ON THE SOLAR ACTIVE ZONES DETERMINED BY THE POSITIONS OF STRONG FLARES

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Abstract: The proper locations of strong (1+ and more) chromospheric flares in the coordinate system connected with an active region centre is investigated. A time-latitude diagram for the vectors of flare's displacement relative to the active region centre is constructed. It is found out the systematic vector's displacements directed to the pole for low latitudes and to the equator for high ones in the beginning of the 11-year cycle. *E*-asymmetry of flare locations are directed to the east in the beginning of the 11-year cycle and to the west in the end ones.

The position of intersections of flare's vector displacements show some centres on a latitude-time diagram which seems to repeat the 11-year cycle curve.

These centre positions are compared with the latitude-time distribution of proton events for the period of 1956—1969. The superposition of two distributions show that the proton flares concentrate round some epicentres but as a rule are not observed in the epicentres itself.

The comparison seems to demonstrate that there are some active centres on the Sun which are determined by the vector displacements of flares where proton regions presumably concentrate. That can have a definite forecasting interest.

The hypothesis of the 22-year solar cycle, presented by Babcock (1961), includes the conclusion about the zonal drift of the sunspots from high latitudes to low, i. e. the Sporer law. As shown by Kopecký (1973) the Sporer law, expressed in terms of the critical field intensity, H_K, produced by differential rotation, acts on both sides of latitudes ±45°, i. e. towards the equator and the pole alike. This gives an explanation of such different phenomena as coronal rays and the well-known prominence drift to the poles.

A less known display of the Sporer law, relative to the non-stationary processes, are the flares. In a number of papers (Kasinskii, 1968, 1970, 1973) we have noted the systematic displacement of flares, relative to the centres of sunspot groups, which represent the proper positions of flares. The proper positions also depend on the latitudinal positions of the sunspot groups (Kasinskii, 1968). For this reason it is interesting to study this problem using the extensive material of the Quarterly Bulletin on Solar Activity, 1954—1971, in order to obtain the time-latitude distribution of proper flare positions. Another interesting fact is that the proper positions of flares, relative to the centres of sunspots, or the magnetic centre, may help in obtaining the vector characteristic of the 11-year cycle. This also draws attention to the problem of the direction of solar activity with respect to flares. As regards the sunspots, this has been demonstrated earlier (Kopecký, 1958) for the high-latitude sunspot zone and theoretically confirmed in the interpretation of the Sporer law (Kopecký, 1963).

The material we have used includes all the flares of the world observatory network, but all small flares of importance 1 or less were excluded. Only flares of importance 1+ or more were considered. Neither were the flares at the limb (±15°) considered, because of the large errors which could be incurred in determining the co-ordinate positions of these flares (Quarterly Bulletin 1954—1970).

The Distribution of the Proper Positions of Strong Flares in the Time-latitude Diagram and its Peculiarities

Because of the inhomogeneity of the world solar flare data (Quarterly Bulletin 1954—1970), in averaging over all the stations the co-ordinates of the flares, observed by a number of stations, should by ascribed different weighting factors as follows:

$$\Delta\varphi(\varphi, t) = \frac{\Sigma N_K \Delta\varphi_K}{\underset{K}{\Sigma N_K}} ;$$

$$\Delta\lambda(\varphi, t) = \frac{\Sigma N_K \Delta\lambda_K}{\underset{K}{\Sigma N_K}} . \qquad (1)$$

Here N_K is the number of stations observing a particular flare ($K = 1, 2, 3, \ldots$), $\Delta\varphi_K$ and $\Delta\lambda_K$ are the displacements of the flare in terms of the latitude and longitude, relative to the centre of the active region at the time of the flare's beginning.

The averaging in Eq. (1) was carried out over a space-time interval of 1 year and 10° in latitude, relative to the equator. The mean displacements $\overline{\Delta\varphi}$ and $\overline{\Delta\lambda}$ define the components of some vector $R\ \{\overline{\Delta\varphi(\varphi, t), \Delta\lambda(\varphi, t)}\}$, which can be denoted as a vector index of the mean displacement of the flares position inside the space-time interval chosen.

The observed vector indices were compiled into the time-latitude diagram, covering the years 1954 to 1971. The diagram showed strong fluctuations, apparently due to annual variations. In order to verify the 11-year variation reliably, we have to smooth $\overline{\Delta\varphi}$ and $\overline{\Delta\lambda}$ linearly, using the following formulas:

$$\bar{x} = \frac{1}{3}\,(x_{-1} + x_0 + x_{+1}),$$

$$\bar{x} = \frac{5}{6}x_{-1} + \frac{1}{3}x_0 - \frac{1}{6}x_{+1} .$$

The latter formula is to applied to the extreme points of the diagram. The results of two time smoothings of the R-vectors, first for $t = \text{const}$ and then for $\varphi = \text{const}$, are shown in Figure 1.

It should be noted that in the northern and southern hemispheres mirror-type coordinate systems are to be applied, i. e. the vertical component of the $\overline{\Delta\varphi}$-displacement is always directed towards the poles (the west on the right-hand side and the east on the left-hand side). As can be seen from the diagram, the R-vectors are oriented non-randomly, as displayed by the systematic changes of the R-vectors with latitude, as well as with time.

In the beginning of the 19th and 20th cycles the vector displacement was directed to the east and, possibly, to the poles, while at the end of the cycle its direction was nearly opposite — towards the equator and the west.

Another peculiarity of the R-vectors is their different behaviour in the high (30—40°) and low (10—15°) latitudes. In high latitudes as a rule an equatorial shift is observed, while in low latitudes a polar shift. This tendency is disrupted somewhat towards the end of the cycle, when two sunspot zones from opposite hemispheres move towards each other at a short distance of the order of 10°.

Another peculiarity of the diagram in Figure 1, the so-called "edge effect" should be noted. In the years of maximum activity 1958—1959 and 1966—1969 the absolute values of the R-vectors are noticeably less in the centre than in the edges of the diagram. This can be explained reasonably. In as much as the summarized flares are maximum in the centre of the diagram, the general increase in the number of flares leads to an isotropic distribution of the R-vectors which is reflected in a decrease of their absolute values.

The enumerated peculiarities of the φ-t vector diagram are displayed more clearly, if the northern and southern hemisphere vectors are added (Fig. 2). Figure 2 shows clearly that the changing from the eastern-polar direction to the westernequatorial occurs in the maximum of the cycle, i. e. the maximum appears as the point where the sign of the asymmetry of the flare's relative position with respect to the sunspot groups changes.

The Changing of Directions of the Displacement of Flares and the Positions of Proton Flares in the Time-latitude Diagram

The mean displacement of the position of flares can be interpreted as due to the bipolar structure of the magnetic field or of the sunspots. As is well known, the bipolar group consists of two unequal components, the western of which has a longer lifetime and a stronger magnetic field, while the eastern one presents a somewhat weaker magnetic structure.

The changing of the mean displacements means in general that at the beginning of the cycle the flares, generated in the east (following sunspots) dominate, while at the end of the cycle the flares, generated in the west, predominate. This can explain the fact that after the maximum of the cycle the flares are more geoeffective than in the minimum,

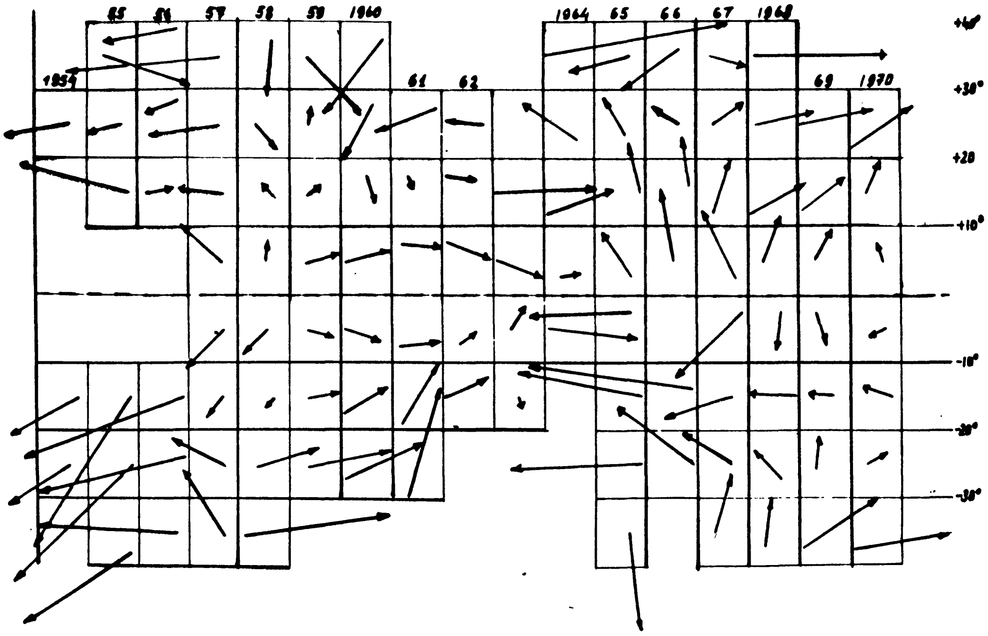

Fig. 1.

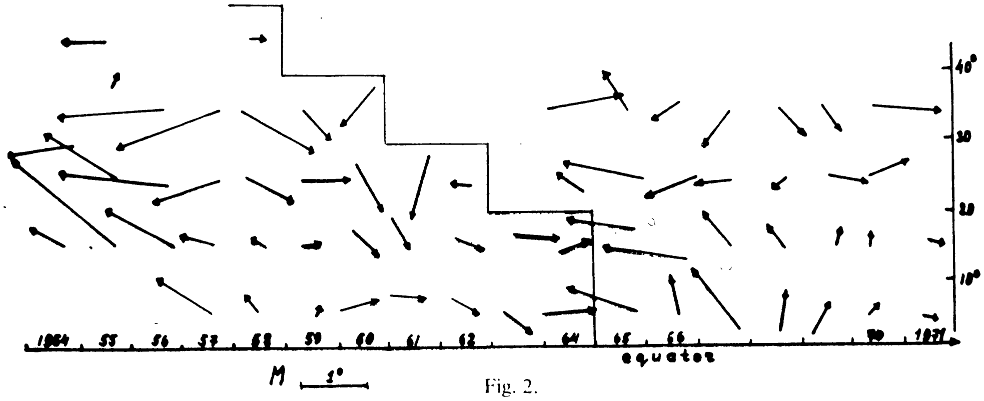

Fig. 2.

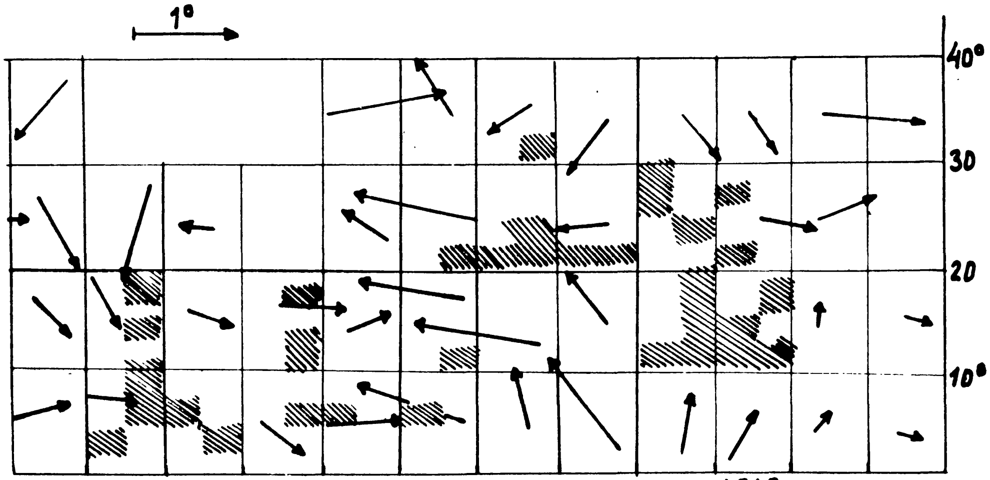

Fig. 3.

or during the increasing phase of the cycle. Therefore, they frequently obscure the leading sunspots, the magnetic field of which is stronger. As shown by Bumba and Sýkora (1972) one can also consider that the mighty flares are in good correlation with gigantic regular structures of the magnetic field. This field may shift the general structure of the magnetic field in the process of its evolution, displacing the flare positions in the sunspot groups to the east or to the west.

In Figure 3 the general positions of the epicentres of the proton flares are shown. The vector displacements of the flares are also plotted. This allows one to compare the general proton flare distribution with the changing of the direction of flare activity (Papagiannis et al., 1972: Catalogue of Chromospheric Flares 1972). If one admits that the vectors in Figs 1—3 reflect not only the statistical, but also the individual displacement of one particular flare, one can see that the proton flares are concentrated at the intersections of vectors in the nearest time-space intervals (Fig. 3). Therefore, one can speak of the possible coincidence of proton flare events with the centres indicated by the vector displacements of flares.

If one constructed the same diagram for the sum of the northern and southern hemispheres, the same results would be obtained, but with a more pronounced 11-year proton-flare drift, as well as a displacement of the *R*-vectors. However, one may again give different interpretations to Figures 1 and 2. As can be seen from the diagrams, at the beginning of the cycle the direction of the high-latitude vectors points towards the pole and to the east, where the high-latitude sunspot generation zone is located. It is, therefore, possible that this direction of the *R*-vectors is a consequence of the influence of the neighbouring sunspot activity zone.

In the minimum of the cycle, when the two sunspot zones come close to each other, the northern and southern hemispheres act together in a similar manner, serving as zones of attraction for one another, In this case the vector displacement in each zone is oriented towards the neighbouring zone. Which of the three interpretations mentioned is correct, is to be proved by future investigations in this field.

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