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SOME COMMENTS ON THE EAST-WEST SOLAR FLARE DISTRIBUTION DURING THE 1976-1985 PERIOD

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Abstract. We present the results of an analysis of the east-west asymmetry in the solar flare distribution, observed during the years from 1976 to 1985. We conclude that flare events, all type of Hα flares, are not uniformly spread in heliolongitude over the solar disc when considering events with heliolongitudes greater than 60°, or even closer to central meridian for certain periods. This lack of homogeneity, however, does not have an influence on the definition of east-west asymmetries. Simple random distribution of flares over the solar disc can not account for the asymmetries found, but they can be explained in terms of the transit of active regions in front of the observer's position. Nonetheless, this is not the case for the distribution of flares equal or more intense than importance 1F, observed during 1979.

1. Introduction

A substantial number of papers on how solar activity phenomena are distributed over the solar disc have appeared during the last decade. A topic usually discussed is the existence of spatial asymmetries (Schwentek and Elling, 1984; Bai, 1987, 1988), their periodicity (Bai and Sturrock, 1987; Vizoso and Ballester, 1989) and their relation with gradients of high-energy cosmic rays (Swinson, Shea, and Humble, 1986; and Shea *et al.*, 1989). The existence of asymmetries in the north-south distribution of solar activity has been suspected for a long time; actually, it is well established that they are real and extend over long periods. However, there are relatively few studies addressing the heliolongitudinal distribution of solar activity. Letfus and Růžičková-Topolová (1980) have analyzed the east-west asymmetries of flare distribution from 1936 to 1976, and their conclusion was that they were statistically significant, for certain periods of time. Nonetheless, as east-west asymmetries would be dependent on the observer's position, there is no obvious physical reason why they should exist over a long period. The only possible influence in the seeing, over a few solar rotations, might come from the transit of active flaring regions on the solar disc. In fact, preferred heliolongitudes for solar activity have recently been pointed out by Bai (1987, 1988), who has shown the existence of certain areas on the Sun in which flare occurrence is higher than elsewhere.

If E-W asymmetries were found in selected periods, care should be taken when using

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them as statistical evidence for east/west interplanetary effects. These episodes of activity may dominate the interplanetary medium and could subsequently bias the analysis made with the observations. That is the main reason why we have studied the possible existence of heliolongitudinal asymmetries as a function of time. The period from September 1978 to February 1980 is particularly interesting for the analysis of interplanetary shocks and their relation with solar flares because several spacecraft were operating simultaneously. At that time, a number of shocks observed were attributed to eastern hemisphere solar activity (Hewish and Bravo, 1986); curiously, the heliolongitudinal distribution of intense flares during this period shows an important asymmetry towards the east. The aim of this paper is to extend the analysis of E–W asymmetries on solar flare distribution through 1985, to check the reliability of the E–W asymmetry over the interval 1976–1985, and to look for a possible explanation. To do this, it is important to ensure that the results are statistically significant since large variations in the size of the samples may affect the definition of the nature of the observed fluctuations.

2. Data Source

The data for this analysis have been provided by the World Data Center-A for Solar-Terrestrial Physics (WDC-A) at NOAA, Boulder (Colorado). The flare reports provided to WDC-A are grouped in accordance with the IAU specifications, these reports being currently published in *Solar Geophysical Data*. We have used the published flare group reports instead of the individual flare reports; events without enough information to generate a definite group of specified importance have not been used. A magnetic tape with an updated version of this flare data has been graciously provided by J. A. Joselyn from NOAA.

We have divided the solar flares into three groups as listed in Table I. The distribution of Hα flares which are equal or more intense than importance 1B (hereafter referred to as the 'BF' set; second column in Table I) was our first interest because this class is

TABLE I

Number of events

Year	Flares ≥ 1B ('BF')	Flares ≥ 1F ('FF')	Subflares ('SF')
1976	3	21	593
1977	17	111	1613
1978	169	439	5075
1979	259	735	9277
1980	264	857	9274
1981	225	652	8560
1982	419	1021	6903
1983	96	325	3714
1984	111	272	2628
1985	19	89	884

generally associated with interplanetary shocks. Unfortunately, the paucity of BF events, especially around solar minima, does not permit any definite statistical conclusion about their spatial distribution. Therefore, the second set of data includes all flares equal or more intense than importance 1F (the 'FF' set; third column in Table I). Finally, the third set of data contains all subflares, flares with importance less than 1F (the 'SF' set; fourth column in Table I), which gives a sample large enough for meaningful statistics when considering different groupings of flares, both by sectors in heliolongitude and by monthly intervals.

3. Analysis of the Flare Data

In this paper we have analyzed the solar flare data to search for possible E–W asymmetries, which means that more flares occurred on one half of the visible solar disc than on the other, for a definite time interval. The usual method of proceeding is to evaluate an index of asymmetry, δ, defined by

$$\delta = (n_E - n_W)/(n_E + n_W) .$$

Here n_E and n_W stand for the number of flares observed on the eastern and western hemispheres of the solar disc, respectively. However, before determining δ it is important to ascertain the homogeneity of flare distributions for different heliolongitudes. In fact, it is reasonable to expect that the frequency of flares observed decreases near the solar limbs due to the perspective view of these regions.

3.1. Homogeneity of the Sample

The homogeneity of the flare distribution can be checked by using the FF and SF data sets, with flares being allocated by years. The number of flares in the FF set is large enough that we can apply the χ^2-test to the flares grouped in 18 sectors covering 10° heliolongitude, from E 90° to W 90°, with meaningful statistics. The conclusions about uniformity are quite similar for both sets, thus we only present the analysis for the FF distribution. The χ^2-test shows that, whenever the sample of classes includes flares at heliolongitudes greater than 60°, flares are not uniformly distributed in heliolongitude, at the 95% level of statistical significance. A large part of the samples formed by classes of flares selected inside the interval [E 60°, W 60°] (in short, EW 60) show fluctuations that have a high chance to be random. This result is essentially independent of the grouping; samples built from sectors 15°, 20°, or 30° wide yield the same trend. Therefore, the observed distribution of flares becomes less complete as more extreme heliolongitudes are taken into account. Hence, to prevent unexpected bias due to flare distribution near the limbs, this analysis has been restricted to flares with heliolongitudes inside the EW 60 interval. Even with this restriction, periods of inhomogeneity are still present in 1977, 1979, 1981, and 1982.

Figure 1 shows the fraction of flares from the BF set contained in different heliolongitude intervals from 1976 to 1985, represented year by year. The four overlapped histograms for each year and panel refer to the fractions observed inside the intervals

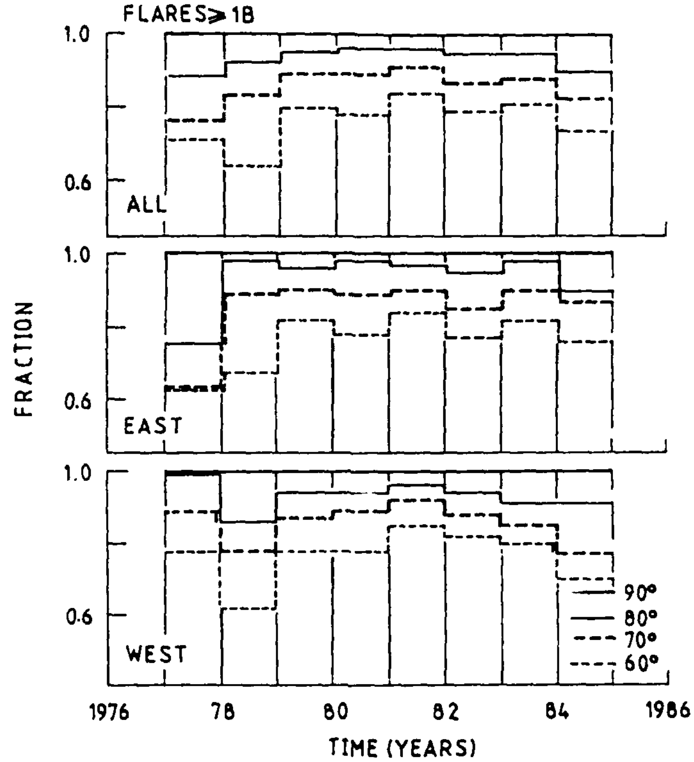

Fig. 1. Distribution by heliolongitude of samples of Hα flares equal or more intense than importance *1B*. Flares have been grouped by years from 1977 to 1985. (The years 1976 and 1986 have not been included due to the low number of events.) Four overlapped histograms in the top panel show the fraction of flares whose heliolongitude is smaller than 90°, 80°, 70°, and 60°, respectively, from the upper histogram (which always is a straight line at 1.0) to the lower one. The top panel contains all flare data, while in the middle and in the lower panel of the figure, the data are subdivided into the east and the west hemisphere of the solar disc, respectively.

EW 90, EW 80, EW 70, and EW 60, normalized to the total number of flares of the type considered. Values for years around the solar minimum have not been included in this figure due to the very low number of events (Table I). From top to bottom, the three panels of Figure 1 show the flare fraction for all flares and then separately, for east and west heliolongitudes, respectively. Figures 2 and 3 show, as in Figure 1, the same values for FF and SF sets, respectively. The subflares histogram (Figure 3) shows that during the solar maximum epoch, 1981 and 1982, the fraction of events observed in the outer parts of the solar disc is slightly lower than at the minimum. This difference becomes bigger for the BF set (Figure 1) and it is striking for the FF set (Figure 2). These variations can not be accounted for just by considering random fluctuations, because the number of events in each interval is large enough to make them significant. Thus, during solar cycle 21, flares and subflares were not uniformly distributed in heliolongitude, and their distribution varied with the cycle. These conclusions agree with the

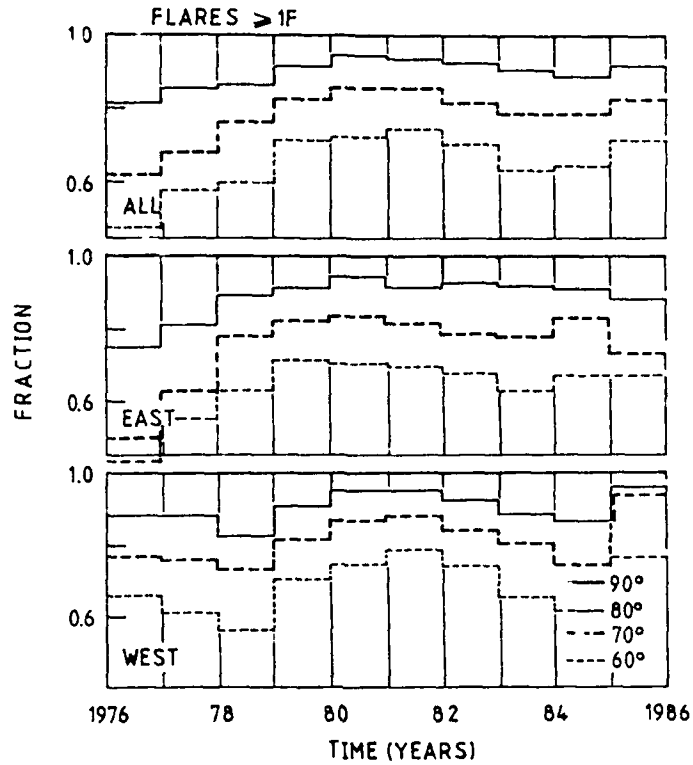

Fig. 2. As depicted in Figure 1 but for Hα flares equal or more intense than importance 1F, including 1976 and 1986.

results of Wilson (1987) for the year 1975, which show an excess of flares equal to or more intense than 1F importance for heliolongitudes greater than 45°.

We have not been able to find a physical reason which could explain the differences between FF and SF distributions, either when taking only the east side of the solar disc ('east' panel on Figures 2 and 3) or, more generally, when comparing the fraction values at the minimum with the values around the maximum. Maybe it is a systematic bias caused by the fact that at solar minima observers are anxiously observing the Sun and reporting every little flare; there are very few 'large' flaring regions on the Sun, so everything gets reported somewhat equally. During solar maximum, observers 'see' lots of activity and their eyes are 'drawn' to the central part of the disc as they report these large flaring regions. Since there are many regions in the center of the disc, smaller subflares might be missed, while limb flares have a tendency to look alike. From the distribution by halves, 'east' and 'west' panels on Figures 2 and 3, it is also clear that this non-uniformlity does not affect the possible presence of any asymmetry between both solar hemispheres (except, perhaps, in 1976 and 1985 if asymmetry exists).

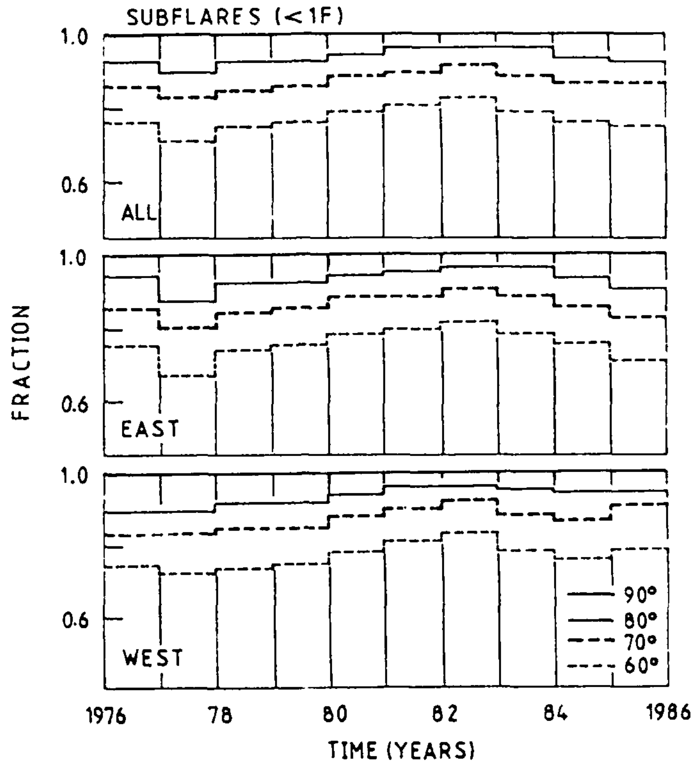

Fig. 3. As depicted in Figure 1 but for subflares (Hα flares with importance less than 1F).

3.2. East–west asymmetry analysis

To study the E–W asymmetry in the Hα-flare distribution for the period from 1976 to 1985, we have considered the FF and SF sets and flares in the EW 60 interval. Figures 4 and 5 display the evolution of the asymmetry index (top part) and of the number of events per month (bottom histogram) for both distributions. The continuous thick line in the top plot shows the mean value of δ for each month. In Figure 4, δ has not been plotted when the number of flares per month is smaller than 15. The δ-value has been calculated averaging over the flare data which correspond to the same month, plus those corresponding to the three following months ('four-month running averages'). For one-month averages, δ peaks are very sharp and striking, although their significance is low. The asymmetry index behaves in a similar manner when other running averages (up to six-months) are used instead; the only differences noted are a general softening of asymmetry peaks and a slight temporal biasing in their occurrence. The dashed thin line in the top part of Figures 4 and 5 shows δ-values obtained by the random generation of a uniform distribution which has at each point the same number of events as the real one. These randomly generated δ-values seldom exceed 0.2 (and only when the number of events is small). Therefore, we assume that $|\delta| \geq 0.2$ differentiates the statistically significant from non-significant values of the asymmetry index. In other

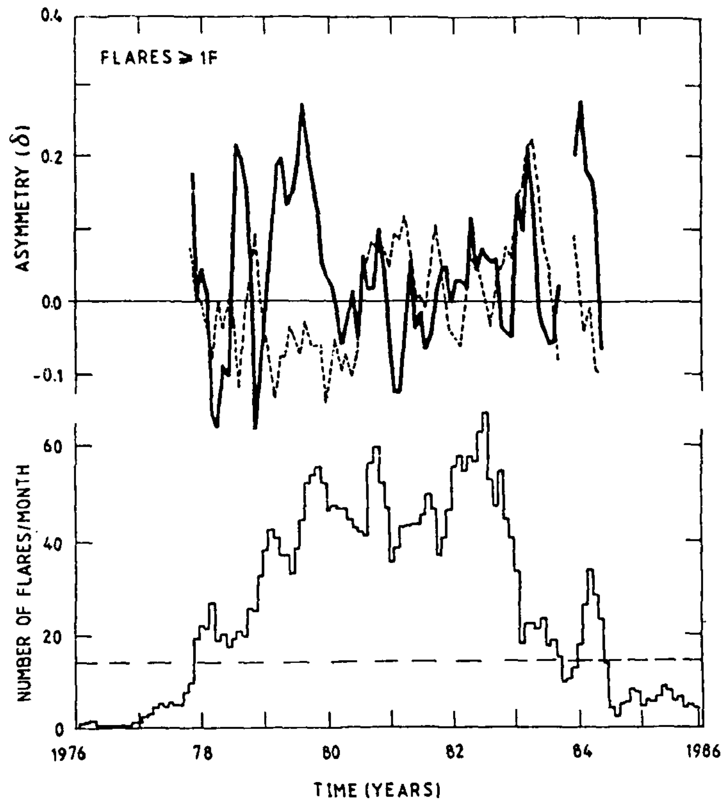

Fig. 4. The E–W asymmetry index for flares equal or more intense than 1F type ('FF' set, in the period 1976–1986) is plotted in the top part of the figure as a function of time. The thick line represents true δ-values while the dashed thin line represents randomly generated δ-values for a distribution which has, at each point, the same number of events as the true one. The bottom histogram represents the number of flares per month. When this number is too small, δ-values have not been plotted; the horizontal dashed line marks this limit.

words, the reliability of an E–W asymmetry in the distribution is stated when there are 1.5 times more flares in one half of the solar disc than in the other. This choice is quite similar to the definition of significance adopted by Letfus and Růžičková-Topolová (1980), although our choice is probably more restrictive. In Figure 5 this limit could be reduced to 0.10 (even to 0.05) since subflares are at least ten times more abundant than any other type of flares.

From Figure 4 we note a western hemisphere excess (indicated by negative values) for the FF set of flares during 1978, which changes to an eastern excess (positive values) in 1979 and 1984. The evolution of δ-values for subflares (Figure 5) is amazing because for some periods the index of asymmetry is even higher than for flares. The periods of clear asymmetry tend to concentrate near the solar minima, 1976, 1977, 1984, and 1985, and most probably during 1982 and 1983. Asymmetry in 1976 is consistent with the value derived by Letfus and Růžičková-Topolová (1980) and Knoška (1985), although

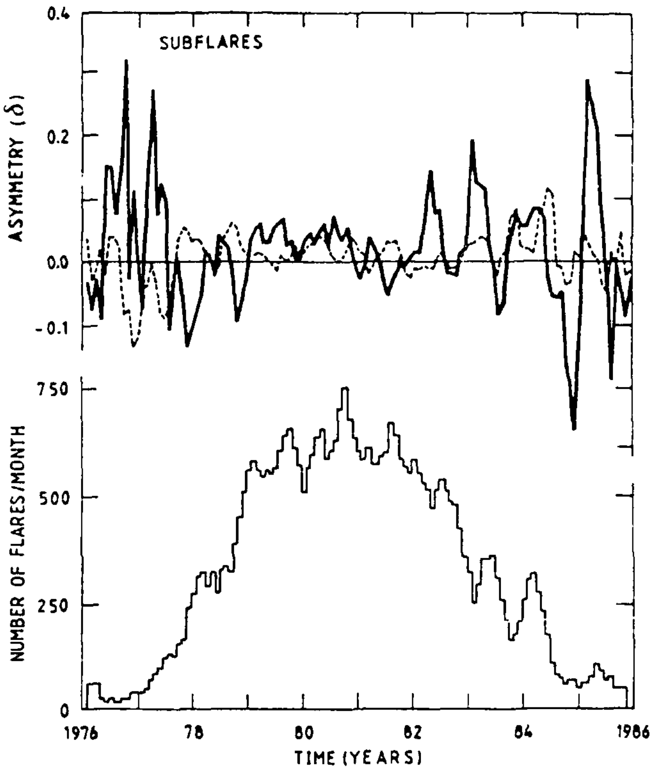

Fig. 5. The same representation as in Figure 4 but for subflares.

it can not be compared directly because these authors give only one value per year. This result also agrees with Wilson's (1987) results which show a significant western excess of flares for 1975. No special correspondence seems to exist between the periods where the FF and SF sets show asymmetries. Finally, it is important to point out that large deviations from symmetry contain more than one time point, which means that they stand out for more than two solar rotations. We have calculated the power spectrum of δ-values on the FF and SF distributions for the periods in Figures 4 and 5, by using Fourier transform and a trapezoidal window (Bloomfield, 1976); we have not found any periodicity.

4. Active Region Effects

The main question to address now is the origin of the E–W asymmetries found. A clue could be the fact that subflare asymmetries preferentially appear, and are large, near the solar minima. Bai (1988) has found that a small number of 'superactive regions' were responsible for the production of the majority of major flares during the period from February 1980 to August 1985. Thereby, accepting that non-random flare activity occurs upon episodic periods, we have differentiated between flare activity coming from 'acti zones' and from 'less active zones' on the solar disc. If subflare activity is really more important in these active regions than in the rest, the asymmetry index would be largely affected by their contribution, especially near solar minima. Asymmetry values will change markedly depending on where (east or west half) and when these active regions 'switch on' or 'switch off' the subflare production, while travelling across the visible solar disc. Indeed, it is necessary to define adequately what is meant by 'active zone'. Bai's superactive regions result from his 'major flares' definition, which is based on five different observational criteria. Nonetheless, these criteria can be applied neither to the SF set, because subflares represent weak solar activity, nor to the FF set, because this gives a too small sample for statistical analysis. Therefore, we have adopted a rather different definition: we qualify as 'active region' for subflare production, ARSF, any solar plage in which more than 9 Hα flares are produced during its transit from E60 to W60°. The results are weakly dependent on this flare rate threshold (± 2 events). In the same manner, 'active region' for 1F flare production, ARFF, qualifies a plage whose flare rate is greater than 4 flares equal or more intense than type 1F. This quantity is the same as adopted by Bai (1987) to define an active zone from solar plages. Following these definitions, NARSF and NARFF will refer to the solar plages which develop at least one event but can not be classified as ARSF and ARFF, respectively.

To quantify the contribution of both ARSF and NARSF to the asymmetry, we will define two partial indexes of asymmetry:

$$\kappa_{AR}(SF) = (n_{E(ARSF)} - n_{W(ARSF)})/N,$$

$$\kappa_{NAR}(SF) = (n_{E(NARSF)} - n_{W(NARSF)})/N,$$

where distinct n-values refer to the number of events observed in each one of the solar hemispheres from central meridian to 60° away, as defined in the former paragraph. N is the total number of events, $N = n_{E(ARSF)} + n_{W(ARSF)} + n_{E(NARSF)} + n_{W(NARSF)}$. Thus, κ_{AR} and κ_{NAR} are measures of the asymmetry produced by the ARs and NARs, respectively. Although $\delta = \kappa_{AR} + \kappa_{NAR}$, one should be careful when interpreting quantitatively the asymmetry from κ-values. In the same way, we define two equivalent κ-values for the FF set. Figures 6 and 7 show the variation of partial and total asymmetry indexes for SF and FF sets, respectively. From top to bottom, the three plots in each figure represent the monthly values of κ_{AR}, κ_{NAR} and δ for the same periods considered in Figures 4 and 5.

For the SF set, κ_{AR} peaks correspond almost exactly with δ peaks, except for the end of 1976. The contribution of an AR, both to κ_{AR} and δ, depends on where it was placed with respect to the observer at Earth, and when flare production started or stopped; even more, this is dependent on how the activity evolved while the plage was moving toward the west limb. During solar maximum, when there are many active regions on the solar disc, the contribution of an individual AR is likely to be obscured by an essentially random distribution. Near solar minimum, however, the influence of ARs on asymmetry indexes is more difficult to compensate for individual contributions to asymmetry. For instance, a rather extreme case is found during the period from February

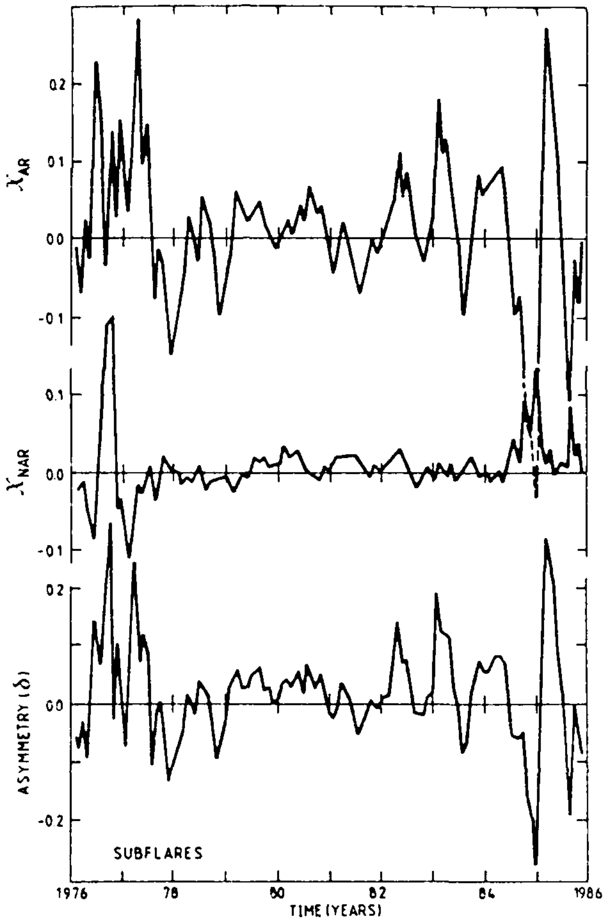

Fig. 6. Partial and total asymmetry indexes for subflares (SF set). From top to bottom, κ_{AR}-values, κ_{NAR}-values, and δ-values. Each point represents one month averaged data.

to June 1985 (close to the minimum of the cycle). During this time, 223 subflares were observed in 24 plages; the corresponding asymmetry indexes are $\delta(SF) = 0.29$, $\kappa_{AR}(SF) = 0.28$ and $\kappa_{NAR}(SF) = 0.01$. Nonetheless, 59% of these events occurred in 3 ARs (plages 14647, 14652, and 14656 from NOAA's classification). These ARs are the only ones responsible for the strong asymmetry observed at that time (Figure 6) because when they were removed from the SF set, the δ-value decreases to 0.08. On the other hand, when we apply the same procedure to evaluate a period that contains a large number of events, like January–April 1980 (2325 subflares in 168 ARs or NARs), δ-value does not vary significantly. In this case, when the 35 most active ARs (which account for 54% of the events) were removed from the sample, δ only changes from 0.05 to 0.07.

One should expect that the E–W asymmetry for the FF set would also be associated with active plages. However, applying our definition of AR to the FF set we do not find

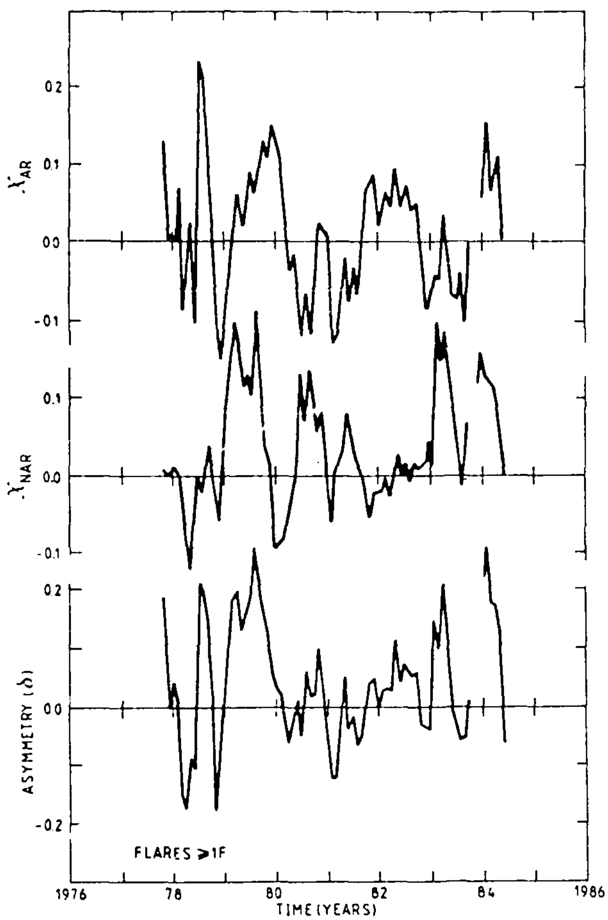

Fig. 7. Partial and total asymmetry indexes for the FF set, as depicted in Figure 6.

any clear correlation between the peaks of κ_{AR} and of δ, as can be seen in Figure 7. Now E–W asymmetries appear in both ARs and NARs; only for the second part of 1978 and in early 1979 do both peaks, κ_{AR} and δ, coincide. A possible reason is that the mean number of events per plage is small, thereby each individual AR has little influence in the asymmetry index. Furthermore, the result does not change significantly if the adopted threshold is modified. For example, for the period from July to October 1979, $\delta(FF) = 0.28$ and there are 7 ARs which produce 67 events (37% of the set); the δ-value just changes to 0.32 when these ARs are removed from the sample. These are very active flaring regions, but their global contribution to the asymmetry is small. (Proceeding in the same manner with subflares, $\delta(SF)$ passes from 0.07 to 0.09.) A possible reason for this behavior could be that these ARs are usually long lasting, thus they keep producing flares or bunches of flares during a large part of their transit over the solar disc. As a consequence, they have a higher chance to simulate a homogeneous distribution of events. However, to check this possibility would imply tracking the activity of each individual plage during its transit across the solar disc.

It is beyond the scope of this analysis to look into the details of each particular distribution of flares and their association with active plages. Nevertheless, as a first approximation, we have developed a Monte-Carlo simulation of the E–W flare distribution, considering the fact that flares from the same plages are related. For every plage, a random value between zero and the total number of flares (or subflares) observed in the plage is generated to represent the quantity of events which occurred in one of the solar hemispheres, which is also randomly assigned. The number of events in the other hemisphere is the number of remaining events. The asymmetry obtained in this way for the FF set behaves as the observed one, namely, with high fluctuations at the minima and small values at the maximum. The simulation also accounts for the highest values of $|\delta|$ in the FF set; after one hundred trials, however, we have not obtained periods of prolonged significant asymmetry (positive or negative) like that observed in 1978–1979 period. As a final remark, it is worth noting that over the period analyzed (1976–1985), the global asymmetry indexes are $\delta(SF) = 0.02$ and $\delta(FF) = 0.05$; these low values indicate that the temporal E–W asymmetries compensate over a long period of time. Applying the Monte-Carlo simulation and after forty different trials, we obtain $\delta(SF) < 0.03$ and $\delta(FF) < 0.06$, which reproduces the asymmetry indexes deduced from observations.

5. Summary

We have presented an analysis of the solar flare distribution over the solar disc, for the period from 1976 to 1985. Our main conclusions are as follows:

(a) Flare events – all type of Hα flares – are not uniformly spread in heliolongitude when considering events in heliolongitudes greater than 60° from central meridian. Nonetheless, this non-homogeneity does not have influence in E–W asymmetries.

(b) Pronounced and prolonged E–W asymmetries are found in the solar distribution, both for flares and subflares. The values of the asymmetry coefficient during these periods of time exceeds the expectation from pure random fluctuations.

(c) E–W asymmetries for subflare distribution can be explained in terms of episodes of subflare activity produced in solar active plages. The transit of these regions in front of the observer's position produces a large part of the observed E–W asymmetries.

(d) Except for 1979, the episodes of asymmetric solar activity for flares greater or equal to 1F importance can be simulated by a randomly generated distribution in which flares from the same plage are related. We have no physical explanation for the prolonged eastern asymmetry during 1979.

(e) The period 1978–1979 is a distinctive example of E–W asymmetry in the heliolongitudinal distribution of flares. Consequences of this asymmetry should also be apparent in observed solar-induced phenomena, although a statistical relation to asymmetry in solar activity will require a further global study of these phenomena.

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