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Problem of Short-Term Prediction of Solar Flare Activity V. Spatial Consistence between Hard X-Ray Enhancement and Strong X-Ray Appearance

by

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ABSTRACT

The aim of this paper is verification of the suggestion that small faint flares with enhanced harder X-ray flux may be precursors of strong flare activity and, as precursors, they should be located in the sunspot group where strong X-ray flares occure. Statistical analysis is based on the observations obtained at Debrecen Heliophysical Observatory and also on the standard flare observations given in Solar Geophysical Data. The analysis proved that we should reject the hypothesis of random location over the area of the sunspot group of both precursors and the other faint flares. Consequently, we may say that before strong flares the precursors appear more often in their vicinity than the other faint flares do.

1. Introduction

In the procedure of short-term flare activity prediction the knowledge of reliable precursors of strong flares is a necessity. Among other things, pre-flare brightenings in many parts of the spectrum turned out to be possible precursors what is comprehensively discussed by Sawyer at al.(1986).

In Paper II of this series Jakimiec (1987) has shown that flare activity population is nonhomogeneous. So we suggest that small faint flares with enhanced harder X-ray flux may be used as precursors of strong flares. Moreover, it was found in Paper III of the series (Jakimiec and Wanke-Jakubowska 1987) that such precursors, similarly to pre-flare brightenings discussed by

Sawyer et al. (1986), occur very often before strong flares in time interval shorter than 24 hours.

Authors of the paper believe that good precursor ought to be the indication of some changes of physical situation preceding strong flares. The aim of the work is to study whether small faint flares with the enhancement of harder X-ray flux and strong flares occur in the same area of sunspot group. This supposition is confronted with the hypothesis that faint flares are randomly scattered over the sunspot group area.

2. Description of the observational data

The observational data were gathered for the time interval from October 1979 to June 1981. The flare observations obtained in the H_α line wings (± 0.5 Å and ± 1 Å from the line center) at the Debrecen Heliophysical Observatory were combined with the standard H_α flare data given in Solar Geophysical Data (SGD). Moreover, for each flare observed at Debrecen Observatory we have taken the X-ray fluxes recorded on GOES (and given in SGD) for two wavelength intervals: fs for the interval $1-8$ Å, and fh for the interval $0.5-4$ Å. We excluded from our analysis such flares, for which the X-ray flux values cannot be read unambiguously, *e.g.* when at the same time two Hα flares were recorded.

Table 1

The distribution of the bidimentional variable (fs, fh)

fs \ fh	≤.03	.04-.07	.08-.12	.13-.3	.4-.5	≥.6	Total
0	38 19D						38
1	43 19D	18 3D	14 2D	4 2D			79
2		1	10 1D	4 3D			19
3				8	2	1 1D	11
4		1		4	3		8
5-9				1	5	15	21
≥10						19	19
Total	81	20	24	25	10	35	195

The distribution of bidimentional variable (fs, fh) is shown in Table 1. The double line separate the precursors, according to the definition of Jakimiec (1987), *i.e.* the flares with enhanced harder X-ray flux. The flares, that were observed at Debrecen Observatory and not reported in SGD, are marked by "D". One can see that the total number of such flares is rather high: n_D=50. The number of faint flares (F), with $fs \leq 1 \cdot$

10^{-2} erg cm^{-2}s^{-1} and $fh \leq 0.03 \cdot 10^{-2}$ erg cm^{-2}s^{-1} is $n_F = 81$. The number of precursors (P) is $n_P = 65$. The number of strong flares (S), with $fs \geq 5 \cdot 10^{-2}$ erg cm^{-2}s^{-1} and $fh \geq 0.6 \cdot 10^{-2}$ erg cm^{-2}s^{-1}, is $n_S = 34$. One can see that among the flares not reported in SGD there are also flares, which we call precursors. The bidimentional (fs, fh) distribution given in Table 1 cannot be considered as common for all flares. In the analysis, only strongly flaring sunspot groups were taken into account. Consequently, this selective choice of the sunspot groups is visualized through the fact that the fraction of precursors in the analysed sample is higher than in the population of all flares. In the sunspot groups with low flare activity only faint flares occur and the flares with $fs \geq 2 \cdot 10^{-2}$ erg cm^{-2}s^{-1}, occuring very seldom, have smaller hard X-ray fluxes than the precursors do. So, the high fraction of precursors in our data could be regarded as an argument confirming the hypothesis that in strongly flaring active regions the precursors occure more often than in active regions without strong flare activity.

3. Flare location obtained from Debrecen observations

In order to get knowledge whether our 68 faint flares with harder X-ray flux enhancement are really precursors of strong flares, we search in the Debrecen observational data for such pairs of flares (denoted Pb–S), for which the precursor Pb precede strong flare S in time interval shorter than 24 hours. We found 22 Pb–S pairs. Moreover, we have found 12 S–Pa pairs for which Pa flare occured after S flare. Pa flares could be the indication of the persistent strong flare activity in the sunspot group. For 14 (F–P) pairs F flare preceded P flare. For 12 (Fb–S) pairs F flare occured before S flare, and for 11 (S–Fa) pairs F flare followed S flare. Our hypothesis is that for all pairs, the flares are located randomly over the area of sunspot group. The chi-square statistics have been used to the verification of the hypothesis. For instance, for the hypothesis that Fb flares and Pb flares have similar location in the vicinity of strong flares, the value of χ^2 is equal to 4.30 and is higher than $\chi_\alpha{}^2 = 3.84$ with the significance level α=0.05. So, the hypothesis should be rejected, and we conclude that Pb flares occure more often at the strong flare sites than Fb flares do. We obtained the χ^2 values for following comparisons of locations:

a) 4.30 for the comparison Fb–S and Pb–S,

b) 1.11 for the comparison Fb–S and S–Fa,

c) 1.33 for the comparison F–P and Fb–S,

d) 3.50 for the comparison S–Fa and S–Pa,

e) 8.76 for the comparison Pb–S and S–Pa.

One can see that for the comparison of the locations of Pb flares occuring before strong flares and Pa flares occuring after strong flares (e), the χ^2 value is also higher than the assumed critical value. It means that the precursors appearing before strong flares are placed more often in the vicinity of strong flares than the precursors occuring after strong flares do. For the other comparisons the χ^2 values are less than critical values. Then, we conclude that our hypothesis should be rejected in the cases when the precursors occured before strong flares (Pb–S).

4. Flare location obtained from SGD data

Because we have used previously very small sample for the verification of our hypothesis the analysis is performed once more based on standard H_α flare data given in SGD for the years 1979 and 1980. Only the precursors and faint flares occuring before strong flares in time interval shorter than 24 hours were taken into account. Moreover, only the flares occuring in sunspot groups of D,E,F Zurich classes were included and we excluded from the analysis the active regions with more than one sunspot group. The size of the sample of the pairs Pb–S is $N_P = 193$, and the size of the sample Fb–S is $N_F = 241$. For each of the pairs Pb–S or Fb–S were obtained the positions of flares and were calculated their distances d:

$$d = \sqrt{\Delta\varphi^2 + \Delta\lambda^2}$$

where $\Delta\varphi$ is the difference between the heliographic latitudes of Pb and S (or Fb and S) flares, and $\Delta\lambda$ is the difference between the flare longitudes, with the longitude of the Pb (or Fb) flares corrected for the solar rotation.

In Table 2 one can see the comparison of the number (n_{Pi}, n_{Fi}) and frequency (f_P, f_F) distributions of the distance d obtained for the pairs Pb–S and for the pairs Fb–S. We put the hypothesis $H_0(f_P = f_F)$ against the hypothesis that both, precursors and other faint flares occuring before strong flares are distributed not randomly over the area of the sunspot group. The hypothesis H_o should be rejected, since the obtained value of χ^2 statistic is equal to 32.07, what is greater than critical value of 16.9 adopted for the significance level $\alpha = 0.05$ and for the number of degrees of freedom $r = 9$. One can conclude that faint flares Fb, similarly to precursors, occure close to strong flares ($d < 2°$), but the probability of small distances is higher for the pairs Pb–S than for the pairs Fb–S. Moreover, there are only a few (1%) P flares that occured at the distance $d > 6°$, and more faint flares are placed far (up to 10°) from strong flares. The difference between Pb–S and Fb–S pairs can be easily seen in Fig. 1, where the result of subtraction of the frequencies ($f_P - f_F$) is plotted against the distance d.

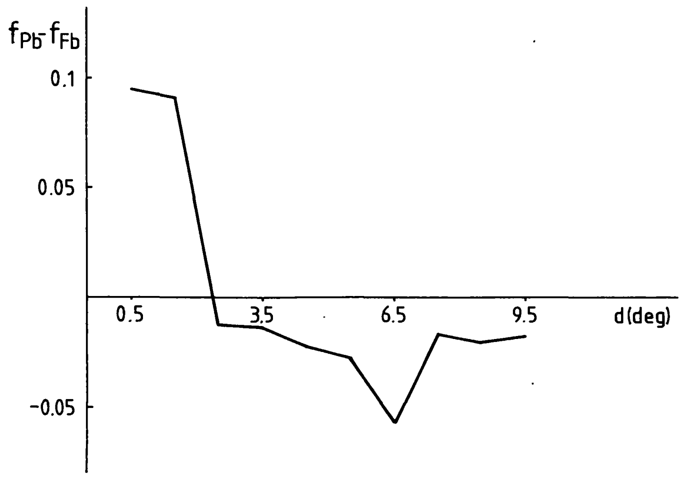

Fig. 1. The difference between the frequencies f_P and f_F plotted against the distance d.

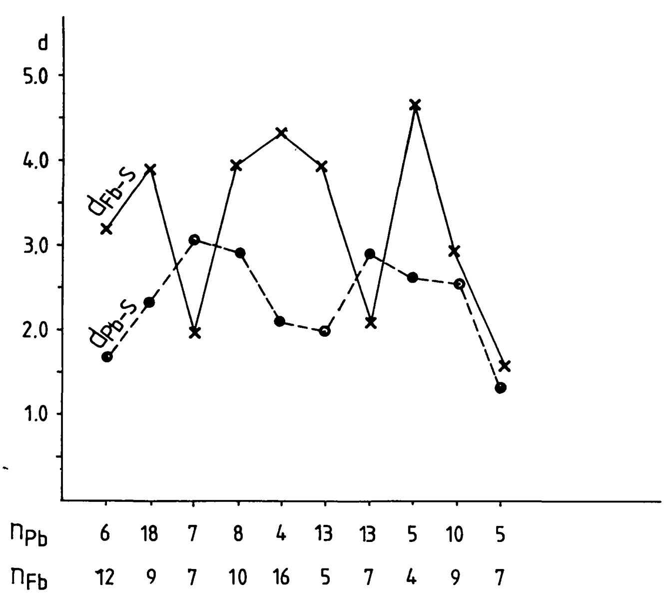

Fig. 2. The mean values of the distances d_{Pb-s} (croses), and d_{Fb-s} (points) calculated for the ten strongly flaring sunspot groups. The number of precursors n_P and the number of faint flares n_F are given on the bottom.

Table 2

The number and the frequency distributions of the distance d obtained for the pairs Pb–S (n_P and f_P) and for the pairs Fb–S (n_F and f_F).

i	d (deg)	Pb-S n_{Pi}	Pb-S f_{Pi}	Fb-S n_{Fi}	Fb-S f_{Fi}
1	0.5	31	0.161	16	0.066
2	1.5	61	0.316	54	0.224
3	2.5	41	0.212	54	0.224
4	3.5	26	0.135	36	0.149
5	4.5	19	0.098	29	0.120
6	5.5	13	0.067	23	0.095
7	6.5	1	0.005	15	0.062
8	7.5	0	0.000	4	0.017
9	8.5	1	0.005	6	0.025
10	9.5	0	0.000	4	0.017
Total		193	1.000	241	1.000

Although, in our analysis are taken into account only the solar flares occuring in sunspot groups of D,E,F Zurich classes, one can suppose that the obtained frequency distributions f_P and f_F could be strongly burdened with the fact that the sunspot groups may have various extents. In order to examinate such an effect, the ten strongly flaring sunspot groups were investigated individually. For these sunspot groups in Fig. 2 the mean values of the distance d_{Pb-S} are marked by croses, and the mean values of the distance d_{Fb-P} are marked by dots. The appropriate values d_{Pb-S} (and d_{Fb-S}) are linked up together. For each sunspot group the number of precursors n_P and the number of faint flares n_F that were employed for the calculation of the mean values, are given on the bottom of Fig. 2. The number of flares occuring in the other analysed sunspot groups was not very high. In some sunspot groups occured many faint flares, and before strong flare only one precursor was observed. In the others groups, appeared only the precursors without faint flares. One can see from Fig. 2 that for 8 of 10 sunspot groups the mean distance between Pb and S flares is about 1.5 degree less than the mean distance between Fb and S flares, and for 2 of 10 sunspot groups d_{P-S} is greater than d_{F-S} by less than 1 degree. It means that close to strong flares the appearance of the precursors is more probable than the appearance of other faint flares.

5. Conclusions

There are not such observational data which may enable us to compare the locations of strong flares with the locations of preceding them precursors or of other faint flares. However, using the Debrecen observations we may compare the flare locations with good precision, and moreover, using SGD data we may verify the hypothesis that all flares are randomly distributed over the area of sunspot group. The hypothesis should be rejected, and we state that precursors preceding strong flares are more often placed close to the site of strong flare activity than the other faint flares do. This effect is statistically significant, but we can not say that it is common for all sunspot groups. There is a number of strong flares that are not preceded by a precursor at all, but there is also many strong flares that are preceded by one or more faint flares with enhanced harder X-ray flux, called in this paper precursors.

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