A STATISTICAL ANALYSIS ON SUNSPOT-GROUPS CORRELATED TO M AND X FLARES

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Abstract

Very energetic flares and Coronal Mass Ejections may have important consequences on Space Weather and Earth magnetosphere. In the last years, thanks to theoretical modelling, ground based and satellite observations, the comprehension of flares and CME has greatly improved. Nevertheless, it is not yet possible to surely forecast whether and when an active region may give rise to these events. In this context, we have focussed our attention on the possibility to identify the most favourable conditions an active region must develop in order to be flare-productive. We have therefore used data on sunspot-groups (INAF-Catania Astrophysical Observatory and NOAA reports) during the period January 1998 - April 2002, and data on very energetic flares (M and X) obtained in the soft X-ray range by GOES 8, in order to define the characteristics of several parameters which may indicate whether an active region is going to produce a flare.

Key words: Sunspot-groups; flares; Space Weather.

1. Introduction

Solar flares are explosive phenomena occurring in active regions and involving several atmospheric layers. Observations performed by Yohkoh, SOHO and TRACE have stressed that these phenomena begin at coronal levels and then propagate in the lower atmosphere, involving different physical processes, like magnetic reconnection, particle acceleration, shock waves, plasma motion, chromospheric evaporation (Priest & Forbes, 2002). These processes produce observable effects at different wavelengths, therefore, in order to have a complete scenario, it is necessary to coordinate satellite observations with ground-based ones during a period which goes from few hours before the event to its end: this means that one should be able to determine in advance the characteristics of an active region which is going to host a flare.

Nevertheless, despite many precursors have been singled out, it is not yet possible to surely forecast whether a sunspot-group is going to produce a flare. In this regard, it must be stressed the importance of flare forecasting also in the framework of the Sun-Earth connection. Very energetic transient phenomena occurring in the Sun atmosphere may in fact induce variability in Space Weather and consequences on Earth magnetosphere and ionosphere.

In this context, we have carried out a statistical analysis on several parameters characterizing sunspot-groups, aimed at defining in what circumstances a flare takes place.

This work consists of two parts: in the former we make a statistical analysis on parameters characterizing sunspot-groups; in the latter we investigate the evolutionary history of each sunspot-group.

We have used data on sunspot-groups collected at INAF - Catania Astrophysical Observatory (IOACt) during the period January 1998 - April 2002, together with data deduced by NOAA reports. These data have been correlated with M and X flares data obtained in the soft X-ray range by GOES 8.

2. Data acquisition and analysis

At INAF-Catania Astrophysical Observatory, solar observations in the optical range (white light and \( H_\alpha \)), are performed by means of an equatorial spar, which includes: a) Cook refractor, used for visual observations; b) 150-mm refractor feeding a \( H_\alpha \) Zeiss filter interfaced to a 1360 × 1200 CCD camera, used
to acquire full disk chromospheric images; c) 150-mm refractor feeding a $H_{\alpha}$ Halle filter, used for limb observations.

The program of solar patrol allow us to determine the following sunspot-groups parameters: heliographic coordinates of the group center of mass, number of sunspots in the group, number of pores in the group, corrected area in millionths of the solar hemisphere, type according to Zurich classification, type of penumbra in the largest spot, relative importance of the Leading (L) or Following (F) spot and Sunspot Population Density (SPD).

Using GOES 8 data on M and X flares, together with data on sunspot-groups deduced both by NOAA reports and by IOACt observations, we have carried out a statistical analysis based on the determination, for each sunspot-group recorded at IOACt, of daily parameters (a) number of sunspots in the group; b) number of pores in the group; c) area of the group in millionths of the solar hemisphere (msh); d) type of penumbra; e) type according to Mc Intosh classification) and on the identification of the spot-group hosting each M or X flare by means of NOAA number and heliographical coordinates. The total number of sunspot-groups recorded during the period under examination is 2420; for these groups, 11371 daily records have been collected.

As far as flares are concerned, we processed 621 flare records. The flares occurring in strict spatial association with a spotgroup were 593 (the 28 [% 4.5%] the total flare number) flares remaining probably occurred during some intervals of lacking observations.

In fig. 1 squares indicate the number of M and X flares (hereafter referred to as $N_{MX}$) as a function of the number of sunspots in the group: $N_{MX}$ shows its maximum value for groups with a low number of sunspots (1 - 5) and decreases monotonically when the number of sunspots increases. In the same figure, triangles indicate the ratio between $N_{MX}$ and the total number of groups having the same number of sunspots $N_{ST}$ ($N_{MX}/N_{ST}$). We can see that the highest probability of flaring is found for groups with a number of sunspots in the range 26 - 30. Therefore, even if groups with high number of sunspots are the most uncommon, they actually are the most flare-productive.

This means that, even if the groups with a small...
number of sunspots, being the most frequent, appear to produce a high number of flares, they actually have the lowest probability of flaring.

An analogous result is found for the number of pores in the group: despite the highest number of flares is recorded in sunspot-groups with a low number of pores (the most frequent), the highest probability for flare occurrence is related to groups with the highest number of pores (the most rare).

Moreover, we determined that the maximal value of $N_{MX}$ is found for relatively small spotgroups (area in the range $300 \approx 400 \cdot 10^{-6}$ solar hemisphere), whilst the probability of flaring increases with the spotgroup area. Since large areas characterize older than $3 \approx 6$ days spotgroups, that suggests that the rate of flaring is higher for mature, large area spotgroups, than for young, small area ones.

This result is confirmed by the analysis concerning the Zurich type, which indicates that the most flare-productive are the P groups.

Fig. 2 gives the number of M and X flares as a function of the penumbra type of the largest spot in the group ($s = \text{no penumbra}; r = \text{rudimentary penumbra}; a = \text{small, symmetric}; k = \text{large, asymmetric}$ (McIntosh, 1990)) (squares) and the ratio between $N_{MX}$ and the total number of groups characterized by a certain penumbra type (stars). We can see that the highest number of flares is related with penumbra types $a$ and $k$, i.e. with both small and large asymmetric penumbra. Therefore there is a strong correlation between high flare productivity and the asymmetry of the penumbra of the largest spot in the group.

Fig. 3 gives the number $N_{MX}$ for various McIntosh classes. We can see that the most flare productive are groups characterized by "open spot distribution".

4. Dependence of flare productivity on sunspot groups evolution

In this section, our attention is focussed on how the history of a spotgroup affects its capability to produce energetic flares. As already mentioned, the spot records were firstly recognized to describe 2214 groups. These groups were identified as first appearances or returns of 1654 recurring groups. For the sake of brevity, the groups considered throughout their lifetime (including, in general, more than one passage) will be referred to as "extended" groups.

The authors are aware that no identification of a group with a previous one is free of doubts, due to the lack of continuity in the observations which occurs for the time each recurring group spends on Sun far side, and for the difficulty in singling a group out, when lying close to the limb. A work in progress reveals, indeed, that the visibility of a group is function of its distance from the central meridian. We loose in fact from $20\%$ to $30\%$ groups in the longitude sectors $\pm (30 \sim 70^\circ)$ and more than $50\%$ for groups lying beside $\pm 70^\circ$.

The "extended" spotgroup set has been divided into the subsets of the flare-productive and the not-flare-productive groups (hereinafter, active and not active groups). An "extended" group is required to produce some flare in one passage at least, in order to be defined active.

Thanks to such conventions, we counted in our sample 182 active and 1472 inactive "extended" groups.

In Figure 4 diamonds indicate the number of the active groups at each passage on the solar disk.
Squares report the number of active groups at the passages at which they actually hosted flares, and triangles the number of groups at the passages at which they did not host any flare. Figure 4 reveals that both at the 1-st and 2-nd passage the active groups hosting flares are more than those which do not host them. Starting with the 3-rd passage, the active, not-hosting flares groups are more than the others.

The number of flares produced at each passage is shown in Figure 5.

Moreover, we have computed the ratio of the number of flares to the number of groups, for equally-old groups (namely, for groups at their 1-st, 2-nd ... 5-th passage), so as to measure the capability of the active groups to produce flares, as a function of the age. Such a ratio assumes the values 1.52, 1.47, 1.55, 0.32, 0.36 for the groups at the passage 1, 2 ... 5. The first three appearances of an active group are characterized, therefore, by the highest flare-production rate; after that, the flare-production rate abruptly decays.

These results suggest, therefore, that a program of flare warning should include the careful monitoring of the spotgroups which have already produced flares in some epoch of their lifetime. Indeed, a group which has already hosted one flare is expected yet to host $2.26\pm1.5$ flares.

On the other hand, no inactive group has been observed after its 6-th passage.

The average number of passages on the disk was $\approx 4.6$ for active and $\approx 1.5$ for inactive groups.

That means that the active groups roughly live three times more than the inactive groups. This result confirms and extends a previous one, found by these authors (Contarino et al., 2002; Ternullo et al., 2002; Zuccarello et al., 2002), which was concerned only with groups at their first passage.

Since, for any type of groups, the ratio of the group number at the (n+1)-th passage to the group number at the n-th passage measures the probability that the (n+1)-th passage actually occurs, it results that such a probability is quite higher for active than for inactive groups: if we consider, for the sake of brevity, only the probability that a group returns after its first appearance, we get 71.43% and 16.92% for the active and inactive groups, respectively.

5. Conclusions

This work originates in the frame of flare forecasting studies which are carried out at the INAF - Catania Astrophysical Observatory. We have focussed our attention on the possibility to find any kind of relationship between the spotgroups and their capability to produce energetic (M or X type) flares by using a statistical analysis.

The results indicate that – for a given group – the probability of flaring is related with its complexity, expressed by its large number of spots and pores, its large area, its membership of some of the most evolved Zurich types and with the asymmetry of the penumbra of its largest spot.

These results are fully compatible with the well known tendency of the magnetic flux toward reconnection in the presence of a complex magnetic topology. Moreover, a large spotgroup offers a large “cross section” to newly buoyant flux, so that destabilization and flaring are easily triggered.

Moreover, the study of the sunspot group evolution has shown that the groups hosting energetic flares roughly lives three times longer than the others. This behaviour may be related to the continuous emergence of new flux from the underlying regions, as observed in active longitudes (Stanek, 1972), and again with a greater probability of magnetic reconnection between the old magnetic flux tubes and the new ones which emerge from the subphotospheric layers.

On the contrary, sunspot-groups forming in sites not belonging to active longitudes are less flare-productive because the probability of interaction (and reconnection) between flux tubes emerging in different times is very low.

References


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