ASYMMETRIES DURING THE MAXIMUM PHASE OF SOLAR CYCLE 22

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Abstract. This paper presents the results of studies of the asymmetries (N–S and E–W) for different manifestations of solar activity events (sunspot groups, Hα flares and active prominences/filaments) during the maximum-phase (1989–1991) of solar cycle 22. During the period considered, the results obtained show the existence of a real N–S asymmetry, whereas the E–W asymmetry may exist only for Hα flares. There is no definite relationship between the asymmetries and the occurrence of events; however, around low activity sometimes we find enhanced asymmetry, and low asymmetry around high activity. Our study suggests a good agreement with similar studies made by others.

1. Introduction

It is well known that sunspots are the most obvious manifestation of solar activity. The number of sunspots changes over an average period of approximately 11 years – the so-called sunspot cycle – during this time there is a variation in the level of solar activity as a whole. Figure 1, based on the data published in *SGD* (1986 –1994), shows a plot of mean number of sunspots for solar cycle 22 (the best fit in the data points is represented by the thick line). Here activity data are binned in units of Carrington rotation period (synodic rate 27.2753 days) represented by Carrington rotation numbers (CRNs). The figure shows the occurrence of the onset of the cycle from 1986, attaining a maximum in 1989, and beginning to decline from 1992. The figure also shows the maximum phase of the cycle lasting from 1989 to 1991. The activity was lower in 1990 compared to 1989 and 1991 (the annual mean sunspot numbers were 157.6, 142.6, 145.7, respectively, for 1989, 1990, 1991).

The N–S asymmetry is well known from many studies (Bell, 1962; Roy, 1977; Swinson, Koyama, and Saito, 1986; Vizoso and Ballester, 1987, 1990; Özgüç and Üçer, 1987; Verma, 1987); some authors have also studied the E–W asymmetry (Letfus, 1960; Letfus and Růžičková-Topolová, 1980; Heras *et al.*, 1990). In the past, very few authors studied both these asymmetries together (e.g., Růžičková-Topolová, 1974; Knoška, 1985). Růžičková-Topolová (1974) studied the N–S and E–W asymmetries in the numbers of large solar flares (imp ≥ 2) for the period 1957–1965. The N–S asymmetry displayed a dominant role of activity in the northern hemisphere. The E–W asymmetry was low. Using the flare index (q) introduced by Kleczek (1952, 1953), Knoška (1985) also studied the N–S and E –W asymmetries of flare activity during 1937-1978. No unique relationship was

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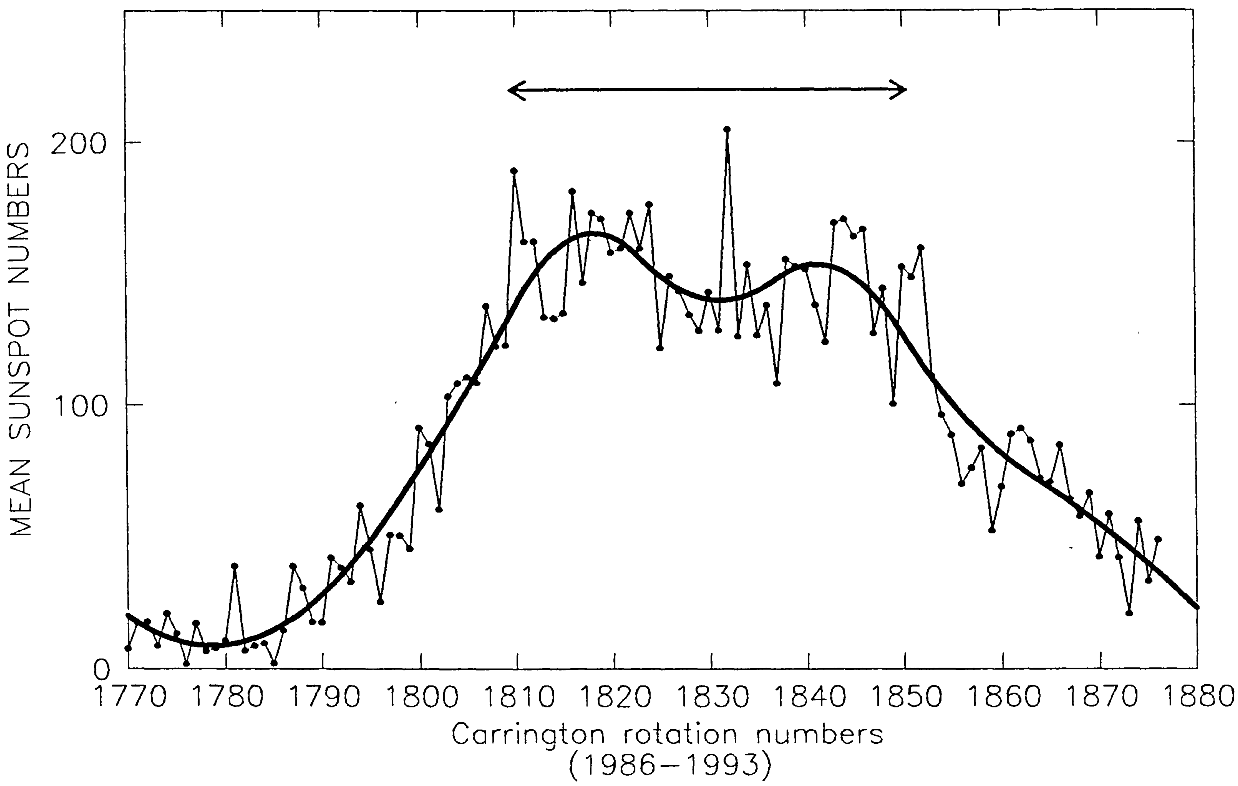

Fig. 1. Solar cycle 22 mean number of sunspots (thick line denotes best fit in the data points). The double-headed arrow indicates the interval during which the activity was in the peak stage, i.e., the maximum phase (1989–1991) of the cycle.

found between the asymmetries of flare activity and the eleven year solar cycle. In the case of both these asymmetries, the positive asymmetry of flare activity on the solar disk predominates, i.e., dominant role of activity was noticed in the northern and eastern hemispheres. The values of the E–W asymmetry oscillate about zero, i.e., the E–W asymmetry of flare activity is small on the whole.

Taking all this into account, here we have made an attempt to analyse asymmetries (N–S and E–W) of different signatures of solar activity during the maximum phase (1989–1991) of solar cycle 22. Although recently Oliver and Ballester (1994) analysed the N–S asymmetry of sunspot areas during cycle 22, performing such analysis on different datasets could be interesting and useful.

2. The Asymmetries

The occurrence of solar activity events on the solar disk is not uniform and more events occur in one (northern or eastern) or the other (southern or western) part of the disk in various time spans; the phenomenon is referred to as asymmetry (N–S or E–W) and can be observed in all manifestations of solar activity events. For studying both the above asymmetries, the chosen solar activity events are

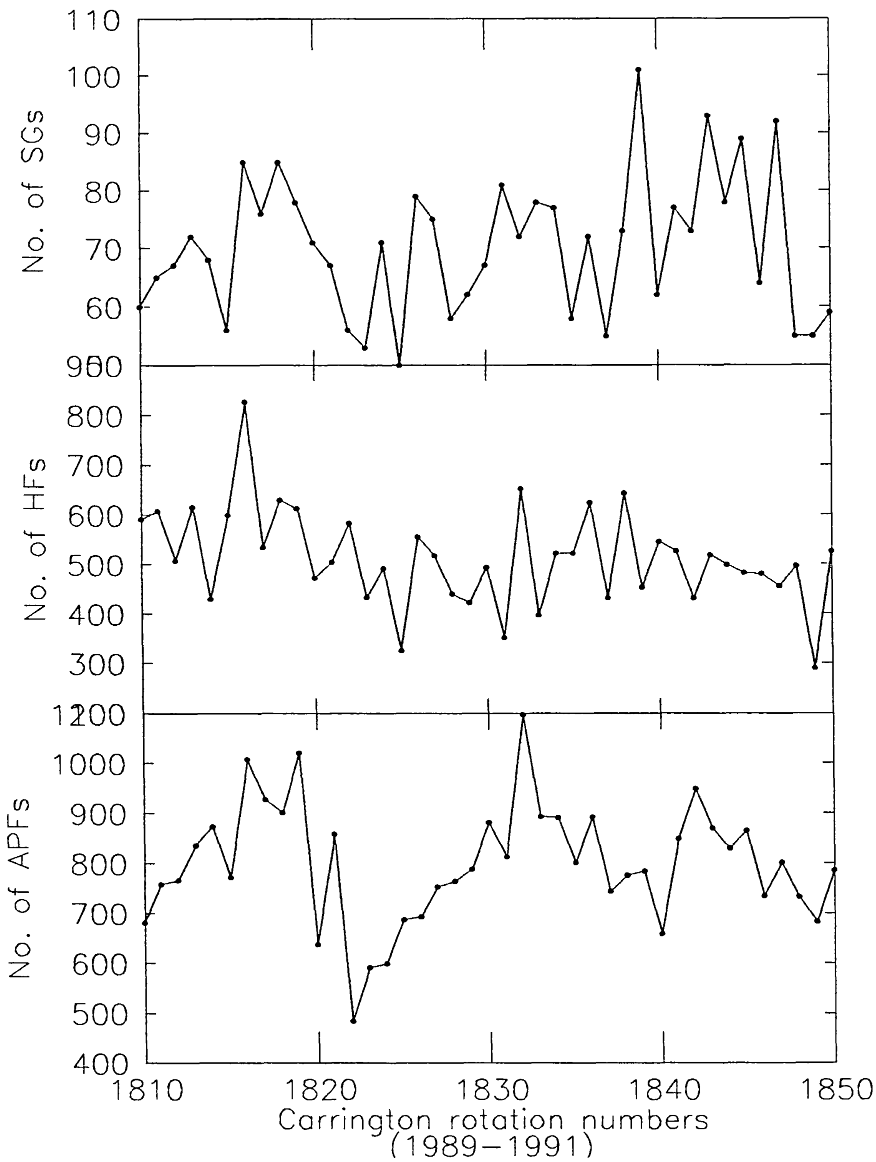

Fig. 2. Occurrence of number of sunspot groups, Hα flares and active prominences/filaments.

the sunspot groups (SGs), Hα flares (HFs) and active prominences/filaments (APFs).

To study asymmetries, the total number of events, collected between the period 12 December, 1988 to 5 January, 1992 (covering 41 Carrington rotations from 1810 to 1850), were 2885, 21044, and 32729, respectively, for SGs, HFs, and APFs (*SGD*, 1989–1992). Three curves of Figure 2 represent variations of number of SGs, HFs, and APFs, respectively (the annual mean number of SGs are 77, 75, 82; HFs are 630, 541, 539; and APFs are 892, 903, 883, respectively, for 1989, 1990, 1991). As given in *SGD* (1987), the listing of APFs is not complete and may exclude events of lesser visibility. Similarly, due to observing gaps in the Hα flares, the HFs list is also not complete.

TABLE I

The N–S asymmetry of SGs, HFs, and APFs

CRN (1989–1991)	N–S asymmetry NSAS_{SGs} $\left(\frac{SGs_n - SGs_s}{SGs_n + SGs_s}\right)$	NSAS_{HFs} $\left(\frac{HFs_n - HFs_s}{HFs_n + HFs_s}\right)$	NSAS_{APFs} $\left(\frac{APFs_n - APFs_s}{APFs_n + APFs_s}\right)$
1810	0.200	0.008	−0.040
1811	−0.077	0.002	0.216
1812	−0.015	0.283	0.272
1813	0.083	0.311	0.187
1814	−0.059	−0.019	0.127
1815	0.0	0.002	−0.122
1816	0.129	−0.211	−0.170
1817	0.158	0.320	0.107
1818	0.129	−0.415	−0.176
1819	0.231	−0.111	−0.307
1820	0.268	0.025	0.060
1821	0.075	−0.145	0.009
1822	0.0	0.564	0.291
1823	0.019	0.169	0.052
1824	−0.099	−0.305	−0.139
1825	0.040	0.233	0.214
1826	−0.089	−0.054	−0.045
1827	0.040	−0.313	0.007
1828	−0.172	0.068	0.113
1829	−0.065	−0.028	0.030
1830	−0.015	−0.198	−0.087
1831	−0.086	0.244	0.097
1832	−0.167	−0.061	−0.046
1833	−0.077	−0.013	−0.088
1834	−0.039	−0.143	−0.075
1835	0.0	0.277	0.096
1836	−0.056	0.365	0.168
1837	−0.200	−0.292	−0.250
1838	−0.370	−0.502	−0.255
1839	−0.347	−0.483	−0.339
1840	−0.387	−0.696	−0.420
1841	−0.429	−0.116	−0.232
1842	−0.123	0.072	0.015
1843	−0.247	0.075	−0.087
1844	−0.128	−0.006	−0.016
1845	−0.191	−0.174	−0.128
1846	0.0	−0.379	−0.124
1847	0.0	−0.314	−0.179
1848	−0.200	−0.480	−0.176
1849	−0.418	−0.366	−0.303
1850	−0.234	−0.541	−0.416

2.1. THE N–S ASYMMETRY

We defined the N–S asymmetry of SGs, HFs, and APFs as

$$\mathrm{NSA}S_\sigma = (\sigma_n - \sigma_s)/(\sigma_n + \sigma_s) ,$$

where σ denotes SGs (or HFs or APFs), σ_n and σ_s are the numbers of SGs (or HFs or APFs) in the northern and the southern hemispheres, respectively. Thus, if $\mathrm{NSA}S_\sigma > 0$, the acivity in the northern hemisphere dominates, and, if $\mathrm{NSA}S_\sigma < 0$, the reverse is true. The calculated values of the N–S asymmetry are listed in Table I. To show the statistical significance of these values, we followed Letfus (1960), whereby we could define the N–S asymmetry of the random distribution of SGs, HFs, and APFs on the disk as

$$\Delta\mathrm{NSA}S_\sigma = \pm[2(\sigma_n + \sigma_s)]^{-1/2} ,$$

which depends on the total number of cases in the northern and the southern hemispheres, respectively. To verify the reliability of the calculated N–S asymmetry, we used the χ^2 test and found

$$\chi = 2(\sigma_n - \sigma_s)/(\sigma_n + \sigma_s)^{1/2} = \sqrt{2}\,\mathrm{NSA}S_\sigma/\Delta\mathrm{NSA}S_\sigma .$$

Thus, for $\mathrm{NSA}S_\sigma < \Delta\mathrm{NSA}S_\sigma$, $\mathrm{NSA}S_\sigma = \Delta\mathrm{NSA}S_\sigma$, and $\mathrm{NSA}S_\sigma > \Delta\mathrm{NSA}S_\sigma$, the probability that the N–S asymmetry exceeds the dispersion value is $p < 84\%$, $84\% \leq p < 99.5\%$ and $p \geq 99.5\%$, respectively. Here the first, second and third limits imply for the statistically insignificant, significant and highly significant values, respectively. The limits divided the values of the N–S asymmetry into three categories: with a low, intermediate and high probability. The behaviour of the N–S asymmetry is presented in Figure 3.

Table I and Figure 3 for SGs, HFs, and APFs on the whole suggest that the activity in the southern hemisphere dominated. The curves of SGs, HFs, and APFs in Figure 3 show that, mostly, the N–S asymmetry was highly significant, suggesting that the N–S asymmetry is real and not due to random fluctuations. Apart from this, for the complete period (1989-1991) taken together we have also determined the N–S asymmetry for SGs, HFs and APFs. The results are -0.072, -0.083, and -0.060, respectively. In all cases the statistical significance is high. From these results also we conclude that, on average, there exists a constant and persistent N–S asymmetry which is real.

2.2. THE E–W ASYMMETRY

We defined the E–W asymmetry of HFs and APFs as

$$\mathrm{EWA}S_\sigma = (\sigma_e - \sigma_w)/(\sigma_e + \sigma_w) ,$$

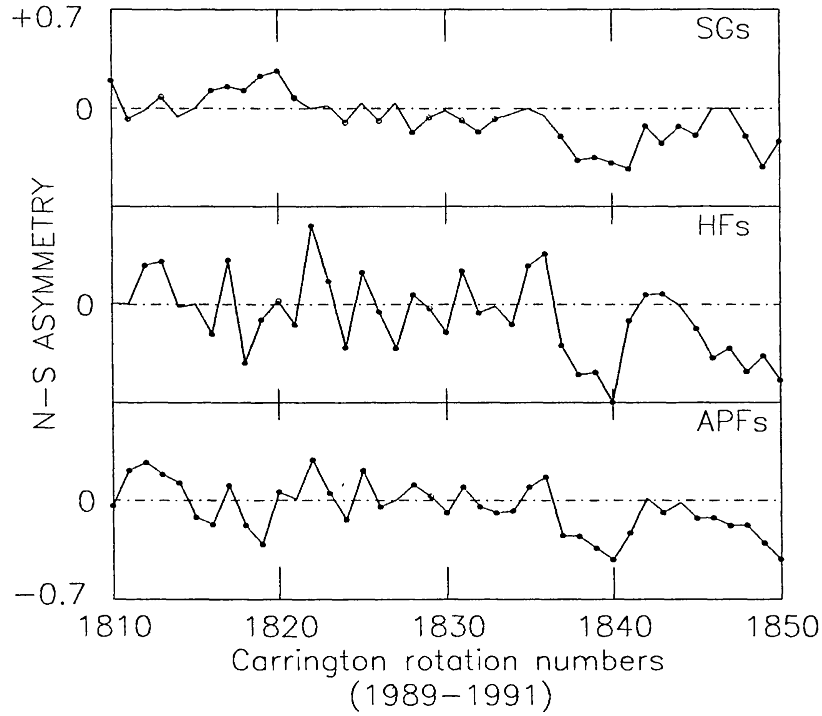

Fig. 3. Occurrence of the N−S asymmetry of sunspot groups, Hα flares, and active prominences/filaments. In the curves the values with a low probability are not marked, with intermediate probability are marked by white circles, and with a high probability by black circles.

where σ denotes HFs (or APFs), σ_e and σ_w mean the number of HFs (or APFs) in the eastern and the western hemispheres, respectively. Thus, if $\text{EWA}S_\sigma > 0$, the activity in the eastern hemisphere dominates, and, if $\text{EWA}S_\sigma < 0$, the reverse is true. The calculated values of the E−W asymmetry are listed in Table II. To show the statistical significance of these values, as earlier, we again followed Letfus (1960) and found

$$\chi = 2(\sigma_e - \sigma_w)/(\sigma_e + \sigma_w)^{1/2} = \sqrt{2}\,\text{EWA}S_\sigma/\Delta\text{EWA}S_\sigma\ .$$

Now, the three limits obtained, $\text{EWA}S_\sigma < \Delta\text{EWA}S_\sigma$ ($p < 84\%$), $\text{EWA}S_\sigma = \Delta\text{EWA}S_\sigma$ ($84\% \leq p < 99.5\%$), and $\text{EWA}S_\sigma > \Delta\text{EWA}S_\sigma$ ($p \geq 99.5\%$), imply for the statistically insignificant, significant and highly significant values, respectively. Thus, the values of the E−W asymmetry were also classified into low, intermediate and high probability categories. The behaviour of the E−W asymmetry is presented in Figure 4.

Only for the HFs did dominant activity in the eastern hemisphere exist, which is real because on average the values are highly significant; whereas the significance of values is also shown in case of APFs, they are almost evenly distributed on both sides of the axis – when integrating the curve we get a result close to zero (cf., Table II and Figure 4). Apart from this, as earlier, we have also determined the value of the E−W asymmetry for HFs and APFs for the complete period (1989

TABLE II
The E–W asymmetry of HFs and APFs

CRN (1989–1991)	E–W asymmetry	
	$EWAS_{HFs}$ $\left(\frac{HFs_e - HFs_w}{HFs_e + HFs_w}\right)$	$EWAS_{APFs}$ $\left(\frac{APFs_e - APFs_w}{APFs_e + APFs_w}\right)$
1810	−0.056	−0.034
1811	−0.051	0.016
1812	0.067	0.016
1813	0.044	0.081
1814	−0.042	0.038
1815	−0.088	−0.010
1816	0.150	−0.023
1817	0.308	0.133
1818	0.100	0.008
1819	0.268	−0.148
1820	−0.017	−0.047
1821	0.050	−0.021
1822	−0.057	0.047
1823	0.021	−0.090
1824	0.089	−0.072
1825	−0.123	−0.066
1826	0.291	0.154
1827	−0.004	0.076
1828	−0.018	−0.047
1829	0.009	−0.018
1830	0.223	0.042
1831	−0.165	−0.087
1832	0.107	−0.036
1833	0.093	0.003
1834	0.090	0.059
1835	0.036	−0.079
1836	−0.247	−0.182
1837	0.023	−0.075
1838	−0.054	0.023
1839	0.108	0.094
1840	0.132	−0.047
1841	−0.063	−0.152
1842	0.160	0.025
1843	−0.222	−0.028
1844	0.222	0.211
1845	0.133	0.126
1846	−0.254	0.034
1847	0.020	0.029
1848	−0.190	−0.020
1849	0.276	0.122
1850	0.028	0.102

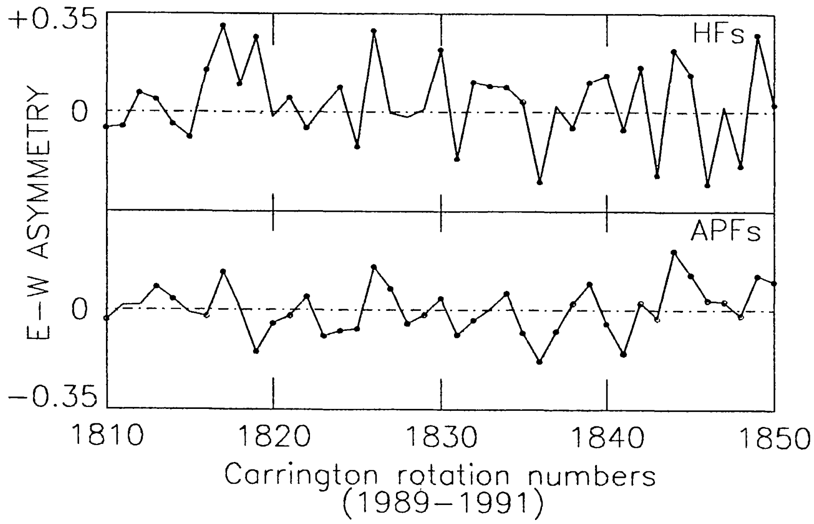

Fig. 4. Occurrence of the E–W asymmetry of Hα flares and active prominences/filaments. The statistical significance is denoted on the curves in the same way as in Figure 3.

–1991) taken together. The results are 0.035 and 0.001, respectively. Only in the case of HFs is the statistical significance high, whereas for APFs it is insignificant. Thus the results also indicate that only in the case of HFs, does there exist an E–W asymmetry, which appears to be real.

3. Conclusions

During the period considered there existed a real N–S asymmetry. We find that the activity was dominant in a particular hemisphere (i.e., in the southern hemisphere) for all the events considered. A strong N–S asymmetry that favours a particular hemisphere was pointed out earlier by Waldmeier (1971), Roy (1977), Vizoso and Ballester (1987), and Oliver and Ballester (1994) using different features of solar activity. We find an E–W asymmetry (the dominance of the eastern hemisphere) only in case of HFs. On the whole the E–W asymmetry of flare activity (i.e., HFs) is small. Letfus and Růžičková-Topolová (1980) have also shown the existence of a small but realistic E–W asymmetry for flares, F (with imp ≥ 1 and sb), for the period 1935–1976, 1935–1958, 1959–1976, 1963–1976; for subflares, S, (only sf and sn) for the period 1963–1976; and for the sum (N) of F and S for the period 1963–1976.

The N–S asymmetry showed similar behaviour for HFs and APFs, in other words the N–S asymmetry varied nearly in parallel for both these events. Figure 5 shows the correlation between the asymmetry of HFs and APFs and yielded a correlation coefficient of 0.86. No correlation between the behaviours of SGs and HFs (or APFs) was found. Here, following Roy (1977), we may conclude that the rates of occurrence of HFs and APFs depend on the complexity of SGs, rather than on the number of SGs. Roy (1977) points out a plausible correlation between the

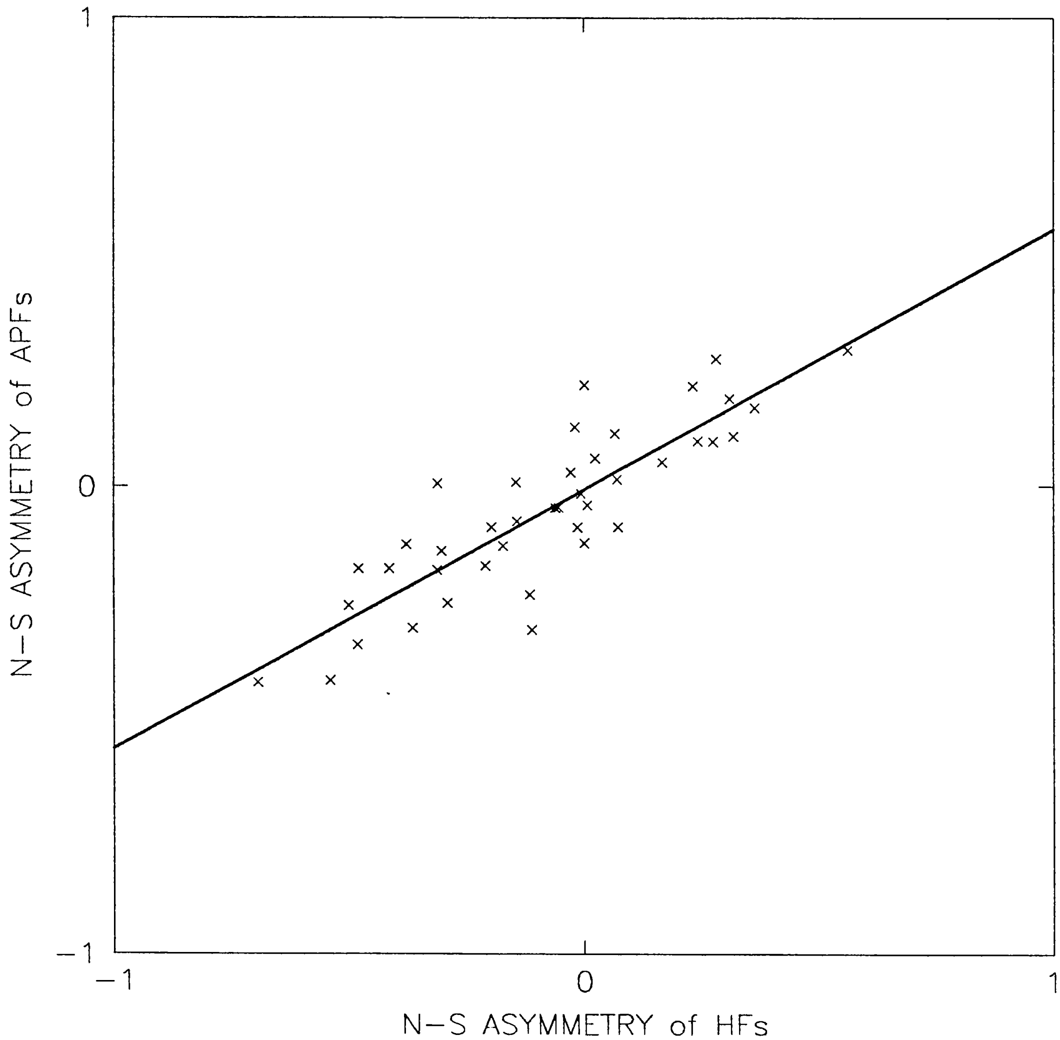

Fig. 5. Scatter diagram showing the correlation between the N−S asymmetry of Hα flares and active prominences/filaments.

energetic flares and the complexity of the magnetic configuration of the associated sunspot groups.

By studying the N−S and E−W asymmetries of events obtained (Figures 3 and 4) with the occurrence of events (Figure 2), we find no definite relationship between the asymmetries of various events and the occurrence of these events. However sometimes it seems that the asymmetries got diminished around the maximum number of events and more pronounced around the minimum number of events. The results of the studies made by Růžičková-Topolová (1974), Roy (1977), Swinson, Koyama, and Saito (1986), and Vizoso and Ballester (1990) also showed a more pronounced asymmetry near the minimum of solar activity.

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