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On the dependence of solar flare occurrence on sunspot polarity

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Abstract. The possibility of predicting flare occurrence on the sun has been examined. It is noticed that the p-polarity dominant spot groups are more productive of flares than the f-polarity dominant spot groups. This high productivity of p-polarity dominant spot groups has been interpreted in terms of (i) high rates of new magnetic flux eruption within the p-polarity dominant spot groups, and (ii) newly erupted magnetic flux triggering flares (*cf.* Heyvaerts *et al.* 1977). Moreover, the productivities of all group types are dependent on the magnetic field strength of the spot groups

Key words: sudden ionospheric disturbances—solar flare—sunspot groups—active region

1. Introduction

Sudden ionospheric disturbances (SIDs) result from an interaction of solar flare radiation with the constituents of the earth's upper atmosphere. The SIDs are highly correlated with the solar flare x-ray, EUV, and microwave bursts (Kreplin *et al.* 1962; Mitra 1966; Richards 1971; Deshpande *et al.* 1972; Das Gupta *et al.* 1973). Since SIDs are mostly due to flares on the sun, we call here SID events as SID-flares. Capability of solar flare x-rays to produce an SID depends on the flux value as well as on the degree of spectral hardening. Deshpande *et al.* (1972) found that about 73% of x-ray flares that produce SIDs have both flux levels and spectral hardening above the threshold value of 1×10^{-3} erg cm^{-2} s^{-1} and 1.5×10^{-2} respectively. In case of EUV burst events Richards (1971) concluded that if change in EUV flux is greater than 4% at $\lambda = 304$ Å, there is 100% probability of sudden frequency deviation (SFD) occurrences.

Solar flares begin to occur as soon as a bipolar magnetic configuration is formed in the solar atmosphere. Flare like brightenings in x-rays occur as soon as tiny bipolar magnetic structures emerge on the sun (Golub *et al.* 1974). However, the frequency and importance of flares generally increase with the rate of change of magnetic field and with the increasing complexing of the active region (Giovanelli 1939; Kleczek 1953; Bell & Glaser 1959; Kunzel 1960). The flares are most frequent in magnetically complex groups (Y or D type groups of the Mt Wilson classification, Solar Geophysical Data Suppl. 1984). According to Bell & Glaser (1959) the average number of flares during the transit of a magnetically complex Y group over the solar disc is 19.1 (22.7, if strength of magnetic field exceeds 2000 gauss), 11.2 for BY complex group; while for magnetically simple B and A groups the average number of flares are only 1.9 and 0.7 respectively. The complex groups also produce the most important flares, and flares from them are the most productive in impulsive x-rays and radio bursts (Svestka & Simon 1969; de Jager 1975).

The study relating to the productivity of flare occurrence for various types of spot groups in various ranges of magnetic field strengths has an important bearing on the understanding of the physical mechanism of flare occurrence. In this paper, an attempt has been made to examine the relationship of the productivity of SID-flare occurrence with various group types and magnetic field ranges of the spot groups. Such investigation may present some clues which may help to know the fraction of solar flares produced for each group type and each range of magnetic field strength and may also throw some light on the possibility of predicting important flares if the group type and the maximum magnetic field strength of a spot group is known.

2. Observational data

For this study, about 2000 SID flares which occurred in 400 spot groups during the solar maximum period of cycle 21, from 1979 July 1 to 1981 December 31 have been considered. The data on these SID flares and the details of spot groups or active regions (ARs) have been taken from the Solar Geophysical Data (SGD).

For each SID flare event we have noted down the corresponding Hale number of the spot group, the type of concerned spot group and the observed range of maximum magnetic field strength. Thus, the total number of the recorded SID flares and the total number of corresponding spot groups in which these SID flares occurred is obtained for each group type and each range of magnetic field strength. This is given in table 1. We decided to study productivity per group rather than the total productivity of all groups, since groups of a particular type may dominate in our study over those of other types. Therefore, for example, even if the productivity of such particular type of spot groups is less, it would appear to show productivity higher than the spot groups of other types, and as a consequence an interpretation merely on the basis of total number of SID flares for a group type may be misleading. We define 'the productivity per group' as the fractional contribution of the spot group to the total SID-flare occurrence and take it as the ratio of total number of SID-flares and total number of SID-producing spot groups. Such productivities for various group types and for various ranges of field strengths have been obtained and are given in table 1. In figures 1 and 2, we have plotted separately the number of SID flares, the number of spot groups,

Table 1. Number of SIDs recorded against number of active regions (ARs) for the various spot configurations and various magnetic field strengths

Magnetic field / Spot configuration	100–500 gauss			600–1000 gauss			1100–1500 gauss			1600–200 gauss			2100–2500 gauss			2600–3000 gauss		
	No. of ARs	No. of SIDs	Productivity	No. of ARs	No. of SIDs	Productivity	No. of ARs	No. of SIDs	Productivity	No. of ARs	No. of SIDs	Productivity	No. of ARs	No. of SIDs	Productivity	No. of ARs	No. of SIDs	Productivity
AP	08	09	1.3	39	62	1.6	48	75	1.6	46	77	1.7	13	25	1.9	00	00	00
AF	01	01	1.0	10	11	1.1	10	12	1.2	03	03	1.0	00	00	0.0	00	00	00
B	02	06	3.0	21	28	1.3	44	83	1.9	119	217	1.8	46	140	3.0	01	05	05
BP	00	00	00	03	05	1.7	20	43	2.2	57	112	2.0	30	66	2.2	02	12	06
BF	00	00	00	02	02	1.0	06	08	1.3	21	31	1.5	03	03	1.0	00	00	00
BY	00	00	00	01	01	1.0	09	14	1.6	54	123	2.3	43	128	3.0	02	04	02
Y	00	00	00	00	00	0.0	01	01	1.0	02	08	4.0	03	12	4.0	00	00	00
D	00	00	00	00	00	0.0	04	08	2.0	51	166	3.3	69	419	6.1	03	09	03

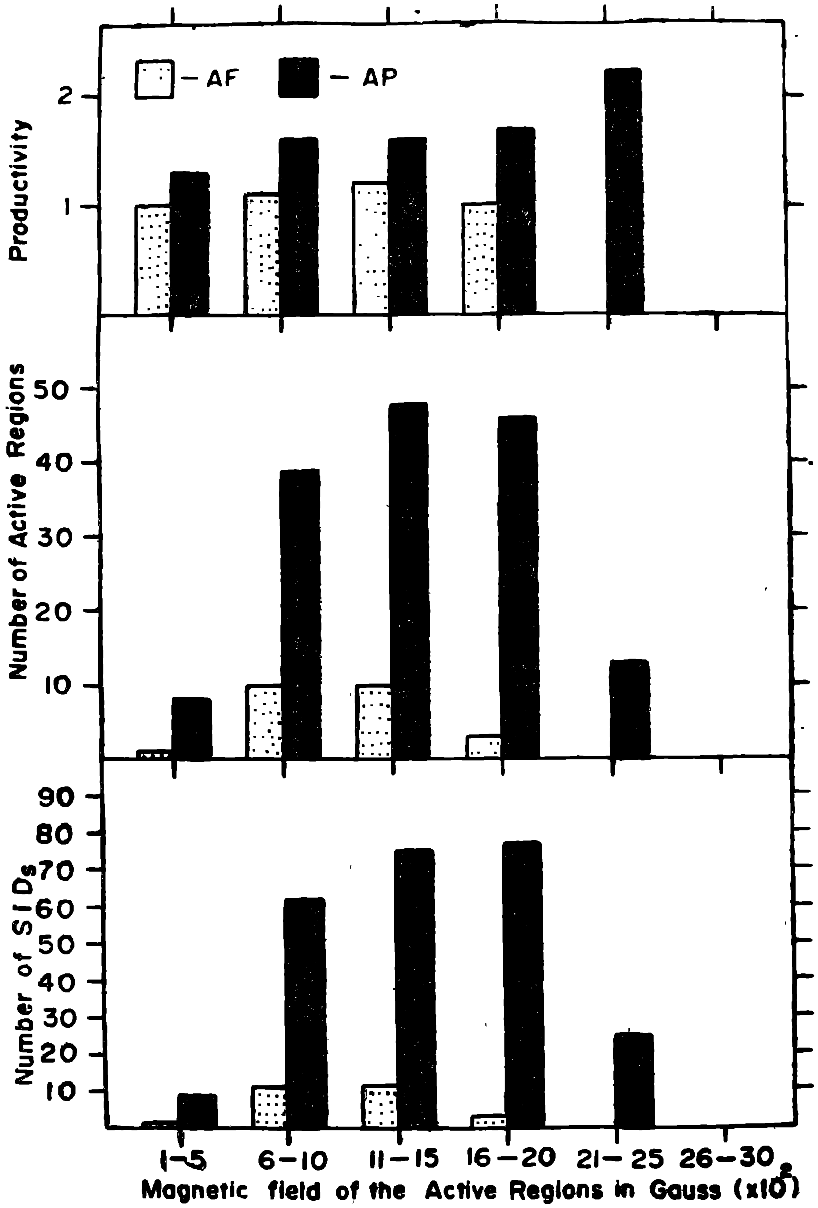

Figure 1. Number of SIDs, number of active regions and the productivities of the AF and AP spot configuration active regions versus the magnetic field strength of the active regions.

and the productivity per group respectively for A and B type groups against the range of field strength. In figure 3, the productivities as function of magnetic field ranges for various types of spot groups are shown.

3. Results

The productivities of AP and AF type spot groups for various field strengths are shown in figure 1. Here AP and AF indicate that all the magnetic measures in the group are of same polarity corresponding to either the preceding or the following

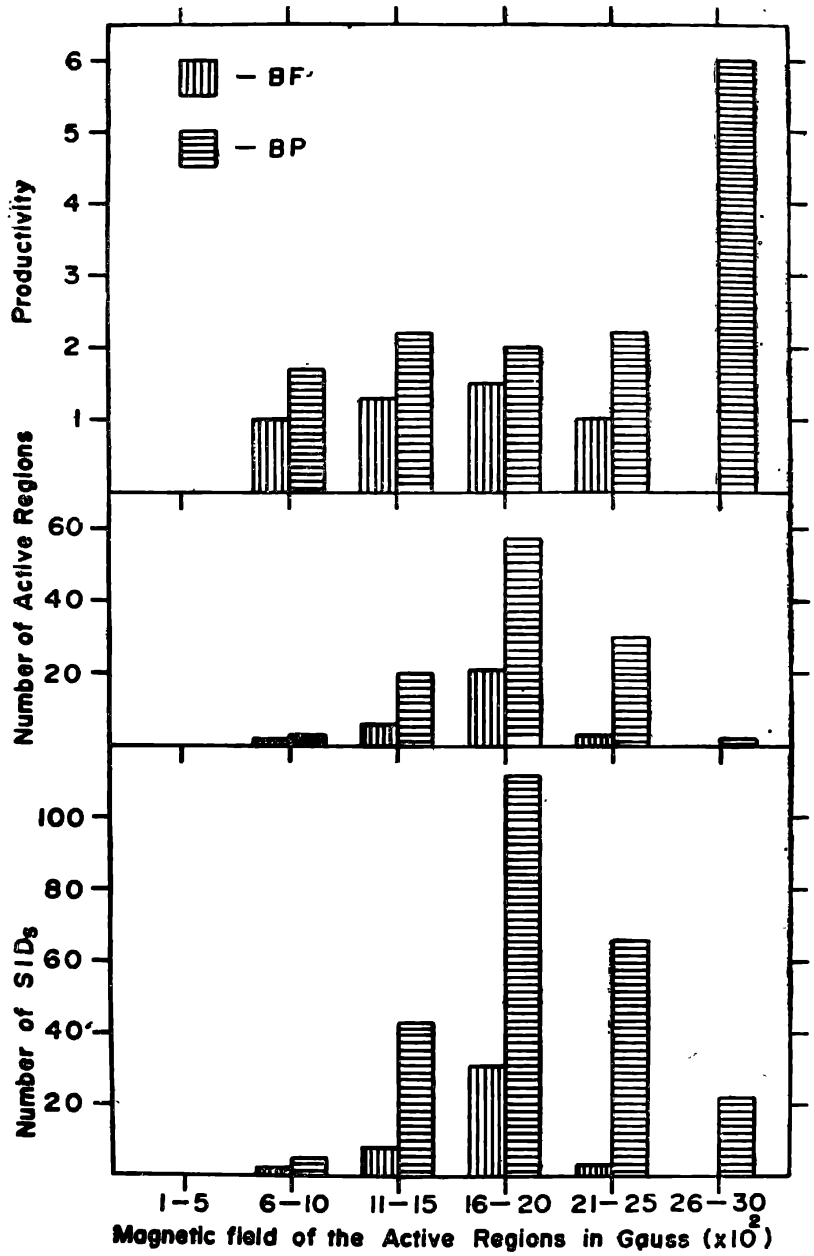

Figure 2. Number of SIDs, number of active regions, and the productivities of the BF and BP spot configuration active regions versus the magnetic field strength of the active regions.

spots respectively. Figure 1 shows that even AP and AF group types are capable of giving rise to SID flares. Sunspot groups of AF and AP types were found to be active even in the lowest magnetic field strength between 100-500 gauss. But in the highest field range of 2600-3000 gauss, both these group types were not SID-flare productive probably because there were very few A type spot groups with strong magnetic fields higher than 2600 gauss. However, in the field range of 2100-2500 gauss, only AP type spot groups were active and their productivity was the highest. Figure 1 shows that the productivity of AF type groups increases

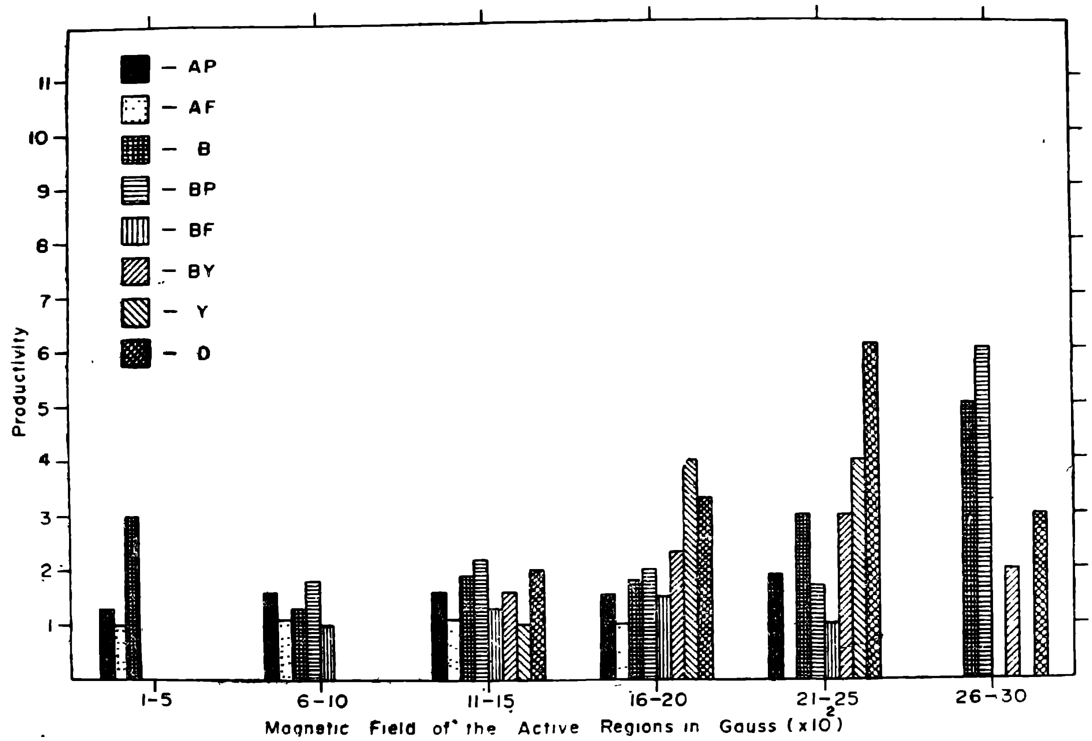

Figure 3. Number of SIDs, number of active regions, and the productivities of various spot configuration active regions versus magnetic field strength of the active regions.

beyond 100-500 gauss, attains its maximum in the range 1100-1500 gauss and thereafter it decreases to zero in the range of 2100-2500 gauss. On the other hand the productivity of AP type spot groups starts rising from 100-500 gauss until 2100-2500 gauss with a greater gradient than for AF type groups. Further, figure 1 reveals an interesting fact that in comparison to AF type spot groups, AP type spot groups are more prolific for the production of SID flares.

The productivities for bipolar active regions with BF and BP type spot groups are shown in figure 2. Here BF or BP respectively stand for bipolar groups in which magnetic measures indicate respectively that the following or preceding spot are dominant. Figure 2 shows that the BP type groups were active at magnetic field strength between 600-3000 gauss. The productivity of BP type groups shows increasing trend in this range with an abrupt increase of productivity in the range of 2600-3000 gauss. On the other hand, BF type groups were found to be active at the field strengths between 600-2500 gauss. The productivity of BF type groups first increases and reaches a maximum in the range of 1600-2000 gauss and then appears to decrease. The comparison of productivities of these BP and BF type groups reveals that the capability of BP type spot groups for producing SID flares is more than that of the BF type spot groups.

In figure 3 the productivities of B, BY, Y and D type groups alongwith the productivities of AP, AF, BP and BF type groups are shown. Here (i) B stands for a bipolar group in which the magnetic measures indicate a balance between the preceding and the following spots; (ii) BY type indicates a group which has general characteristics but in which one or more spots are out of place as far as the polarities are concerned; (iii) Y type stands for a group in which the polarities are completely mixed; whereas (iv) D type groups indicate the groups in which the spots of opposite polarities are within 2° of one another and are in the same penumbra.

Figure 3 shows that similar to AP and AF type spot groups B type groups are SID flare productive even in the field range of 100-500 gauss. The productivities of B type groups as a function of field strength show fluctuations and their maxima appear in the range between 100–500, 1100–1500 and 2600-3000 gauss. In all field ranges, the productivities of B type groups appear to be less than the productivities of BP type groups, except in the range 2100–2500 gauss.

In case of BY and D type spot groups, which are found to be active in the field strengths between 1100–3000 gauss, the maximum productivities show up in the field range of 2100–2500 gauss. These types of spot groups show both rise and fall trends in their productivities. On the other hand, Y type spot groups appear to be capable of producing SID flares in the field strengths between 1100–2500 gauss with maximum productivity in the field range 1600-2500 gauss. Among these three types of spot groups, D type groups show the highest productivity, followed by Y type spot groups. If one compares the productivities of all types of spot groups then the highest productivity occurs in D type, followed by BP, B, Y, BY, AP, BF and AF types in decreasing order. It is interesting to note here that f–polarity dominant spot groups (both A and B types) are least productive of flares among all the other types of spot groups. This study also indicates that no active regions show SID flare activity having magnetic field strength more than 3000 gauss, irrespective of spot configurations.

4. Discussion

We have shown that the p-polarity dominant active regions are more flare productive than the f-polarity dominant active regions. This finding is very interesting because the dependence of productivity of active regions on their p- or f-polarity dominance probably provides an observational evidence for the emerging flux flare model by Heyvaerts *et al.* (1977).

Martres *et al.* (1968a, b), Rust (1968, 1973) and Zirin (1974) have associated emerging new magnetic flux with flare occurrence. Heyvaerts *et al.* (1977) have outlined a flare model based on this supposition. They suggest that the type of flare produced depends on the magnetic environment into which the new flux emerges. Usually, just an x-ray bright point is produced. But emergence near a unipolar sunspot or into a unipolar area near the edge of an active region may give rise to a simple-loop flare. If the new flux appears near the sheared field around an active region filament, then a two-ribbon flare may result, with the emerging flux triggering the release of stored energy in the much larger overlying field. This model also applies to a situation of envolving flux. It has also been stressed that not all the emerging flux situations can produce a simple-loop flare. Flares are triggered only if sufficient flux emerges so that the current sheet occupying the inferface between the new and old flux regions reaches a critical height. This height depends on the flux emergence speed and the associated magnetic field strength.

We associate the SID-flare occurrences with the new magnetic flux emergences in the spot group on the lines of Heyvaerts *et al.* (1977). The high productivity of solar flares in p-polarity dominant active regions, obtained by us, may result from the fluctuations in the rate of magnetic flux eruptions in the pre-existing p- and f-polarity dominant spot groups. The p- and f-polarity dominant magnetic regions represent respectively the regions of especially high and especially low rates of new magnetic flux eruptions (Tuominen 1962; Bumba & Howard 1964; Leighton 1969). The result is that p-polarity dominant spot groups will enhance the rate of eruption of new magnetic flux in them and thereby lead to a greater likelihood of flare occurrences (Heyvaerts *et al.* 1977). On the other hand, f-polarity dominant spot groups will suppress this rate for emerging flux and therefore these spot groups will be least productive of solar flares. It is further noted that the productivity of B type spot groups in which p- and f-spots are magnetically balanced is more than that of BF type groups but certainly less than for the BP type spot groups. This higher productivity of B type spot groups probably may also be accounted for by the enhanced rate of new emerging flux in them.

This investigation further confirms the established fact that the complex D and Y type spot groups are highly productive of SID flares. It should be noted that in a complex spot group the magnetic field appears to depart greatly from a potential field configuration. Evidence for this is the fact that filaments and fibrils in filament channels run largely parallel to the boundary between the positive and negative fields on the solar surface. It is the energy stored in the non-potential fields that is probably the source of energy for a flare. The emergence of new flux triggers the release of stored energy and a flare results. It appears that the productivity of flares depends not only on the rate of emergence of flare triggering flux but also on the rate of energy build up in non-potential fields. Further, from figure 3 and table 1 it is clear that the Y and D spot configuration ARs are active only beyond 1000 gauss.

Another important fact revealed by this investigation is that the AP, AF and B type groups are quite flare productive even in the lowest range of magnetic field strength between 100–500 gauss whereas the BP, BF and BY type groups appear to be active only beyond the field range 600-1000 gauss. For complex D and Y type groups, this starting field range is 1100-1500 gauss. This may probably be a consequence of the circumstance that there are very few BP, BF and BY type groups and very few Y and D type groups that have weak magnetic fields, less than 600 and 1100 gauss respectively. Similarly the upper extremal limit of field ranges in which the groups are productive is 1600–2000 gauss for AF type, and 2100–2500 gauss for AP, BF and Y types. Again this is probably because there are very few AF type groups and very few AP, BF and Y type groups with fields stronger than 2000 and 2500 gauss respectively.

The range of field strength in which the productivities are maximum appears to be 1100–1500 gauss for AF; 1600–2000 gauss for BF; 2100–2500 gauss for AP, BY, Y and D; 2600–3000 gauss for BP and B type spot groups. The spot groups AF, BF, BY and D types show both the rise and fall trends in the productivity, whereas the AP, BP, B and Y type spot groups exhibit only the rising trend, sometimes with fluctuations in their productivities. This indicates that the productivities are strongly dependent on the magnetic field strength. The above study further tells us that a knowledge of the productivity of various spot group types at various ranges of magnetic field strength may help predict the possibility of the occurrence of the SID and flare activity on the sun.

5. Conclusions

The results discussed here may be used to predict flare occurrence in the spot groups if their group types and the ranges of maximum field strengths are known. It is shown that the p-polarity dominant active regions are more flare productive than the f-polarity dominant active regions. This provides an observational evidence for the emerging flux flare model by Heyvaerts *et al.* (1977) and further confirms the results earlier discussed by Tuominen (1962) and Bumba & Howard (1964) regarding the preference of new magnetic flux eruptions within the boundaries of p-parts of old magnetic regions. It is furthei noted that the complexity of the spot groups starts only above a field strength of 1000 gauss and that the productivities of spot groups of various types are strongly dependent on the magnetic field strengths.

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