. N-S asymmetry coefficients of the green line intensity for the years 1955, 1966.

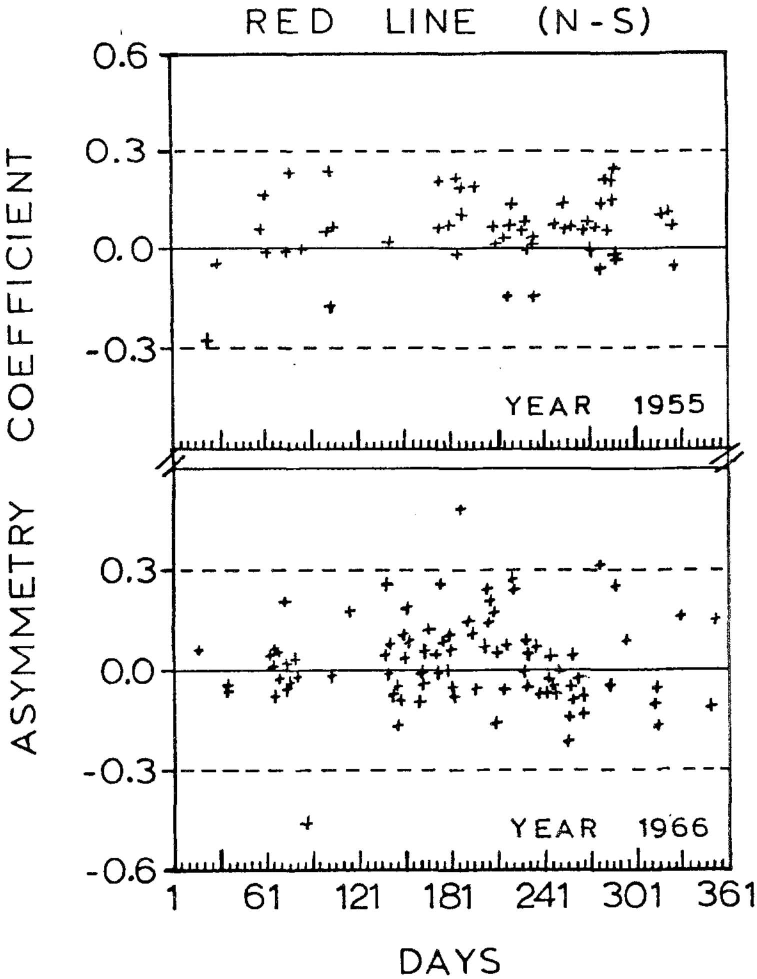

Fig. 2. N-S asymmetry coefficients of the red line intensity for the years 1955, 1966.

The same picture for the N-S asymmetry is shown in Figure 6, where the course of the yearly red line intensity values is presented. It is noted that the red line intensity of the north solar hemisphere appears in general more intensive than the South. The maximum of this asymmetry coefficient appears in the year 1960, while after the year 1971 the north-south asymmetry has the tendency to turn to negative. A 22-years periodicity of the emission line asymmetries during the time period 1944-1973 appears very possible because in both cases after the years 1948 and 1971 the asymmetry turns from positive to negative. In the Figure 7 the N-S asymmetry of the K-corona intensity for the period 1964 to 1976 is depicted. We

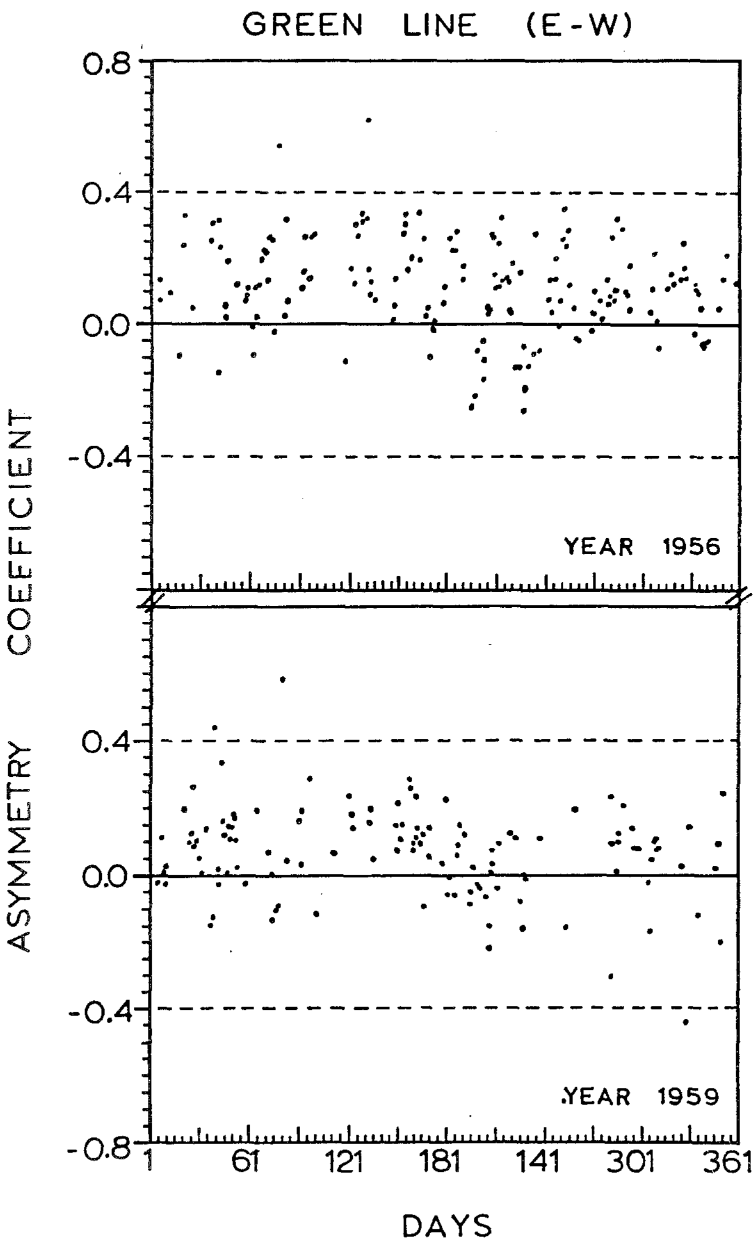

Fig. 3. E-W asymmetry coefficients of the green line intensity for the years 1956, 1959.

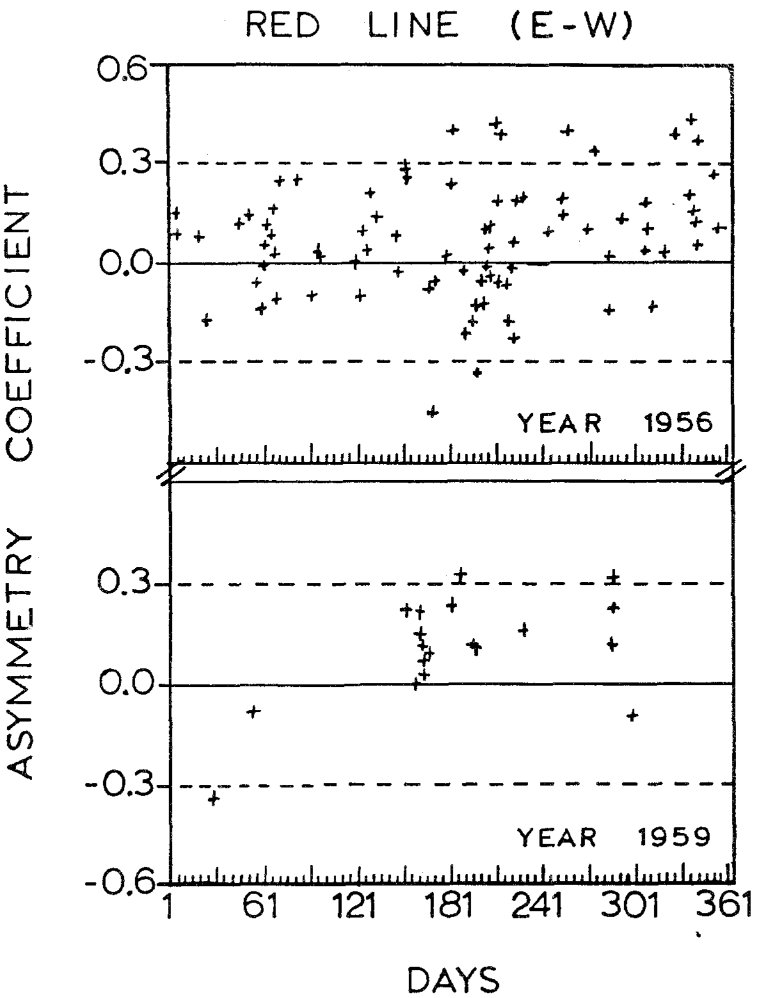

Fig. 4. E-W asymmetry coefficients of the red line intensity for the years 1956, 1959.

note that the asymmetry coefficient of this intensity is generally positive which means that the northern solar hemisphere is more active than the southern one. After the year 1971 the North-South asymmetry has also the tendency to turn to negative.

Closing the description of the N-S asymmetries of Figures 5, 6 and 7 we underline that all corresponding panels of these figures are similar in structure and order of magnitude for the green, the red and the K-corona intensity, confirming the existence of the N-S asymmetry in all coronal intensities. In the lower panels

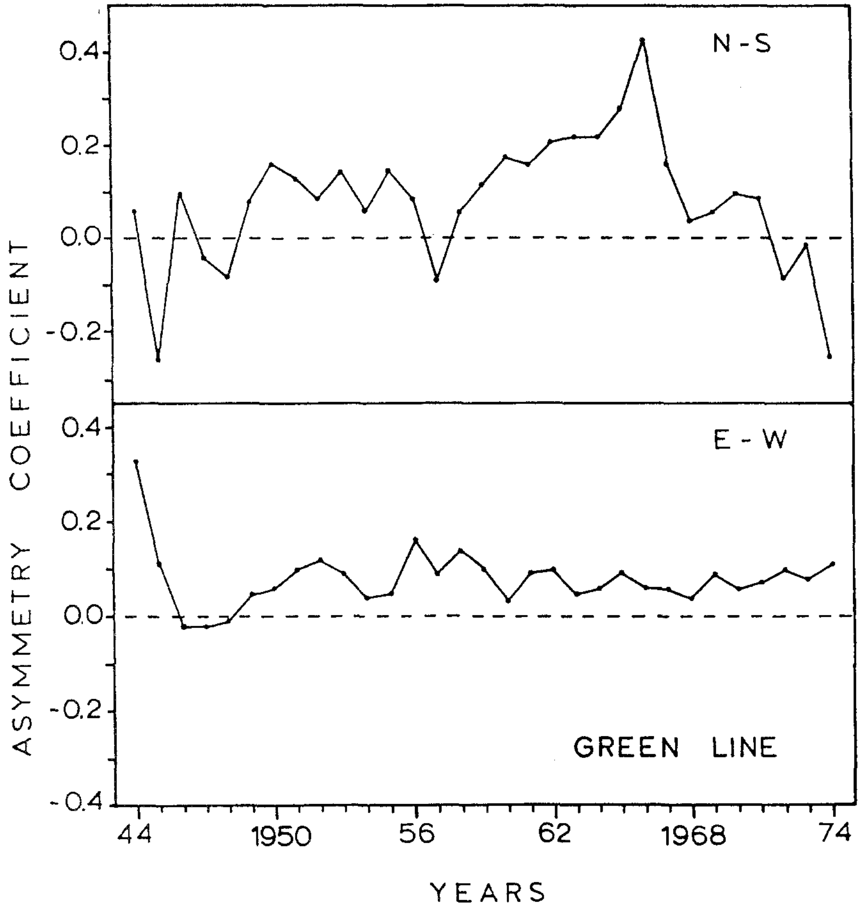

Fig. 5. Yearly values of the N-S and E-W asymmetry coefficients of the green line intensities for the period 1944–1974.

of these figures the E-W asymmetry coefficient of the green, red and K-corona intensities is also depicted.

In Figure 5 (lower panel) the yearly variation of the green line intensity shows clearly that this intensity predominates in the east solar hemisphere for the period 1944–1974. The east-west asymmetry coefficient is continuously positive except during the years 1945–1946–1947 when a small negative value appears. The mean value of this asymmetry has been estimated to be 0.1.

Both green and red line intensity values of the E-W asymmetry appear to variate in a common way. It is noteworthy that from the year 1945 until the year 1960 the asymmetry coefficient is positive with mean value about 0.2 while after 1961 this coefficient continues to be positive with a smaller mean value of about 0.1.

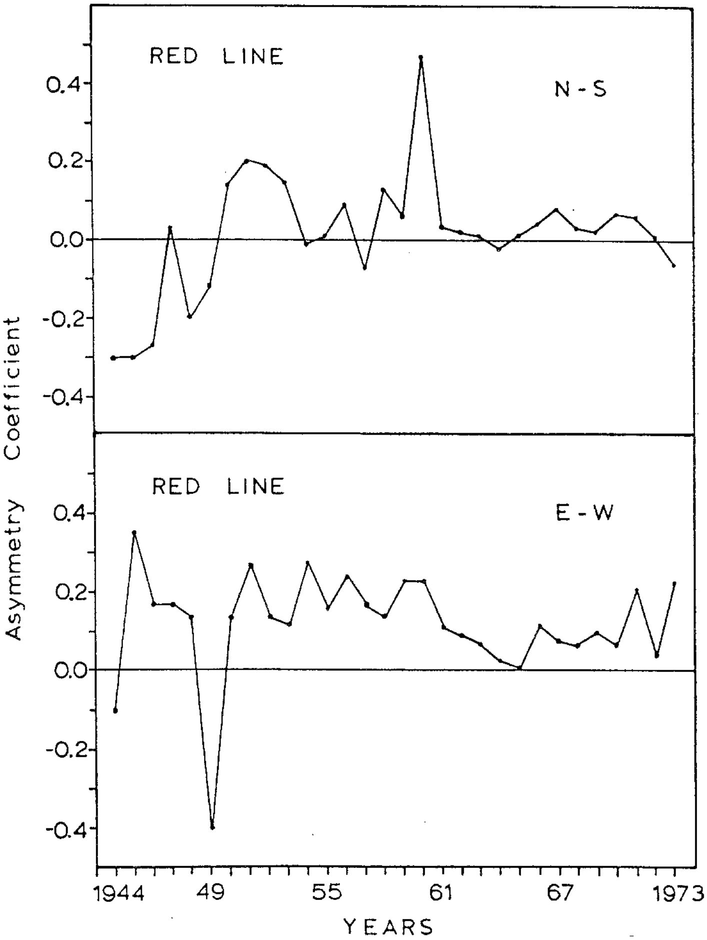

Fig. 6. Yearly values of the N-S and the E-W asymmetry coefficients of the red line intensities for the period 1944–1973.

Concerning K-corona intensity, it has positive values of the E-W asymmetry coefficient during the time period 1964–1976 with an exception in the year 1966. We must mention here that the general positive tendency of the Pic-du-Midi E-W asymmetry of the green corona (Figure 1) is the same as the corresponding one to Sýkora (1971), taking into account that we have more smoothed data (yearly data) than Sýkora had (six-monthly).

We must also notice that we have estimated the E-W asymmetry coefficient for two observation intervals from 6 hrs to 9 hrs and from 10 hrs until 13 hrs. The difference of the asymmetry coefficient in the two intervals was found to be (5.303–4.874) $\times 10^{-8} = 0.429 \times 10^{-8}$, which means that an E-W asymmetry is greater when the sun is near the horizon than in the meridian. The difference between the two examined observational integrals was 10% while the statistical error was

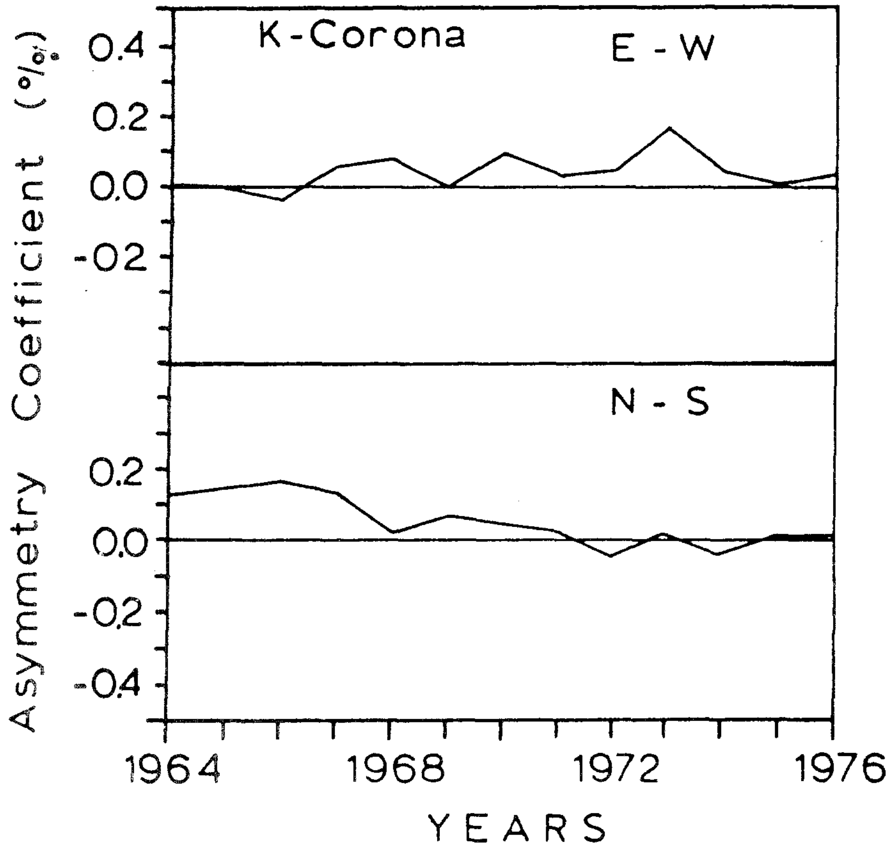

Fig. 7. Yearly values of the N-S and the E-W asymmetry coefficients of the K-corona intensities.

$1/(150 \times 10^{-6} B_0)$. Consequently, we can conclude that the E-W asymmetry is greater when the sun is "low" and smaller when it is "high" with a difference between the two positions about 10%. This is expected if there is indeed an E-W asymmetry in our measurements and consequently a real E-W effect.

4. Asymmetries for Each Solar Quadrant

For the time period 1945–1971, we give also the yearly variation of the NW-SW(1), NE-SE(2), SE-SW(3), NE-NW(4) asymmetry coefficients of the green line intensity, red line intensity and K-corona brightness in Figures 8, 9 and 10 correspondingly. From a first look we can say that the asymmetry coefficient variation in the NW-SW, NE-SE quadrants are similar those with N-S asymmetry for all emission lines, as also the variations of SE-SW, NE-NW quadrants are similar with those of the E-W asymmetry, respectively. Figures 8, 9 and 10 contain interesting characteristics which deserve additional description. The E-W asymmetry of the green, red and K-corona intensities in Figures 5, 6 and 7 are almost the same with the SE-SW (3) asymmetry of the Figures 8, 9, 10 respectively, but after the year 1971 the asymmetry variation follows a descending march which evidently corresponds to the N-S asymmetry variation which has been determined in Figures 5, 6, 7. The descending march of the SE-SW asymmetry after 1971 reveals that the N-S asymmetry starts to be negative in the SE solar quadrant.

A comparison of the SE-SW(3), NE-NW(4) asymmetry coefficients of Figures 8, 9, 10 shows that the contribution of the NE-NW asymmetry in the final formulation of the E-W asymmetry (Figures 5, 6, 7) is more significant than the SE-SW one. In most cases the NE-NW asymmetry reaches higher absolute values than those of the SE-SW, probably implying that in the span 1944–1971 the NE solar quadrant was more active than the SE quadrant.

After 1971 seems to be transferred to the SE quadrant which is illustrated by the rapid increase of the NE-NW variation and which finally causes the inversion of the N-S asymmetry to S-N. Studying also the variation of the NE-SW and the NW- SE asymmetry, namely the asymmetries among the four solar quadrants crosswise, we can conclude that the high negative values of the NW-SE asymmetry after the year 1971 argue for the predominance of the SE solar quadrant. On the other hand, it is obvious that the NE-SW asymmetry is positive during most of the period 1944–1974, which implies that the NE solar quadrant predominates the SW quadrant (Tritakis *et al.*, 1988).

In conclusion we can say that the E-W asymmetry in all examined here coronal intensities is consistent with the NE solar quadrant more active than the others. A single exception appears after the year 1971 which is connected with the N-S asymmetry inversion to S-N.

The above result is also in good agreement with the conclusion obtained from the study of the monthly distribution of the green line, red line and K-corona intensity.

White and Trotter (1977) have also observed an excess of sunspot areas in the northern hemisphere of the sun with a clear dominance between the years 1958 and 1971. Swinson *et al.* (1986) indicate also that the northern hemisphere of the Sun has more Hα solar flares than the southern one. The same authors remark that much more "major flares" and type II radio bursts have been observed during the year 1960 than during the other years of solar cycle 19. Leftus and Ruzickova-Topolova (1980) have also observed a N-S asymmetry in the green line intensity in Lomnicky stit data.

All these considerations are in agreement with the theoretical interpretation of the green line intensity attribution given by Xanthakis *et al.* (1981) where the green line intensity is related to the number of proton events and to the area index of solar

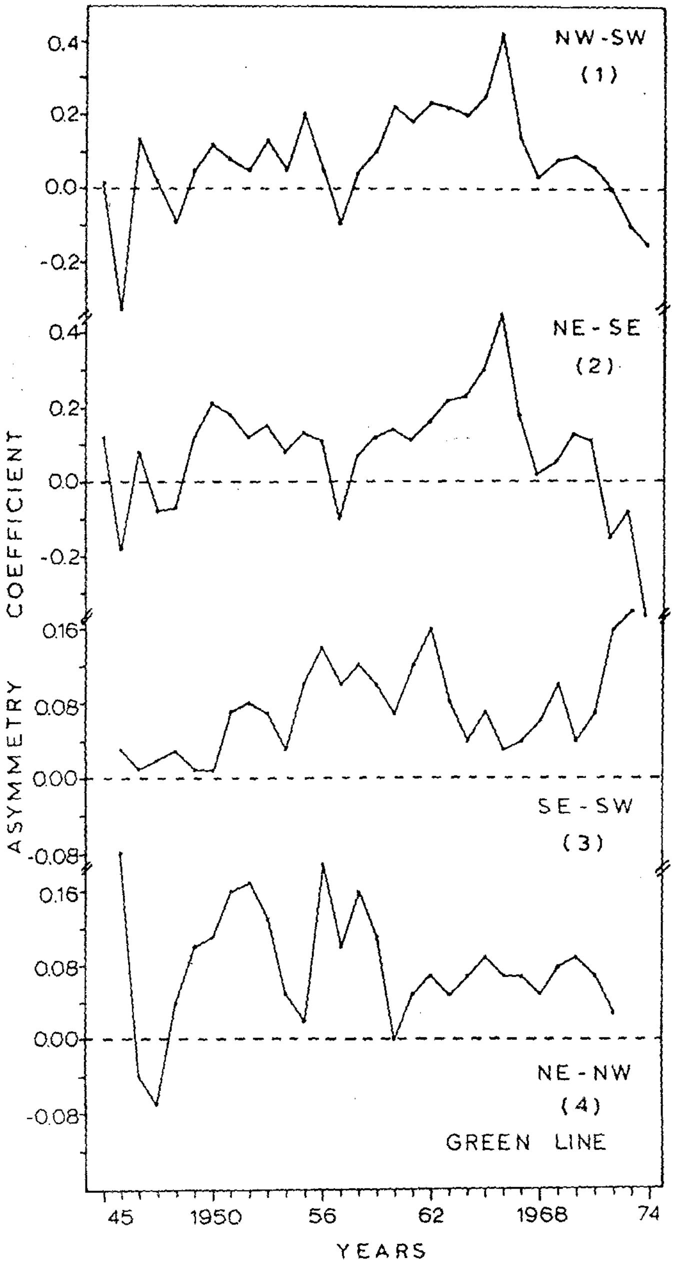

Fig. 8. Asymmetry coefficient Variations of the northwest-southwest (1), northeast-southeast (2), southeast-southwest (3), northeast-northwest (4) solar quadrants for the time period 1944–1974 for the green emission line.

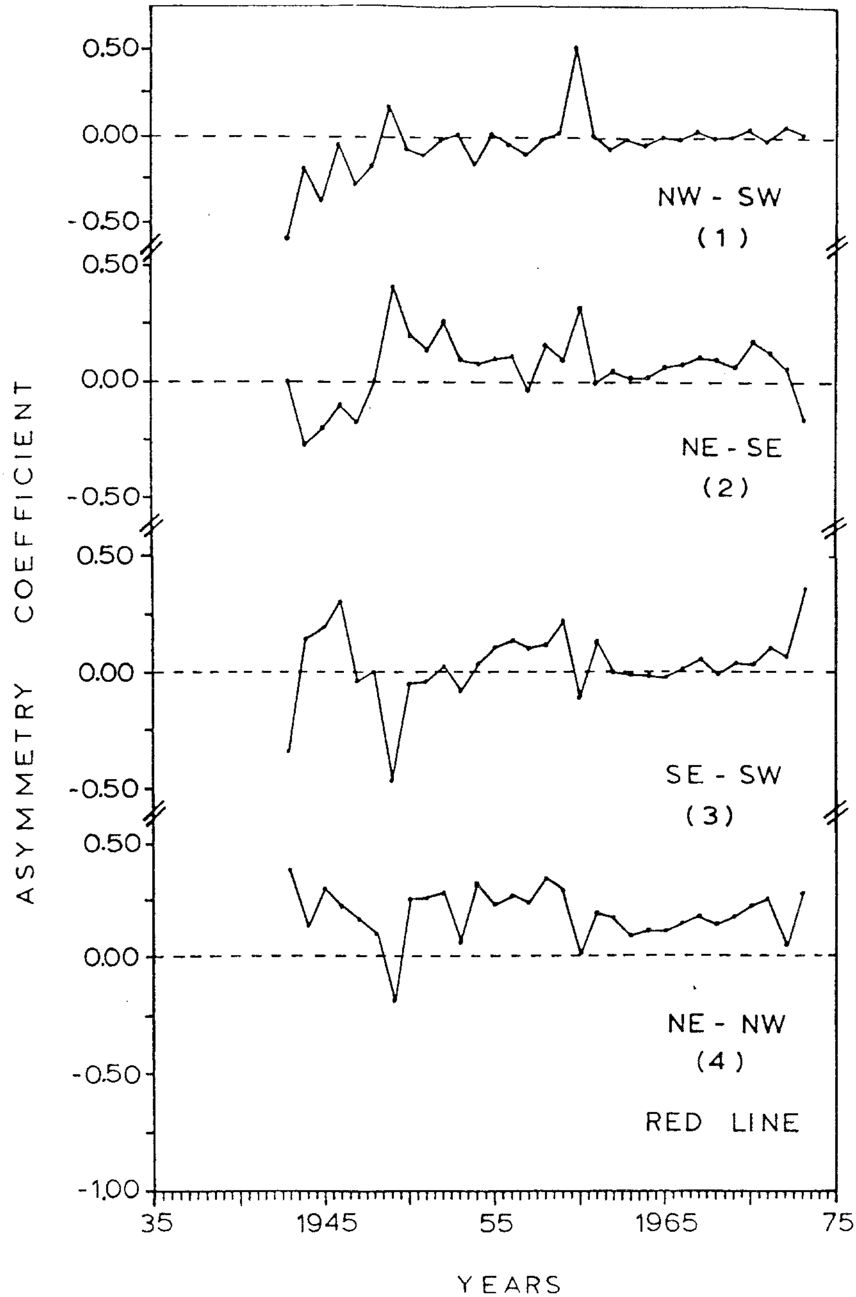

Fig. 9. Asymmetry coefficient Variations of the northwest-southwest (1), northeast-southeast (2), southeast-southwest (3), northeast-northwest (4) solar quadrants for the time period 1944–1974 for the red emission line.

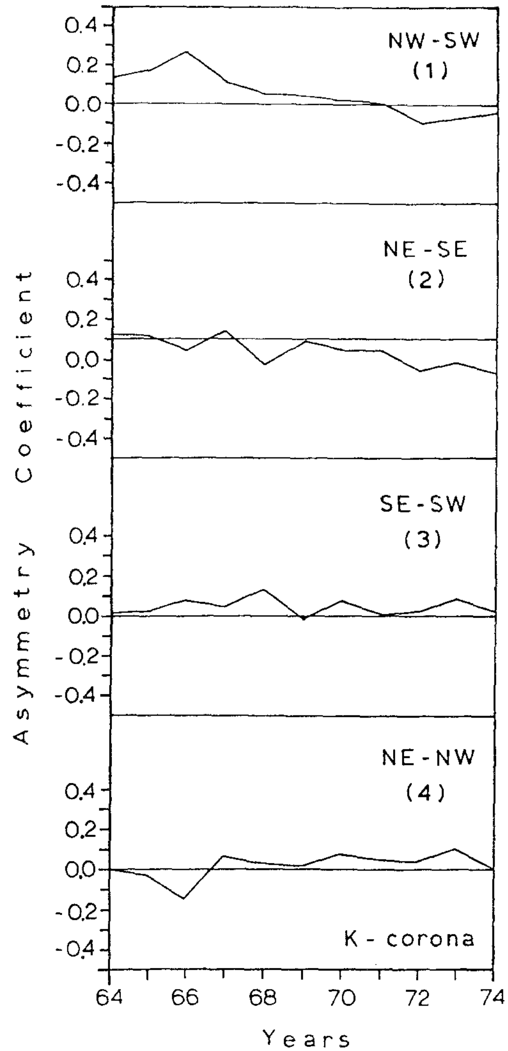

Fig. 10. Asymmetry coefficient Variations of the northwest-southwest (1), northeast-southeast (2), southeast-southwest (3), northeast-northwest (4) solar quadrants for the time period 1944–1974 for the K-corona values.

activity function of sunspot area. The green line intensity inversion which appears in the NE and SE curves during the year 1971 could be interpreted by the effect of the sunspot magnetic field to the green line intensity that ought to be taken into account in the estimation of this intensity (Xanthakis *et al.*, 1981). It is well known that the solar magnetic field changes polarity around the year 1971 (Wilcox and Scherrer, 1972), corresponding the secondary maximum of the green line intensity.

In summary, we can say that there are several temporal or observational reasons which could introduce the above mentioned E-W asymmetry in the green line intensity of the solar corona as well as in the red line and the k-corona intensities.

5. Seasonal Asymmetries in the Coronal Intensities

Trellis (1960) has remarked that the measurements of the 5303 Å line intensity in the corona obtained at Pic-du-Midi Observatory since 1947 showed a time variable asymmetry between east and west limbs of the sun. In order to define the reality of this asymmetry and to confirm the Trellis results we have taken for each day the average of the intensities for latitudes between $-60°$ to $+60°$ [30°–150° for the east limb (i_e), 210°–330° for the west limb (i_w)]. Then we computed the ratio, $R = I_E/I_W$, where I_E and I_W are the averaged values of i_e and i_w for all observations from 1944 to 1974. From this calculation, we take for the green line intensity a mean value $R = 1.18$ for the period 1947 to 1974. Computing the same ratio R for each year separately we observe that we have an extreme value for the years 1953 and 1956 (Table I). If we do not take into account these values, we see that the ratio R becomes equal to 1.13, which confirms earlier calculations made by Trellis (1960) where this ratio had been estimated to 1.12. Since both of the above mentioned values of R are greater than one all along the data record (see Table I) it is reasonable to imply that a predominant disymmetry between the east and west limbs of the Sun is confirmed.

The same work was done for the 6374 Å line of Fe X; the mean value of the ratio R for the period 1944-1974 was found $R = 1.26$, though Trellis (1960) for the same data of Pic-du-Midi Observatory for the time period 1944–1959 had found $R = 1.16$. The yearly values of this ratio have been tabulated in Table I. The behaviour of these values is the same as that of the green line intensity. The yearly ratio R for the values of the K-corona is greater than unity except of the years 1965–1966.

In the following, the study of the monthly averaged intensities I_E and I_W of the green and the red lines reveal another interesting effect. If we take into account values which have been averaged by three daily measurements of a certain month at least, we can calculate monthly values of the ratio R for all the time under consideration. These monthly values for the green, red and K-corona intensities are depicted in Figures 11, 12, 13, respectively. It is noteworthy that the ratio R is greater than one even on a monthly basis.

The seasonal variation of the quantity R for the green and red lines and the K-corona is depicted in the Figure 14. There are two interesting effects which could be denoted in this figure. The former is that the quantity R in all panels of the Figure 14 is permanently greater than one which means that the intensity of the East solar limb is greater than the intensity in the West. The latter is a modulation of the ratio I_E/I_W of one year period with an amplitude of $0.3 \times 10^{-6} B_0$, where B_0 is the photospheric intensity in the center of the solar disk. The maximum of this ratio for the green line (Figure 14) corresponds to January and the minimum to August, while for the red line this modulation is less evident and the corresponding maximum appears in February and the minimum in August (Figure 14). It is very important to say that this result does not match to the relevant analysis of Trellis

TABLE I

Yearly values of the ratio $R = I_E/I_W$ of the green line intensity (1946–1974), of the red line intensity (1944–1974) and the measurements of the K-corona brightness (1964–1976)

	$R = I_E/I_W$		
Years	Green line	Red line	K-corona
1944		1.51	
1945		1.77	
1946	1.02		
1947	1.23	1.20	
1948	1.07	1.61	
1949	1.11	1.71	
1950	1.11	1.10	
1951	1.23	1.12	
1952	1.26		
1953	1.34*	1.58	
1954	1.00	1.27	
1955	1.22	2.29*	
1956	1.35*	1.40	
1957	1.15	1.29	
1958	1.25	1.31	
1959	1.23	1.66	
1960	1.13	0.45	
1961	1.18	1.25	
1962	1.17	1.11	
1963	1.05	1.10	
1964	1.11	1.07	1.028
1965	1.19	1.03	0.996
1966	1.03	1.10	0.946
1967	1.09	1.13	1.128
1968	1.01	1.11	1.117
1969	1.13	1.07	1.018
1970	1.04	1.09	1.124
1971	1.09	0.94	1.084
1972	1.12		1.073
1973	1.24	2.85*	1.270
1974	1.16	1.89	1.059
1975			1.026
1976			1.191

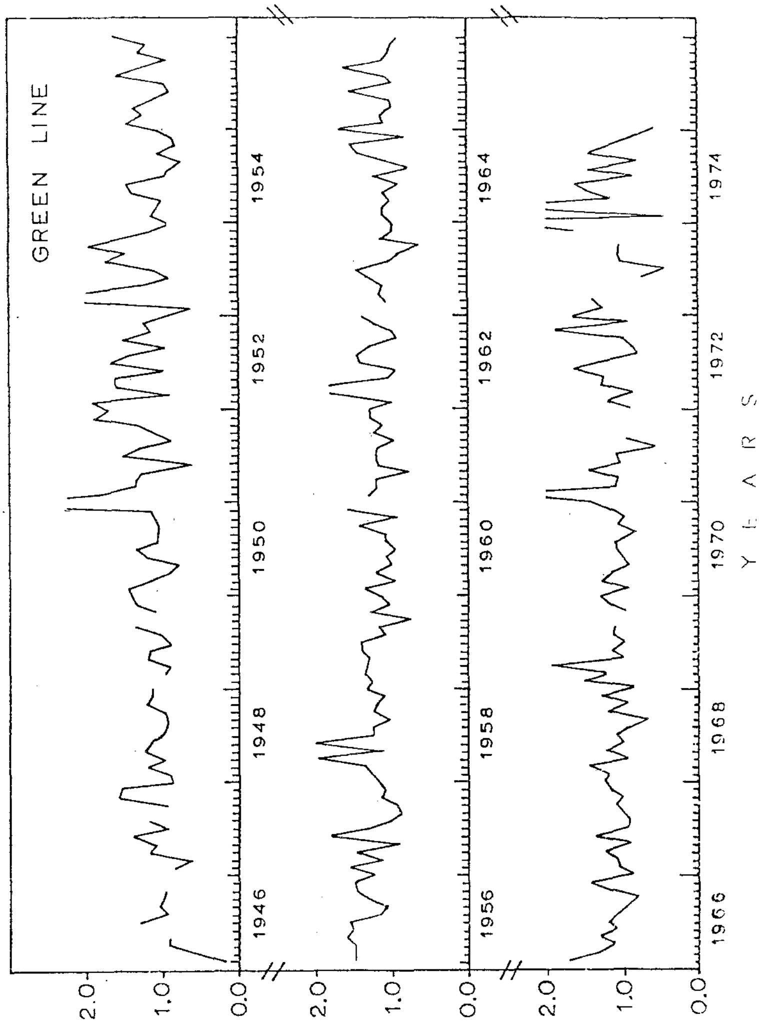

Fig. 11. Monthly distribution of the ratio I_E/I_W for the green line intensity.

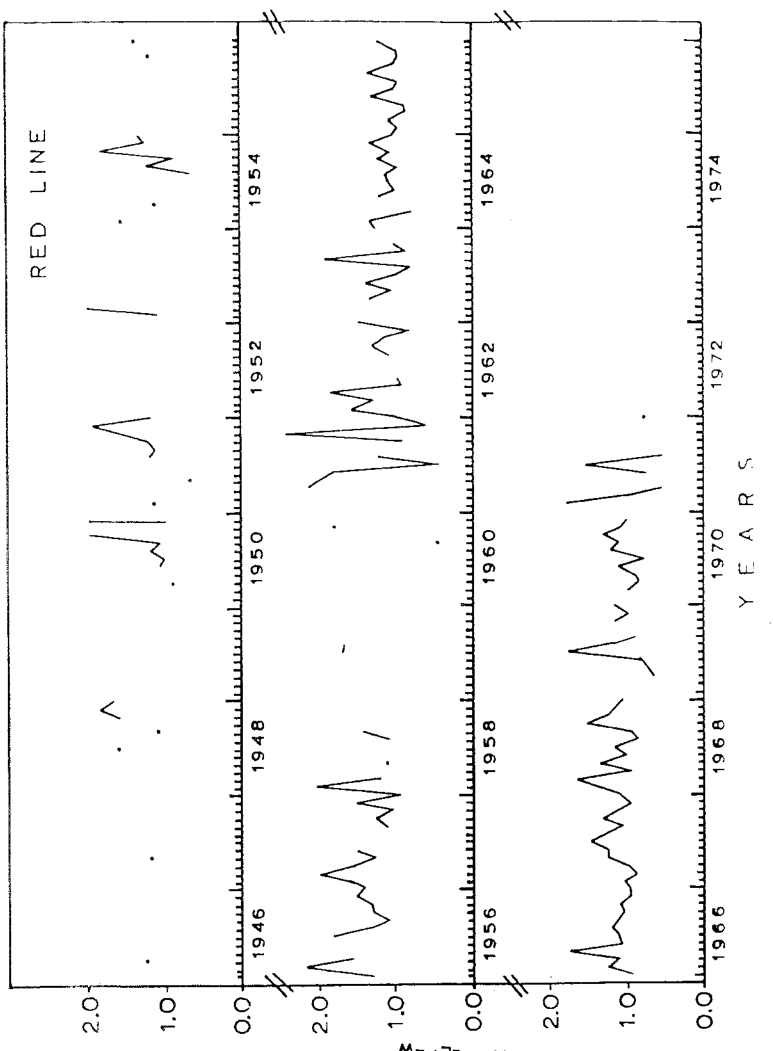

Fig. 12. Monthly distribution of the ratio I_E/I_W for the red line Intensity.

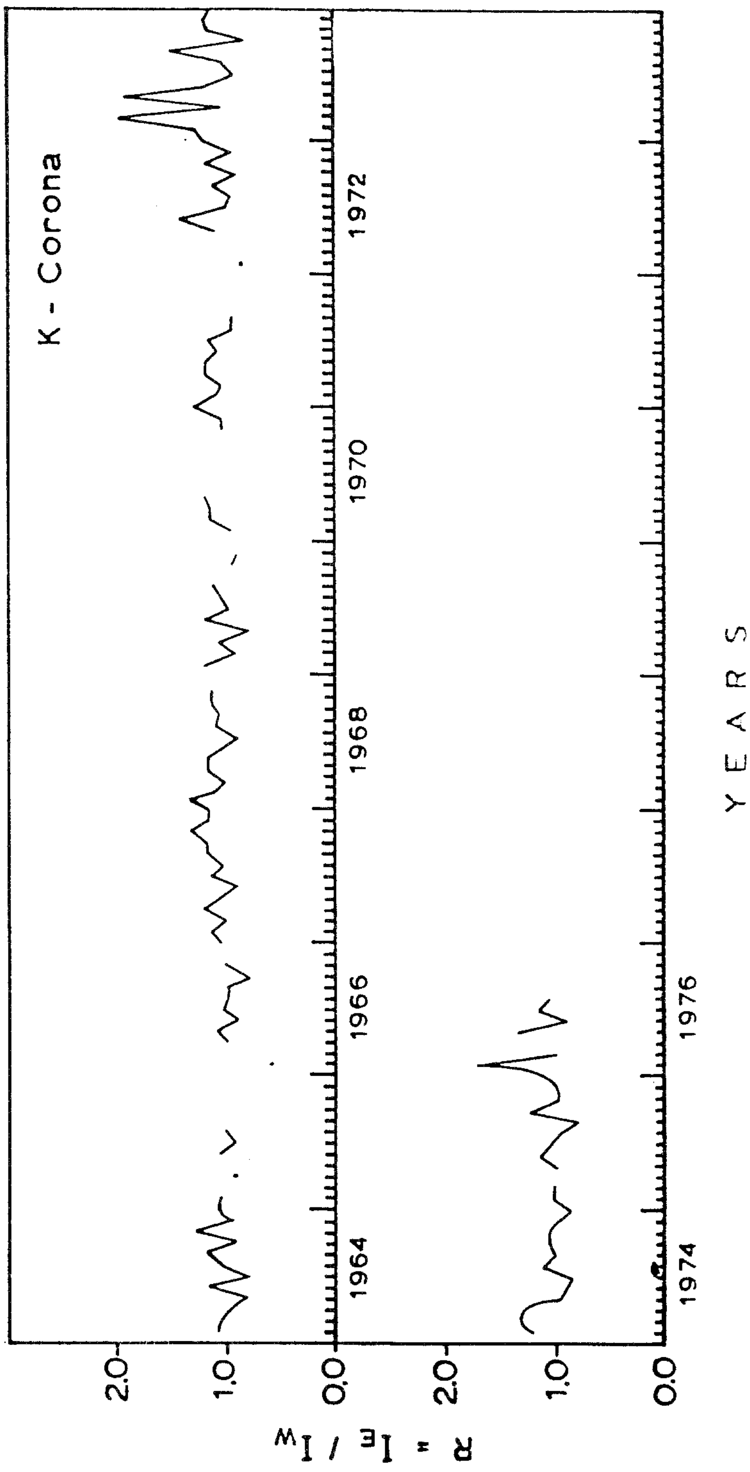

Fig. 13. Monthly distribution of the ratio I_E/I_W for the K-corona values.

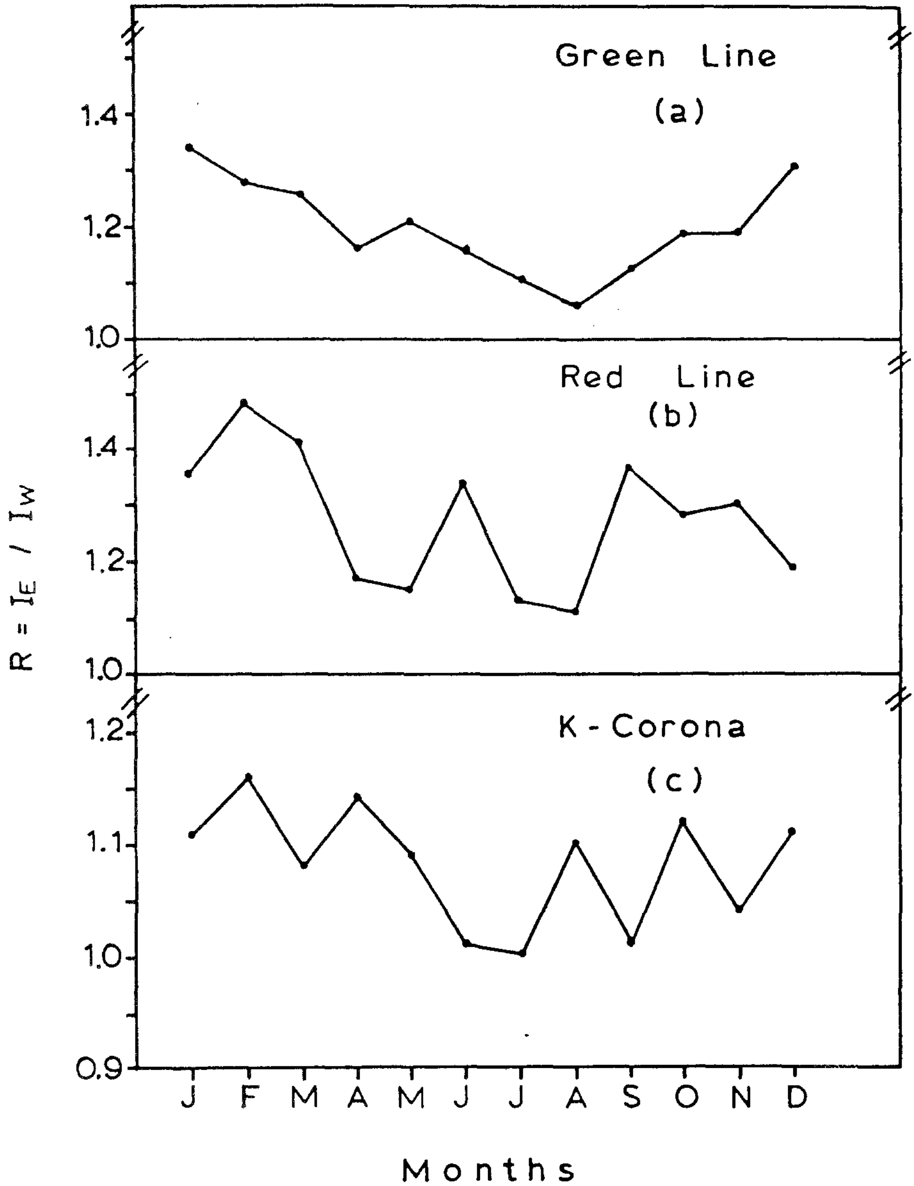

Fig. 14. Superposed epoch analysis of the ratio I_E/I_W for the green and red line emissions as well as the K-corona brightness.

(1960) for the green line intensity. At the last appearance the minimum of this variation for the K-corona brightness (Figure 14) appeared in the summer (July) and the maximum in the winter period (February).

Tyagun and Rybansky (1981) found also an annual variation of the global asymmetry between the East and West limbs by an analysis of the 1969–1972 period for the red line and the 20th cycle for the green line. They showed that the asymmetry coefficient was positive in the first half of the year and negative in the second one. They tried to adjoin these annual variation extremes of the asymmetry coefficient to the direction close to that toward the galactic center.

Recently Noëns *et al.* (1991) reported also an annual variation in the green and the red emission lines as well as of the K-corona brightness detected in the Pic-du-Midi data. The principal result of this analysis concerns a seasonal variation with minimum in the summer (July or August) and maximum in the winter period (December-January). A secondary maximum appears for all intensities between March and May where the amplitude of the K-corona variation is smaller than the relevant variations of the green and red lines.

6. Discussion and Conclusions

A very likely E-W asymmetry of the emission coronal intensities has been mentioned in the present article.

A significant, permanent and time variable E-W asymmetry of the coronal green and red line intensities, which have been measured at the Pic-du-Midi Observatory, has been detected in the time period 1944-1974.

The analysis of the monthly values of these intensities during the 19th and 20th solar cycles has shown that the NE quadrant of the solar corona appears to be more active than the others, while after 1971 SE is the most active quadrant. A primary indication of this asymmetry has been detected by examining the ratio $R = I_E/I_W$ on a yearly and a monthly basis. Where this ratio is permanently greater than unity, the intensity of the east solar limb is greater than of the west limb. In addition, it manifests seasonal variation with minimum in August and maximum in the January–February period. Probably the contribution of the instrument to the formation of this asymmetry or observations which have been made in different height above the horizon as well as the method of taking the measurements, would affect this asymmetry. However, the seasonal variation of this asymmetry allows us to relate it better with the position of the Earth on its orbit around the Sun.

Sýkora (1971) tried to explain this E-W asymmetry by the geometry of observations and by the flattening of the sun near horizon since coronal observations are made in the early morning hours and the corona stations are localized in the middle north geographical latitudes, which means that the height of the sun above the horizon reaches in these places only 18°–40° at winter noon. He studied the influence of the differential refraction and the differential extinction on the coronal measurements.

Tyagun and Rybansky (1981) have attributed the annual variation of the E-W asymmetry coefficient to the direction close to that toward the galactic center.

N-S and E-W asymmetries appear in several solar phenomena like the number of flares, the number of sunspots, etc. (Shea *et al.*, 1990). The existence of such asymmetries in the coronal green line intensity defines this emission line as an integrated index of the solar activity which can express all photospheric and coronal phenomena of the Sun and could be useful in the study of special areas of the solar corona on the North-East solar quadrant. (Xanthakis *et al.*, 1990). This region appears to have a suractivity for the 22-year period 1949–1971, which seems to depend on the orientation of the total solar magnetic field.

The physical mechanism of the E-W asymmetry is not very clearly understood, though both external and internal influences on the distribution of the solar activity and related phenomena could contribute to the interpretation of this asymmetry. The motion of the Sun towards the Apex might apply an external influence on the distribution of the solar activity, while short-lived "active" solar longitudes which are formed by temporal clustering of solar active centers may probably manifest an important internal influence which leads to the formation of an E-W asymmetry. (Trellis, 1960; Cantu *et al.*, 1970) . Neverthless, the contribution of instrumental and observational reasons in the above mentioned asymmetries will be discussed in detail in an other work.

We consider that a detailed analysis using the coronal measurements of other stations like Lomnicky stit, Kislovodsk and Norikura is now necessary for a complete understanding of this East-West asymmetry in the solar corona measurements and its annual variation.

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