GEOMAGNETIC ACTIVITY AFTER LARGE CHROMOSPHERIC FLARES

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I. INTRODUCTION

A number of papers have dealt with the influence of chromospheric flares on the geomagnetic activity and have supplied information on the basic features of the connection between chromospheric flares and geomagnetic activity. Amongst what are not classical works are e.g. [1, 2]. Intensive research along these lines, instigated by the practical need for application in forecasting geomagnetic activity, has, however, raised a number of mutually contradictory opinions on the above connection (see bibliography in introduction to [3]). It is obvious that new results in research into corpuscular radiation in the vicinity of the Earth will require certain changes to be made in the interpretation of this connection [4].

From the point of view of forecasting geomagnetic activity, chromospheric flares are an important expression of solar activity, whether they are understood as a direct source of geoactive corpuscular streams or as a time-space indicator of the conditions favourable for the emission of these streams, with respect to their time and space unambiguity and significance. Statistical investigation into the dependence of geomagnetic activity on chromospheric flares must obviously be carried out so that the pre-conditions are obtained for forecasting geomagnetic activity in the different cases; these investigations should be used to explain the relation between chromospheric flares and other expressions of solar activity as well as the whole active region in which the flares occurred. However, one must avoid simplifying or over-estimating the role of flares, as has been sometimes done recently.

The present paper gives a statistical study of the geoactivity of large chromospheric flares so as to be able to compare it with earlier papers on this subject and particularly with paper [5] on which, to a certain extent, it is based. The set of flares used here, however, has very different properties. The geoactivity of flares is understood as ("large") geomagnetic activity caused by corpuscular radiation. Attention is not paid to the mechanism of the emission of corpuscular radiation or to its manner of propagation in the space between the Sun and Earth. Apart from the assumption, based on experience, that the arrival of a geomagnetic disturbance occurs several tens of hours after the emission of corpuscular radiation from the Sun, no other special assumptions are made for the investigation.

II. OBSERVATIONAL MATERIAL

1. Flares

Data on flares were taken from [6] (CGF for short), which contains all observed flares of importance of at least 2+, occurring in the period from 1859 to 1956. The CGF contains altogether 438 flares which could be used for studying some dependences, when observational material on geomagnetic storms is simultaneously available. Since the used index of geomagnetic activity, which

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seems the most suitable for investigating other dependences, is accessible only for a relatively small part of the period of the CGF, we had in this case to confine ourselves to flares from 1937 to 1956. Despite this, however, the number of flares applicable for the investigation did not noticeably decrease since in the initial period, up to the thirties of this century, only very few flares were observed. It can be said that in the initial period of the CGF the observation of flares was an exception while towards the end of the period it was an exception not to observe flares of greater importance; as is known, this is due to the development and expansion of means of observation and the organization of an observational service. The set from the smaller period contains about 84% of the total amount, so that practically the same reliability can be ascribed to investigations on the basis of both sets.

The following flare characteristics in the CGF were used: date and time of flare commencement, distance from central meridian λc, importance of flare i, accuracy in determining importance $\boldsymbol{i}$, i, (i). In regard to the question of flare importance and the accuracy in determining it, it should be noted that the importances of flares, which come into consideration for classification in the CGF, were verified on a unified basis in accordance with the present state of classification, which is important not only for flares from the period before the commencement of systematic flare study, when the importances were not determined in the present-day sense, but also for the later period, when the determination of importances for many flares differs from observer to observer. Determination of the accuracy with which the importance is determined was simultaneously carried out by means of the following three degrees: $\boldsymbol{i}$ — importance given in CGF is well determined, i — exact importance is not certain but was undoubtedly greater than 2, (i) — it is not certain whether the importance was actually greater than 2. For these reasons the CGF represents the most homogeneous, reliable and comprehensive set of large flares up to now.

2. Geomagnetic Activity

The data on geomagnetic activity were taken from the results of observations by the world network of geomagnetic observatories by means of the published indices of geomagnetic activity and data on geomagnetic storms in the CGF.

The most suitable index for investigating geomagnetic activity was chosen as Ap, which, as is known, was introduced as the degree of disturbance of the external geomagnetic field of corpuscular origin in a time interval of one day [7]. The index Ap is derived by a definite procedure from the index Kp, so that the universally recognized advantages of the original index, such as objectivity, accuracy and sensitivity, are preserved. Moreover, the index Ap provides a certain smoothing in the diurnal interval, which, however, emphasizes the geomagnetic disturbances and is at the same time simply connected with the actual average changes in the geomagnetic field, to which the index Ap may eventually be transferred. The choice of other indices of geomagnetic activity, such as C or U, would insignificantly extend the set of flares with respect to longer observational series but would mean a considerable loss in accuracy of the results. Diurnal values of the index Ap from 1937 to 1956 were used for the investigation [8].

Another source of data on geomagnetic activity after flares was the data on geomagnetic storms in the CGF, which gives the time intervals between the flare and each geomagnetic storm, the commencement of which lies in an interval of 14—70 hrs. after the flare. At the same time it gives the main characteristic of the geomagnetic storm — the magnitude — according to its description in the literature. The storms are divided into four groups: *gg* — very strong, *g* — strong, *w* — weak, *ww* — very weak. This classification of geomagnetic storms cannot be transferred to the three-degree classification, based on the index K, which is often used in geomagnetic literature, without special study but a very approximate transformation would be about as follows: *gg* ... *s* severe storm, K max 8—9; *g* ... *ms* medium severe storm, K max 6—7; *w* ... *m* moderate storm, K max 5; *ww* ... disturbance $3 \leqq K_{max} < 5$. The reliability in determination is given in the CGF both for the time interval and the magnitude of the storm; this was also used in the investigation.

III. METHOD OF TREATMENT

In order to investigate whether and in what manner the geomagnetic activity is influenced by the occurrence of a flare it was necessary to divide the flares according to importance i and distance from the central meridian λc into partial sets. Attention was not paid to the heliographic latitude of the flares, which simplified the investigation and in particular ensured a sufficient number of flares in the different partial sets. Of course, this causes a certain inaccuracy, which to a certain extent has a constant character since, as is known, the flares occur in active zones symmetrically with respect to the equator. The heliographic latitude of these zones does not vary very much for the set studied since the period always concerns only a few years around the maxima of the cycles of solar activity.

For a further enlargement of the partial sets, the flares of importance $i = 3$ and $i = 3+$ had to be combined in one group denoted $i = 3$. The division of the flares into partial sets and their number are given in Tab. 1.

Table 1.

Interval in λc	No. of flares	
	$i = 2+$	$i = 3$
90°E — 90°W	197	172
29°E — 29°W	104	78
≧30°E	58	51
≧30°W	35	43
≧30°E + ≧30°W	93	94

The geomagnetic activity curve was determined for each flare in a period of -3 to $+6$ days by means of the curve of the daily values of the index Ap (absolute curve) and the curve of the ratios Ap_i/Ap_0, $i = -3, -2, \ldots +6$ (relative curve), where Ap_0 is the value of the index Ap on the day of occurrence of the chosen flare. The relative curve was introduced in the attempt to obtain more exact data on the increase in geomagnetic activity when a result of the flare occurred in the geomagnetically disturbed period and we were thus interested in finding the increase in geomagnetic activity with respect to the noise for which the value Ap_0 was chosen. The magnitude of Ap_0 may disturb several individual curves but on an average this disturbing effect is negligible, as has already been proved [5] and was found in this paper too.

The average curves for all the partial sets of flares were then determined by the method of the displacement of epochs from the individual absolute and relative curves.

Partial sets of flares were first formed for both classes of importance 3 according to λc: — a set of central flares $\lambda c < 30°$E, W, a set of eastern boundary flares $\lambda c \geqq 30°E$ and a set of western boundary flares $\lambda c \geqq 30°W$ in agreement with the results obtained earlier [9].

Partial sets of 10° in λc with the basic boundary $\lambda c = 0°$, for which the mean relative curves Ap_i/Ap_0 were determined, were formed for both classes of importance for a detailed investigation.

In order to increase the reliability and to verify the reality of the fluctuations in the mean relative curves Ap_i/Ap_0, an attempt was made to determine possible differences between the curves after flares from roughly double the numerous partial sets produced by the combination of two neighbouring or two original sets 10° wide symmetrical with respect to the central meridian. This finer division and greater number of partial sets is given in Tab. 2.

Table 2.

Basic interval in λc	No. of flares		Combined interval in λc	No. of flares	
	$i = 2+$	$i = 3$		$i = 2+$	$i = 3$
80°E	3	4	80°E + 70°E	9	8
70°	6	4	60° + 50°	21	16
60°	9	7	40° + 30°	28	27
50°	12	9	20° + 10°	38	22
40°	6	13	0°E + 0°W	33	29
30°	22	14	10° + 20°	33	27
20°	24	9	30° + 40°	12	15
10°	14	13	50° + 60°	16	16
0°E	12	14	70°W + 80°W	7	12
0°W	21	15	80°E + 80°W	7	8
10°	23	19	70° + 70°	9	12
20°	10	8	60° + 60°	14	14
30°	6	6	50° + 50°	23	18
40°	6	9	40° + 40°	12	22
50°	11	9	30° + 30°	28	20
60°	5	7	20° + 20°	34	17
70°	3	8	10° + 10°	37	32
80°W	4	4	0°E + 0°W	33	29

A detailed investigation of the dependence of the mean absolute curve of Ap on the importance of the flare was carried out for central flares $\lambda c < 30°$ E, W, where attention was paid to accuracy in determining the importance. In order to be able to judge the disturbing affect of isolated particularly high values of Ap on the magnitude of the arithmetic means and thus also the reliability of the mean absolute curves of Ap, the mean absolute curves of Ap were determined for the same sets from the values of the medians.

The dependence of the average amount of disturbance on λc was then studied for both classes of flare importance. The average amount of disturbance for the individual partial sets was expressed by the arithmetic mean of the mean values of Ap and Ap_i/Ap_0 in a period of +1 to +4 days after the flare. This period contains practically all geomagnetic disturbances which could be connected with the corresponding flares, if we take into consideration the assumed time intervals between the occurrence of the flare and the commencement of a geomagnetic storm and the average duration of the storms, which in the period of maximum solar activity was predominantly 1—2 days.

Eruptions of both classes of importance and data on geomagnetic storms or their corresponding increases in Ap were used for the following investigation.

The ratio of the number of increases when $Ap_2 > Ap_0$ or $Ap_3 > Ap_0$ to the total number of central flares was studied as a function of the class of importance; this time, attention was paid to determining the latter accurately. The great majority of all storms and disturbances was thus represented since such an increase is not decided by its absolute value and the time interval corresponds to the assumed time interval, as has been determined experimentally, particularly for strong flares [1]. In the individual cases, of course, an inaccuracy may be seen in connection with large values of Ap_0 which is similar to that mentioned above but which is not very disturbing in the whole set.

The time intervals between the commencement of a flare and the commencement of the following geomagnetic storm have been elaborated by the method of summation curves [10]. Cases of unreliable determination of time intervals and cases when several geomagnetic storms occurred after a flare or when one geomagnetic storm could be ascribed to several flares, were eliminated. Attention was not paid to the importance of the flare and the magnitude of the dispersion of time data on the commencement of the geomagnetic storm. The first investigation was carried out for a set of 154 flares in the whole range of λc, the second for a set of 84 central flares $\lambda c < 30°$ E, W, for otherwise identical limiting conditions.

Finally, an attempt was made to determine the dependence of the time interval on the magnitude of the corresponding geomagnetic storm expressed in degrees gg, g, w and ww. The limiting conditions were the same as before but attention was paid to the magnitude of the dispersion of the time data on the commencement of the geomagnetic storm. The mean values of the time intervals were expressed by the values of the medians so as to suppress the influence of random high and low values of the time interval.

The results of investigating all the above-mentioned dependences have been plotted graphically and are given in the next part of the paper.

IV. RESULTS OF INVESTIGATIONS

1. Geoactivity of Flares as Function of λc and i.

The sought dependence is seen the most clearly for sets of flares $i = 3$ (Fig. 1a). A pronounced increase in the values of Ap is apparent for the set of central flares on the +1 to +3 day after a flare with maximum $Ap = 36$ on the +2 day. Quite different absolute curves of Ap can be observed for eastern and western boundary flares when the maxima are flatter, lower and time displaced with respect to the maximum for central flares. It is obvious that as regards shape both the curves are very approximately complementary, which is also seen in the values of the total curve Ap for boundary flares, which are roughly constant. Obviously this curve in itself does not give a correct answer to the question of the character of the geoactivity of boundary flares. The division of boundary flares into eastern and western, however, gives correct information which can easily be explained by the assumption that the eruptive activity in the active region or the geoactivity of the active region in which the chosen flare occurred lasts a longer time, during which the active region passed through the central meridian as a result of solar rotation, and if in this critical position the conditions for emission and direction of corpuscular radiation were satisfied, this active region could appear as an increase in geomagnetic activity with which the flare in question need not be connected. In individual cases this phenomenon can be directly observed under favourable circumstances [11] (see also [3]).

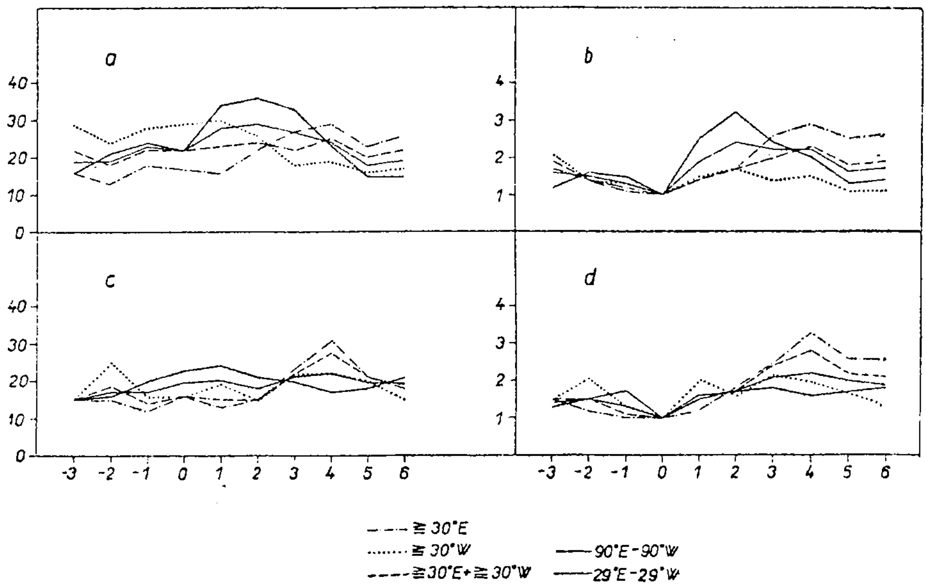


Fig. 1. Mean absolute and relative curves of Ap index after flares of importance $i = 3$ (a, b) and $i = 2+$ (c, d) as a function of distance of flares from central meridian. Horizontal axis-time in days, vertical axis — values of Ap (a, c) and increase in Ap with respect to zero day (b, d).

The probability of flare activity in the active region or geoactivity of the active region keeping in a certain time interval is naturally greater the shorter the interval. This agrees with reality given by the time distance of the maxima of the Ap curve for eastern and western flares from the maximum for central flares. It is obvious that the time distance of these maxima (2 days) corresponds approximately to the time required for the transfer of the active region from the central meridian to the boundaries of the boundary zones (30° in λc), i.e. to places which of all the boundary zones have the greatest probability of maintaining geoactivity. It is important that with this interpretation much smaller dispersion of the time intervals between the flare and geomagnetic storm is sufficient.

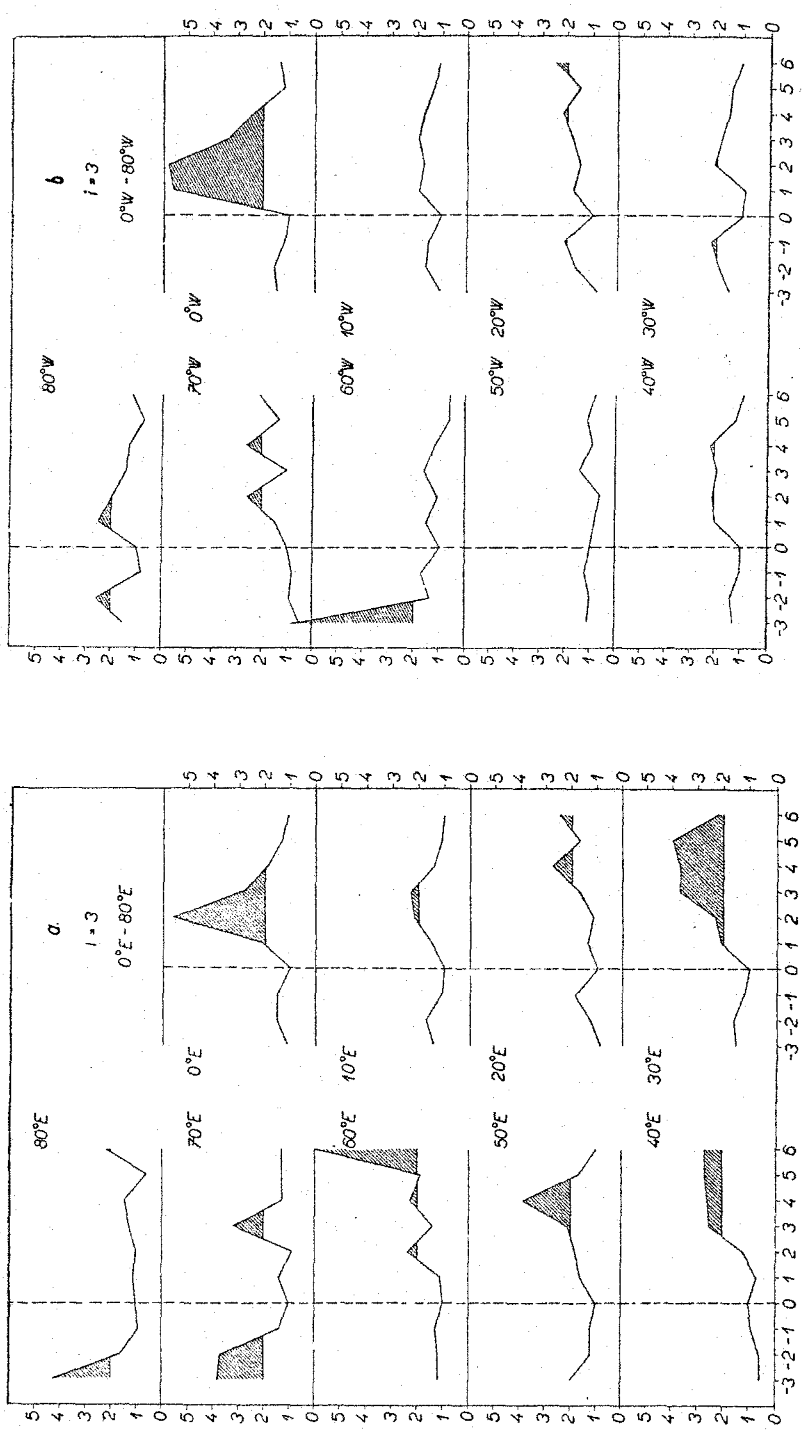
The different courses of the relative curves of geomagnetic activity (Fig. 1b) are quite understandable on the basis of the assumption just made. The pronounced dependence on λc, which is even sharper than for the absolute curves, remains in the curve Ap_i/Ap_0 for central flares $i = 3$, where on the $+2$ day there is a pronounced maximum with more than a triple increase in Ap with respect to the day of the flare. In the curve for eastern flares, too, the maximum remains on the $+4$ day, which is only slightly lower than the maximum for central flares; this supports the assumption that flare activity in the active region or other geoactivity of the active region does not on the whole vary in a certain time interval. It is significant that on the +2 day, when a direct consequence of eastern flares might be expected, no secondary maximum appeared on the relative curve, which is obviously due to the flares far from the central meridian being only slightly active. This conclusion is confirmed by the relative curve for western flares, which has a moderate maximum on the +2 day, the value of which is, however, low $(Ap_2/Ap_0) = 1{\cdot}7)$ and the same as the value of the relative curve for eastern flares symmetrical with respect to the central meridian, which was to be expected.

The investigation into the dependence of flares $i = 2+$ on λc did not provide such clear results by far as for flares $i = 3$. But the similar character of the dependences, in some cases only hinted, can also be seen. The absolute curve (Fig. 1c) for central flares has a very flat maximum around the +1 day, while for eastern flares a pronounced maximum can be observed on the +4 day, comparable with the maximum for flares $i = 3$. It could thus be inferred that the actual geoactivity of flares $i = 2+$ is much smaller than of flares $i = 3$ and that the maximum for the eastern flares $i = 2+$ was actually caused by flares $i = 3$, which occurred in the corresponding active region during its passage through the central meridian. The tendency to systematically higher values of the absolute curve for western flares in the initial period and to lower values in the final period remains, while the absolute curve for eastern flares behaves in the opposite way, which can obviously be explained in the same manner as for flares $i = 3$. The relative curves (Fig. 1d) exhibit primarily a very flat and low maximum for central flares, a pronounced maximum on the +4 day for eastern flares and an indistinct course for western flares. It is important that the values of the above-mentioned curves on the +2 day are practically the same and are low, which indicates the small direct influence of boundary flares of both sets (analogically as with flares $i = 3$) and the low geoactivity of central flares. The pronounced maximum value for eastern flares, comparable with the maximum for flares $i = 3$, again supports the hypothesis that this maximum was produced actually by the action of flares $i = 3$, which occurred in the corresponding active region during its passage through the central meridian.

2. Detailed Investigation of Dependence of Relative Curve of Geomagnetic Activity on λc and i

It is obvious from the above results that the geoactivity of flares depends significantly on λc and i. A detailed investigation of this dependence is possible by introducing finer division of the intervals in λc and interesting results are obtained (Fig. 2). Pronounced reliable maxima (disregarding for the time being strong fluctuations in the curves) appeared only for flares $i = 3$ from the intervals 0° E and 0° W (Fig. 2a, b) while for flares $i = 2+$ (Figs. 2c, d) only an insignificant maximum appears for flares in the interval of 0° W. It follows from this that the geoactivity of the central set of flares is practically determined by the geoactivity of flares in the interval 9° E—9° W, i. e. that the dependence of the geoactivity on λc is unusually sharp.

However, it is necessary to deal in somewhat greater detail with the question of fluctuations in the relative curves, where local maxima often appear at different points and attain considerable values compared with the above-


b
i = 3
0°W - 80°W
80°W
70°W
0°W
60°W
10°W
50°W
20°W
40°W
30°W
a
i = 3
0°E - 80°E
80°E
70°E
0°E
60°E
10°E
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20°E
40°E
30°E

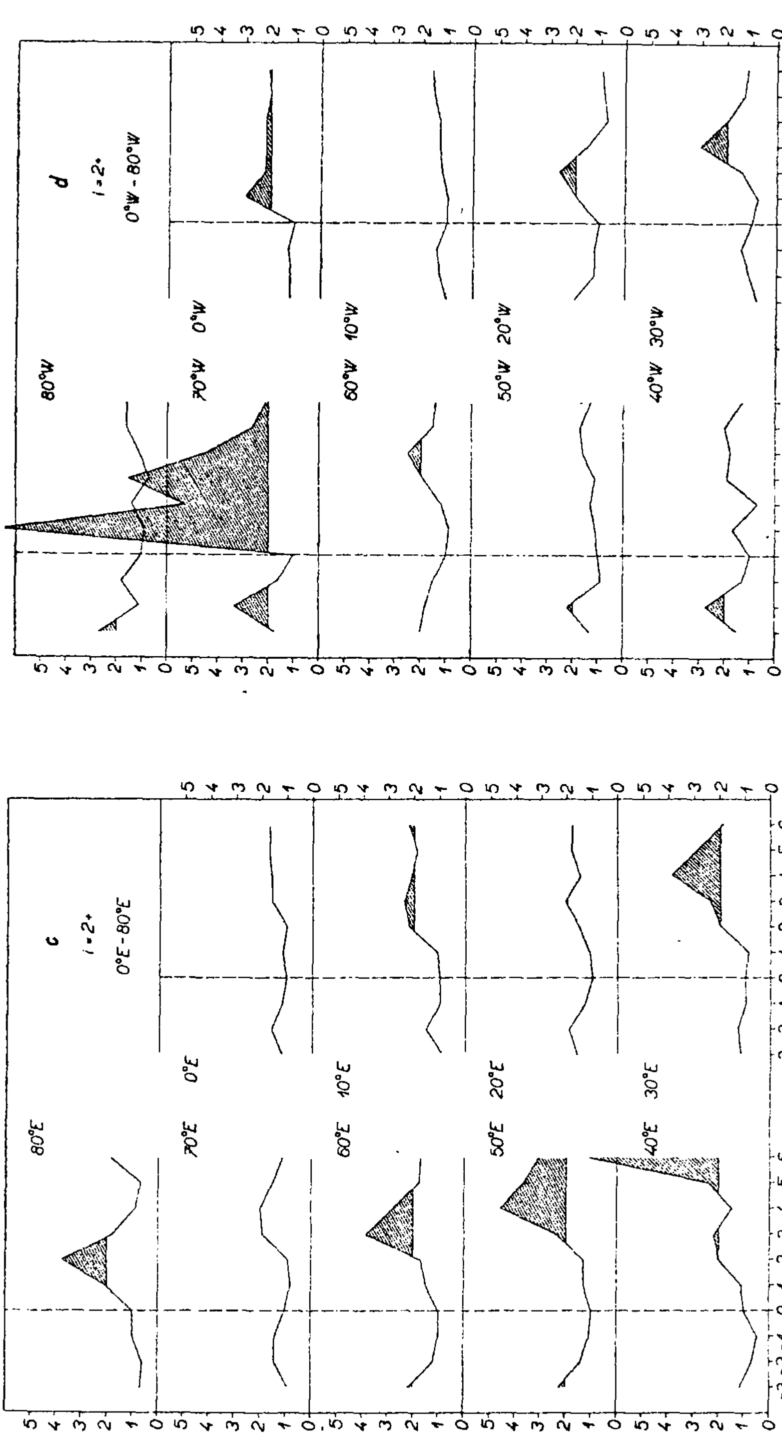
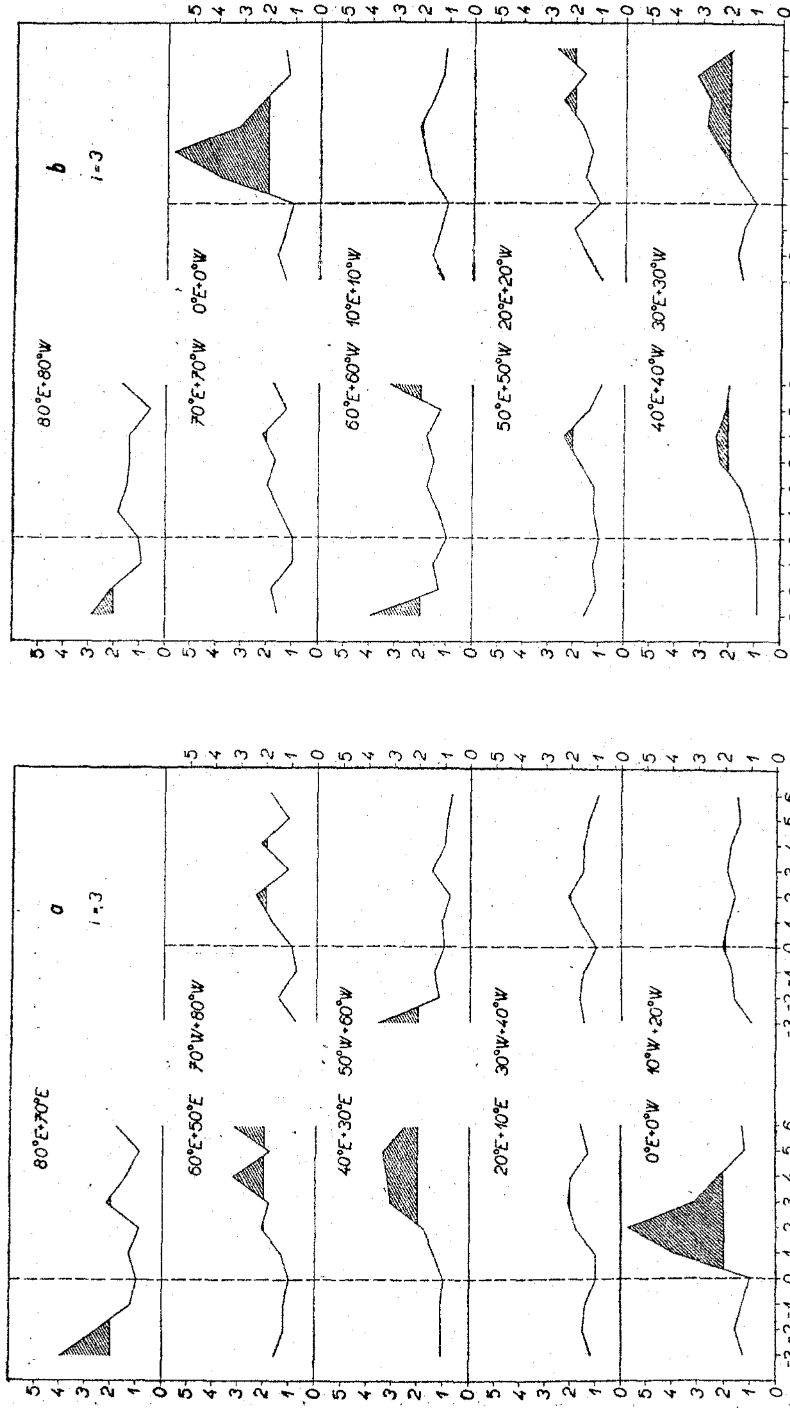


Fig. 2. Mean relative curve of Ap index after flares of importance $i = 3$ (a, b) and $i = 2+$ (c, d) as a function of distance of flares from central meridian. Horizontal axis -- time in days, vertical axis — values of increase in Ap with respect to zero day.


a
i=3
80°E+70°E
60°E+50°E
40°E+30°E
20°E+10°E
0°E+0°W
70°W+80°W
50°W+60°W
30°W+40°W
10°W+20°W
b
i=3
80°E+80°W
70°E+70°W
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30°E+30°W

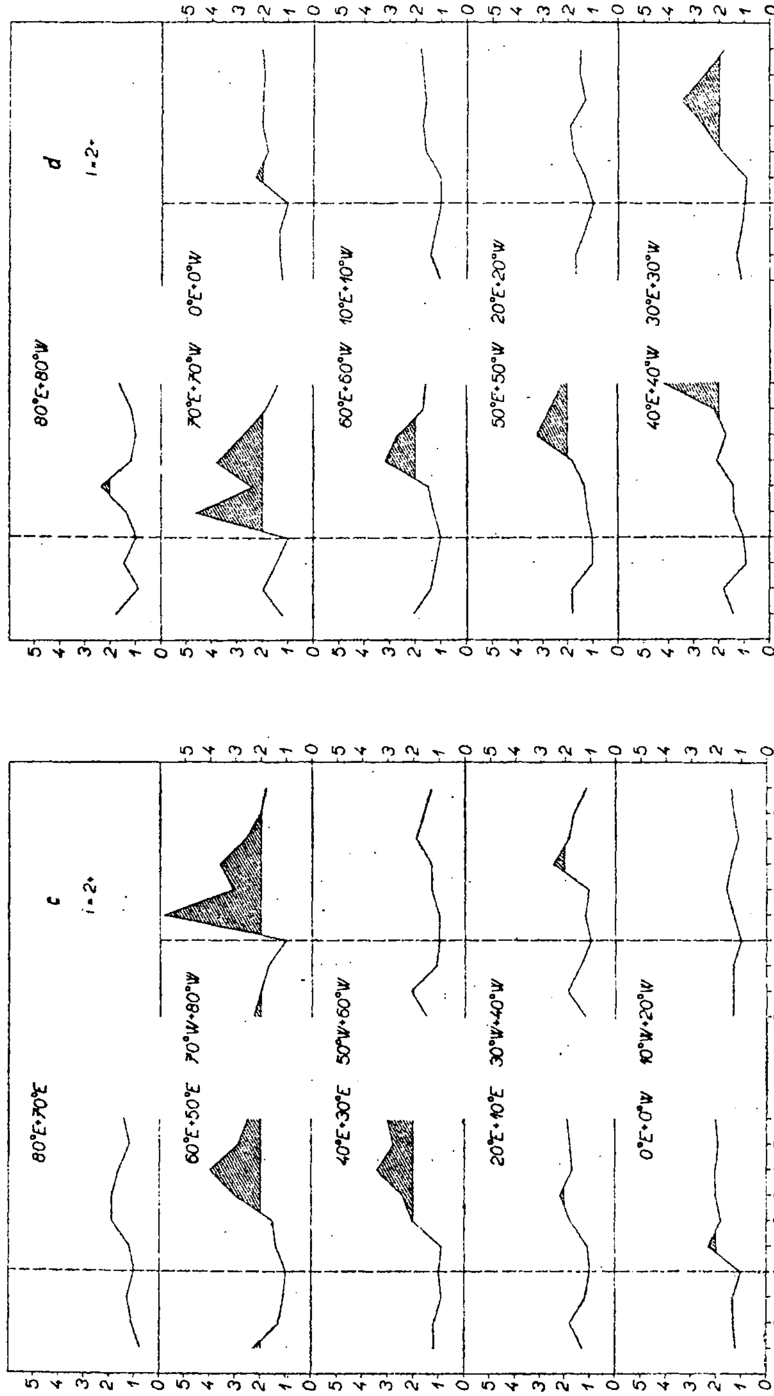

Fig. 3. Mean relative curve of Ap index after flares of importance $i = 3$ (a, b) and $i = 2+$ (c, d) as a function of distance of flares from central meridian. Combined neighbouring intervals (a, c) and intervals symmetrically placed with respect to central meridian (b, d). Horizontal axis — time in days, vertical axis — values of increase in Ap with respect to zero day.

mentioned maxima. It should primarily be emphasized that the occurrence of flares on the disc is not uniform but decreases considerably to the eastern and western edges [12], which is naturally also apparent in this material so that the individual partial sets are not even approximately equal in number (Tab. 2). The random favourable accumulation of one-sided deviations may then lead to different fluctuations, which obviously influences the less numerical sets the most. The enormous maximum for the set $i = 2+$, 70° W, which was investigated separately, was produced in this way. From our point of view, however, important central sets are as a rule quite numerous, so that the results are more reliable as is seen from the relatively smooth curves.

There is another cause which might be considered from these fluctuations, which often appear on the curves in the form of an irregularly shaped increase, irregularly time distributed in the period of several days following the flare. A satisfactory concept here would be that the activation of solar chromospheric activity, appearing with a strong flare (and thus probably also connected with the total increase of flare activity) in some active region far from the central meridian, is not confined only to this active region and its immediate neighbourhood but spreads, more or less simultaneously, to a greater part of the solar surface. If this activation is manifested in the active regions, which are just then in the neighbourhood of the central meridian, these regions may then behave geoactively. The results of activation of filaments far from the flare, as well as the fact that activation and flares probably have a common cause [13], indicates that this concept might be of significance.

The disturbing influence of the random accumulation of one-sided deviations appearing as irregular fluctuations on relative curves could to a certain extent be suppressed by the combination of the basic partial intervals in λc, which was done in two ways. With the combination of two neighbouring intervals possible time displacement of the maxima, due to the progress of the active region over the solar surface, could appear in the result, while with the combination of two intervals symmetrical with respect to the central meridian this influence was roughly compensated. The results for flares $i = 3$ (Figs. 3a, b) and $i = 2+$ (Figs. 3c, d) actually show a certain smoothing of the curves and convincingly confirm the conclusions obtained from an analysis of Fig. 2. Since no systematic displacement of the maxima occurs in the period following the flare or as regards time or magnitude, it may be concluded that direct geoactivity is exhibited only by flares in the central interval 9° E — 9° W, and then practically only by flares $i = 3$. On the other hand, flares further away from the central meridian, i.e. flares of both importances, may to a certain extent appear geoactively, by means of the simultaneously dominating chromospheric activity in the neighbourhood of the central meridian.

3. Dependence of *Ap* Curve on Importance of Flares

A detailed investigation of the dependence of the absolute curve of geomagnetic activity on the importance of flares, which was made only for central flares $\lambda c < 30°$ E, W, showed that this dependence is also very sharp (Fig. 4). Pronounced geoactivity is manifest only by the most important flares, if this importance is at the same time guaranteed. Due to the nature of the investigated material, it is more correct to give greater weight to the results obtained from the curve of the values of the Ap medians. It is seen from them that the geoactivity of flares $i = \mathbf{3}$ and $\mathbf{3+}$ differs very markedly from all other sets, and that the curves for flares $i = 2+$ of all three degrees of accuracy in determining the importance are very unreliable.

4. Average Disturbance After Flares as Function of λc

The increase in the absolute and relative curves of geomagnetic activity after flares of both importances was characterized by an average disturbance Ap or Ap_i/Ap_0 on the $+1$ to $+4$ day after the flare, which thereby eliminated the differences between the individual curves, apparent in the different shape and time position of the maxima, as long as it fell in the most probable period used. For a set of flares $i = 3$ the dependence of this average disturbance on λc is seen in a pronounced increase in the intervals 0° E and 0° W (Fig. 5a) and

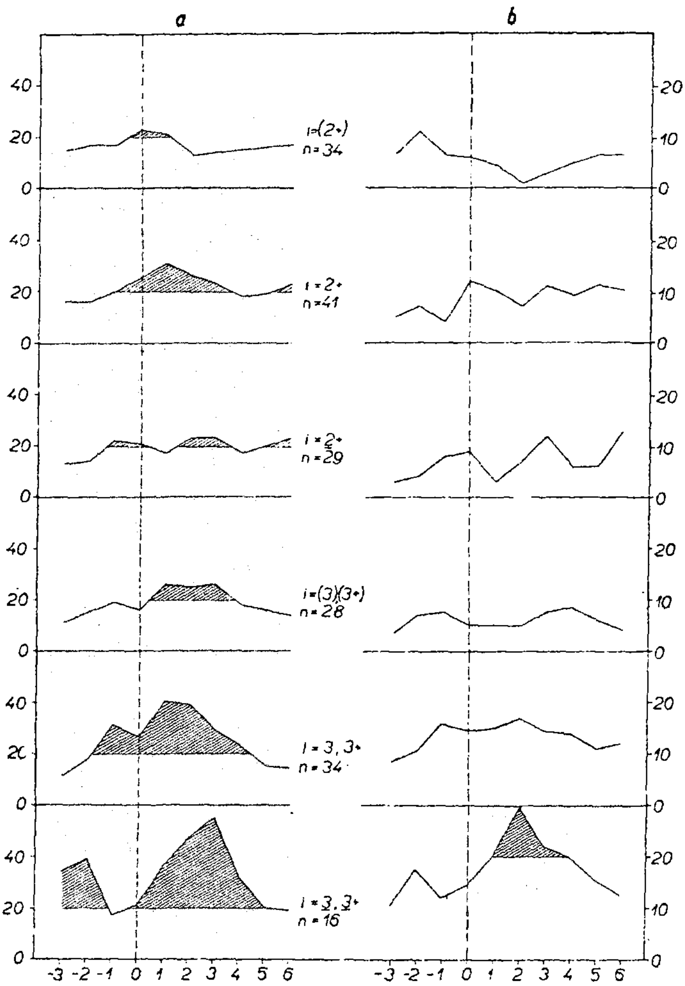

Fig. 4. Mean absolute curve of Ap index after central flares $\lambda c < 30°$ E, W as a function of flare importance and reliability of its determination. Curves from values of arithmetic means (a) and values of medians (b). Horizontal axis — time in days, vertical axis — values of Ap index.

interesting secondary maxima around the intervals 40° E and 40° W, which do not occur however on the curve of the mean disturbance derived from the relative curves. The occurrence of these symmetrically placed maxima, as long as they have physical meaning and are not due to chance in the material,

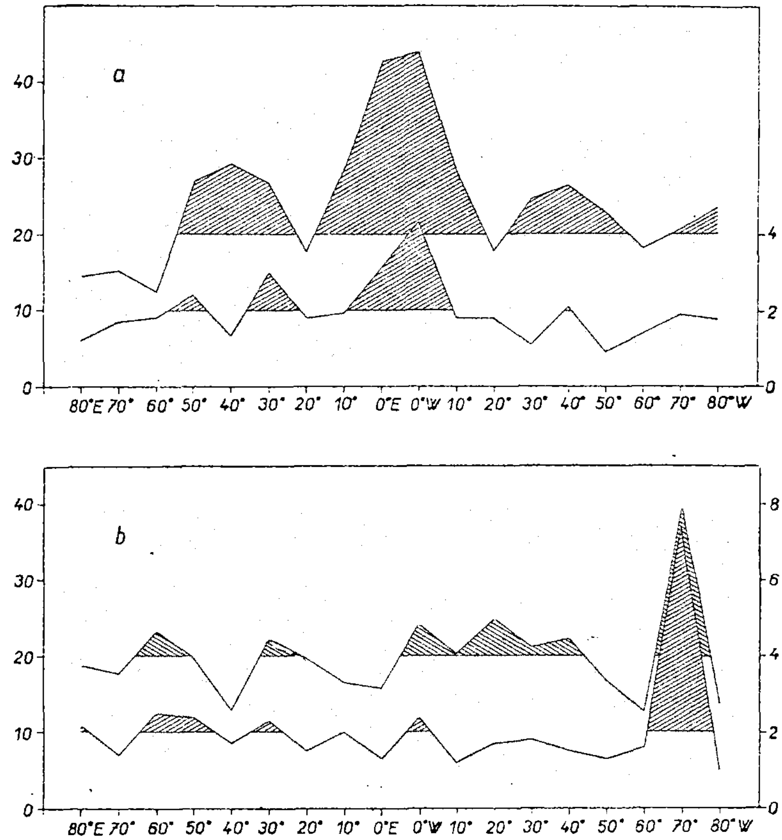

Fig. 5. Mean disturbance on +1 to +4 day after flares of importance $i = 3$ (a) and $i = 2+$ (b) as a function of distance from central meridian. Upper curves — values from absolute curves of Ap, lower curves — values from relative curves of Ap. Horizontal axis — distance from central meridian, vertical axis — values of Ap and of increase in Ap with respect to zero day.

could be an expression of the fact that there exists a certain mean distance between two neighbouring active regions or otherwise denoted sources of corpuscular radiation, which need not of course appear in the pure form in these curves but can be influenced by the length of the period used in determining the average disturbance.

No maximum in the central intervals can be observed in the curves for flares $i = 2+$ (Fig. 5b) which again confirms the small geoactivity of these flares. The maximum in the interval 70°W cannot be ascribed special importance since it was produced by the above-mentioned accumulation of one-sided deviations when there was a small number of flares in the interval.

5. Occurrence of Geomagnetic Storms after Large Flares

The occurrence of geomagnetic storms and disturbances, which were replaced by the increase in Ap determined by the condition $Ap_2 > Ap_0$ or $Ap_3 > Ap_0$, after central flares distinguished according to importance and accuracy of determination, clearly decreases with decreasing flare importance (Fig. 6). This confirms and makes more accurate the results obtained from an analysis of Fig. 4 and simultaneously again confirms that the accuracy in determining the flare importance has real physical significance.

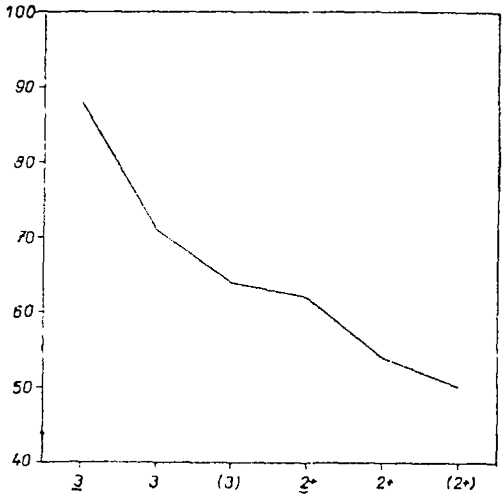

Fig. 6. Occurrence of increase $Ap_2 > Ap_0$ or $Ap_3 > Ap_0$ after central flares $\lambda c < 30°$ E, W as a function of flare importance and reliability of its determination. Horizontal axis — flare importance and reliability of its determination, vertical axis — number of cases in percent of total number of flares of corresponding class.

The results of investigating the time intervals between flares and the following geomagnetic storms by the method of summation curves can provide important independent information on the geoactivity of the flares. The emission of corpuscular radiation during the flare and its propagation can be expected to follow more or less similar laws for all flares, though disturbed of course by a large number of randomly effective influences. This means that the time intervals between the flares and the following geomagnetic storms should exhibit a tendency to systematically increased frequency around a certain typical value, which would appear as an inflection on the summation curve. Since the summation curve for a set of all flares is practically linear (Fig. 7a), it may be inferred that this typical value does not exist. This at the same time means that the mean value of the time intervals (e.g. the arithmetic mean) has only formal significance and depends on the length of the time period after the flare. The shape of the summation curve can, however, be quite well explained by assuming that the geoactivity of flares rapidly decreases with increasing distance from the central meridian and simultaneously by the above conception of the geoactivity of the active region in which the flare was produced (para IV.1).

If the investigation is confined to more effective central flares (Fig. 7b), the shape of the summation curve remains on the whole unchanged; the curve can again be smoothed to a practically linear curve, which enables the same conclusions to be reached about this set as a whole as about the previous one. Fluctuation of the curve around the linear course can, however, be observed which should be an indication that the set of central flares includes several sets with different typical value of the time interval (indications of four inflection points can be observed). It might be thought that a possible dependence of the time interval on the importance of the flare, the force of the geomagnetic storm or the distance from the central meridian, might appear here.

The possible dependence of the time interval on the importance of the flare could not be convincingly determined by means of the summation curves. It seems that on an average the values of the time intervals are longer for flares

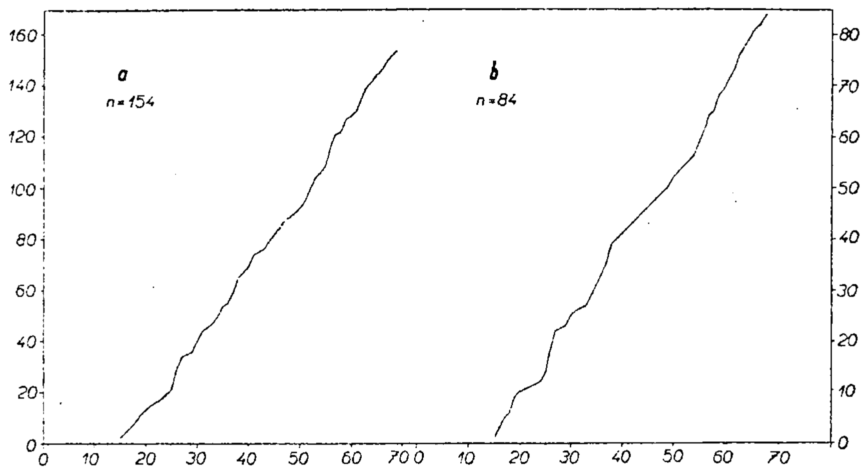

Fig. 7. Summation curves for time intervals between flares and following geomagnetic storm. All flares (a) and central flares $\lambda c > 30°$ E, W (b). Horizontal axis — time interval in hours, vertical axis — number of cases.

of smaller importance. The value of the median of the time intervals for flares $i = 3$ and $i = 2+$ is 38 h and 49 h respectively.

An attempt was also made to determine the possible dependence of the time interval between flares and the following geomagnetic storms on the force of these storms. The result shows that this dependence exists and that a pronounced influence of the magnitude of dispersion of the data on the commencement of the geomagnetic storm is not apparent (Fig. 8).

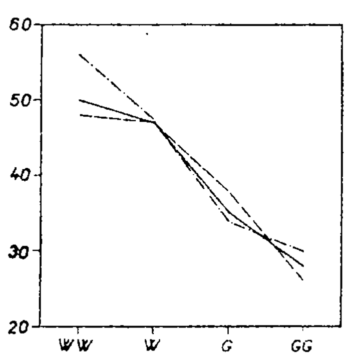

Fig. 8. Dependence of time interval between flare and following geomagnetic storm on size of storm. Dashed — greater dispersion of time data at commencement of storm; — dotted-and-dashed — small dispersion of time data at commencement of storm, full line — combined sets with small and large dispersion of time data at commencement of storm. Horizontal axis — size of geomagnetic storm, vertical axis — time interval in hours.

V. CONCLUSION

Some of the results of this paper were obtained by the same methods as in [5] and can therefore be directly compared. The cases of deviations and disagreement could probably be explained by the differences in the observational material on flares. The set of flares used in [5] was distinguished by the fact that flares of larger importance were relatively little represented and it contained even flares of smaller importance than the set used in the present paper. The set was much more complete and at the same time was only from a short time interval in the period of the maximum of one cycle of solar activity. The investigation of a possible influence of the phase of the solar activity cycle or the order number of the cycle on the dependences determined here did not however lead to the goal set, due to the great decrease in the number of partial sets of flares.

It may be stated on the basis of the statistical investigations that the geoactivity of flares depends very markedly on the distance of the flares from the central meridian and their importance. This dependence is of such a kind that direct geoactivity is manifested only by flares of importance $i = 3$ in the interval 9° E to 9° W, while the geoactivity of other flares may be indirect. It follows from an investigation of the time intervals between flares and the following geomagnetic storms that for the whole set of flares the mean value of the time interval has only formal significance and depends on the length of the used time period after the flare. On an average, the length of the time interval is greater for flares of smaller importance and for weaker geomagnetic storms.

The following two conceptions can be suitably used to explain some of the dependences found:

1. The flare activity in the active region or other source of geoactivity of the active region in which a large flare occurred lasts a longer time during which the active region may pass through the central meridian. If the conditions for the emission and direction of corpuscular stream are satisfied in this critical position, this active region may exhibit increased geomagnetic activity, with which the flare being investigated is not directly connected.

2. The activation of chromospheric activity, apparent inter alia in the occurrence of a large flare in some active region far from the central meridian, need not remain confined only to this active region and its immediate surroundings, but can be manifested more or less simultaneously even on larger parts of the solar surface. If this activation is apparent also in active regions which are just on the central meridian, the regions can then manifest themselves by an increase in geomagnetic activity, with which the flare in question is not directly connected.

It may be assumed that the first conception is proved by the results of this paper. The reasons for the second conception also follow from this paper and from some astronomical results; however, they still need to be verified astronomically.

On the basis of these conceptions a much smaller dispersion of time intervals between flares and the following geomagnetic storms is sufficient. This important result is also supported by the results of investigating the time intervals in section IV. 5. It is also obvious that the solid angle into which the corpuscular streams are emitted during large flares is relatively small.*) The results obtained also lead to the conclusion that chromospheric flares should be understood as a time-space indicator of the conditions favourable for the emission of corpuscular radiation, apparent in an increase in geomagnetic activity.

*) This result will be the subject of another paper.

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Резюме

ГЕОМАГНИТНАЯ АКТИВНОСТЬ ПОСЛЕ КРУПНЫХ ХРОМОСФЕРНЫХ ВСПЫШЕК

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Было проведено статистическое исследование изменений геомагнитной активности, выраженной индексом Ap и появления геомагнитных бурь после всех наблюденных вспышек мощностью $i \geq 2+$ за период 1859—1956 гг. Особое внимание уделялось зависимостям геомагнитной активности от мощностей вспышек и их удаления от центрального меридиана, а также интервалам времени между вспышками и последующими геомагнитными бурями. Была найдена весьма четкая зависимость геомагнитной активности от мощности и удаления вспышек от центрального меридиана. Прямая геоактивность проявляется лишь у вспышек мощностью $i = 3$ и $3+$ в интервале 9°E—9°W,

у прочих же вспышек геоактивность проявляется лишь косвенно. Из исследования промежутков времени вытекает, что для всей совокупности вспышек средняя величина промежутка времени имеет лишь формальное значение и зависит от длительности принятого периода времени после вспышки. В среднем интервал времени для вспышек небольшой мощности и более слабых геомагнитных бурь будет длиннее. Для объяснения некоторых найденных зависимостей были сформулированы следующие положения:

1. Эруптивная активность в активной области или иной источник геоактивности активной области, в которой имела место крупная вспышка, продолжается длительное время, в течение которого активная область может пройти через центральный меридиан. Если в этом критическом положении будут выполнены условия для эмиссии и направления корпускулярного потока, то эта активная область может характеризоваться повышением геомагнитной активности, с которым исследуемая вспышка не находится в прямой связи.

2. Возобновление хромосферной активности, характеризуемое еще и появлением крупной вспышки в определенной активной области, удаленной от центрального меридиана может либо выйти за пределы этой области и ее ближайшей окрестности, либо проявится более или менее одновременно и на более крупных частях солнечной поверхности. Если же это возобновление хромосферной активности проявится как раз на центральном меридиане, то эти области могут характеризоваться повышением геомагнитной активности, с которым исследованная вспышка не находится в связи.

На основании приведенных выше положений можно обойтись гораздо меньшими рассеянием интервалов времени между вспышками и последующими геомагнитными бурями. Далее очевидно, что пространственный угол на который падает корпускулярное излучение при крупных вспышках, относительно мал. На основании полученных результатов можно также придерживаться взгляда, что хромосферные вспышки следует себе представлять в виде указателя условий времени и пространства, благоприятных для эмиссии корпускулярного излучения, характеризуемого повышением геомагнитной активности.

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