

ON LONG-TERM FORECASTS OF PROTON FLARES*

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Abstract. 174 proton flares which were observed during the period from 1956 to 1965, occurred in 81 different active regions. It is shown that these active regions formed in complexes of activity, which stayed on the solar surface for many months, and in some cases even for several years. Since the proton-flare regions develop very rapidly and reach the proton-flare active stage within a few days, these complexes of activity represent the areas on the sun, where proton-flare regions can form at any time. Reference is made to contributions by Bumba and Howard, who investigated the birth of active regions and detected some properties of complexes of activity; nevertheless, at the present time, we do not know any method to predict when a proton-flare region begins to develop in such a complex of activity.

On the other hand, there is a chance of predicting the dangerous longitudes on the sun, as soon as such a complex of activity has been well recognized or, from the opposite point of view, to predict the safe proton-flare free periods on the sun. If, however, all the complexes on both the hemispheres are taken into account and every complex is considered 'proton-dangerous' from 2 days before to 7 days after the central meridian passage, one can prove that no proton-flare free periods existed for more than 3 years around the maximum of the last solar cycle. Applying this result to the present cycle, one can conclude that no safe forecasts of proton-flare free periods can be made from the beginning of 1968 to the end of 1970. During the remaining 7 or 8 years of the solar cycle, long-term forecasts of proton flares could be made provided that our knowledge of the formation and development of the complexes of activity is improved.

It is of interest to notice some properties of the complexes formed in the last solar cycle. While the complexes on the Northern solar hemisphere remained at fairly constant heliographic longitudes for many years, the complexes formed on the Southern hemisphere seemed to travel in two rows around the sun, in the direction opposite to the solar rotation. Another interesting fact is a yearly periodicity in the formation of proton-flare regions in the complexes of activity, with a maximum in the summer period and a deep minimum in the winter season. Such a seasonal variation also appears, if one considers the flare activity, type-IV bursts, PCA's, great magnetic storms, and magnetic crochets. Therefore, one can reasonably believe that this yearly variation, even when similar to the seasonal variation at the earth, is of solar origin.

1. Introduction

At the present time we can mostly recognize the active regions which are capable of producing proton flares, according to the sunspot configuration, the complexity and high gradients of the magnetic fields, intensive radio emission, appearance of loop-prominence systems and some other criteria. These typical properties of the proton-flare active regions, however, develop only shortly before the appearance of the proton-flare phenomenon. Forecasts of proton flares based on these criteria, call our attention to the active region only one, two, or three days before the flare appearance, because the development of such active regions is usually extremely fast. Therefore, it is quite clear that these methods cannot be used for long-term proton-flare fore-

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casts, which are necessary for manned space-flights leaving the close neighbourhood of the earth and which need an information on the proton-flare occurrence for a period of at least one week in advance.

To demonstrate this, we can use as a good example the proton flare of July 7, 1966, which has been the subject of study in the Proton-Flare Project. On the first two days of July, there was nothing suspicious on the solar disk. Only on July 3rd a very fast development of an active region began and two days later, on the 5th, the structure of the developing active region indicated that a proton flare might form in it. A proton-flare alert was announced and $1\frac{1}{2}$ days later a proton flare actually appeared. For the purpose of a study of the proton flare, which was the main task of the Proton-Flare Project, this forecast was very successful; but it is quite clear that 5 days earlier, with our present knowledge, nobody could have any slightest idea that a proton flare might appear in that region of the solar surface.

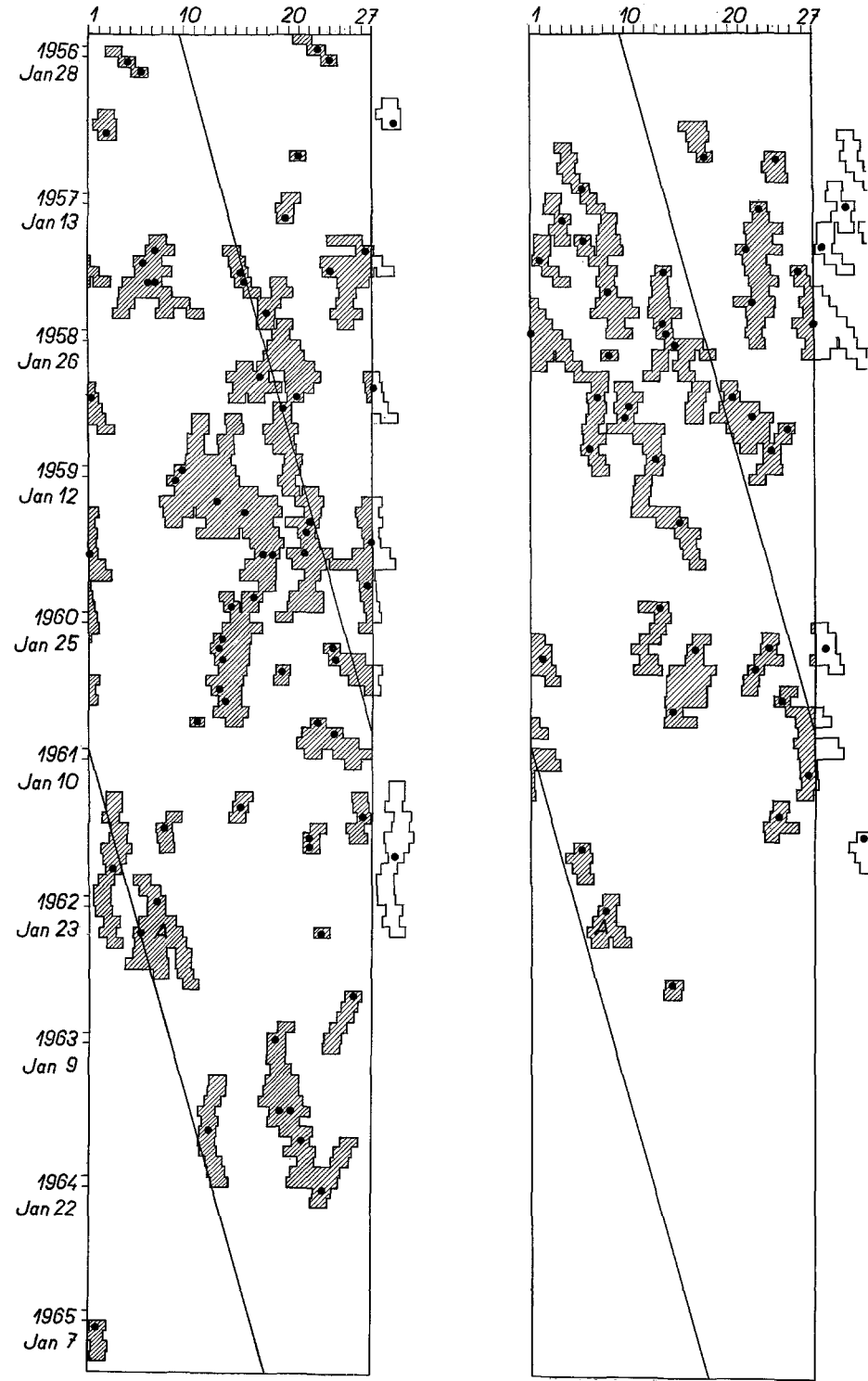
Therefore, long-term forecasts of proton flares need quite different methods. We cannot recognize the dangerous active region a week before. But we can try to investigate what are the conditions in the solar atmosphere, which make the formation of such an active region possible.

2. Complexes of Activity

Let us discuss the period from the beginning of 1956 to the end of 1965. During these 10 years, there appeared 174 flares associated with type-IV radio bursts, which had the characteristics of proton flares (ŠVESTKA and OLMR, 1966; FRITZOVÁ and ŠVESTKA, 1966; GOEDEKE *et al.*, 1967), in 81 different active regions. We have studied the development of these proton-flare regions, according to the McMath classification as published in the Compilation of Solar-Geophysical data. That is, we have followed each active region from its first appearance on the solar disk, through the subsequent solar rotations, up to its final decay and disappearance and we have plotted this development in a graph, which is shown in Figure 1.

Several interesting conclusions can be drawn from this diagram. First, we observe that the active regions producing proton flares are not randomly distributed on the solar disk, but they tend to occur in complexes of activity, which stay on the solar surface for many months, and in some cases even for several years. Thus, for example, we can see that there appeared 6 proton-flare regions in 1963 and 5 of them formed in one complex of activity lasting for 14 months. One complex which appeared on the Northern hemisphere close to the maximum, can be followed on the solar disk for $2\frac{1}{2}$ years and during that time it produced proton flares or series of proton flares 9 times when passing over the visible solar hemisphere.

This does not mean that an active region producing proton flares is continuously present on the disk in the area of such an activity complex. But the newly born proton-flare regions always form in a similar position on the disk and in this way the proton-flare activity is maintained in a given part of the solar surface for a fairly long time.



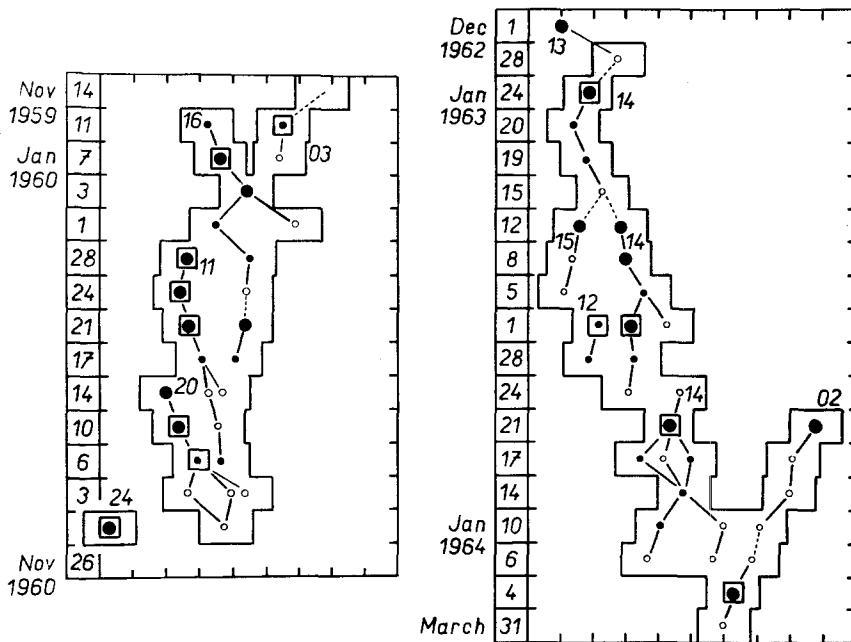


Fig. 2. Details of two complexes of proton-flare activity. Filled circles denote sunspot groups, open circles plages, squares mark groups producing proton flares. Numbers inside the figure denote the heliographic latitude, numbers on the left give the date, as 1960, January 7, February 3, March 1, March 28, etc., of the first day of each of the rotations plotted in the graph.

To make it clear, we can have a look at some of these complexes in detail. Figure 2 shows a very active complex of the year 1960 on the Northern hemisphere. A proton-flare region, close to the solar equator, died in January 1960. But already in December 1959 another region was born close by at a higher latitude and this region produced a proton flare associated with a PCA during its January transit over the solar disk. After several rotations this region decayed, but a new region close to the position of the previous one was rapidly born at the end of March and it produced 6 proton flares when first passing over the solar disk. Two proton flares formed during the first return of this region, one of them associated with a GLE. One more proton flare appeared during the second return of the active region. After that the region dissipated and died in September. But before that, in July, another active region was born in approximately the same position and it produced proton flares in August and September, one of them associated again with a GLE. Finally, not too far from there,

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Fig. 1. Complexes of proton-flare activity on the Northern (left part) and Southern (right part) solar hemisphere. Bartels' solar rotation periods are plotted on the horizontal axis and the subsequent solar rotations on the vertical one. The dashed areas show the areas on the sun occupied by the proton-flare active regions and the circles show the rotations, when proton flares were actually observed on the visible hemisphere of the solar disk. The line shows one of the longitudes (330°), for which C.S. Warwick found the maximum proton-flare occurrence. The complex of activity studied by BUMBA and HOWARD (1965b) is marked by letter A.

another active region, powerful, but with a short lifetime, formed in October and produced the last proton flare which might have been associated with this complex of activity. A similar development can also be followed in the activity complex of 1963 (the right part of Figure 2).

That means that there is a chance of predicting the dangerous longitudes on the sun, as soon as such a complex of activity has been well recognized. BUMBA and HOWARD (1965a) have made some first attempts at this problem. When studying the very first origin of newly born active regions on the sun, these authors have found that new regions always form either in expanding old field areas or immediately adjacent to them. Never did a region form in the middle of an area free of old fields. Bumba and Howard have also found that a newly born active region always forms a new polarity island surrounded by the polarity of the pre-existing fields and it never forms as an intensification of the pre-existing field. The same authors (BUMBA and HOWARD, 1965b) also studied the birth and development of complexes of activity – which, of course, perhaps need not be fully identical with the complexes we are speaking here about – and discovered some rules, according to which such an activity complex develops and decays. The particular complex studied by Bumba and Howard in detail (Figure 6 in their paper) is marked by letter *A* in Figure 1.

These are just the first few steps in understanding the processes of the formation and development of the most active areas on the sun, but they show one of the ways that one should take when investigating this problem. I may mention here that the two active regions, which produced proton flares in July and September 1966 and form the subject of study in the Proton-Flare Project, also occurred in one complex of activity and the conditions which led to the formation of this complex are now studied in detail by Bumba and Howard.

3. The Longitude Distribution

WARWICK (1965) has pointed out that proton-flare regions show a grouping in heliographic longitude. She has concluded from it that the observed pattern must represent an underlying tendency for activity to appear or increase at certain longitudes. Our diagram does not confirm fully this observation. The line drawn in Figure 1 shows one of the longitudes (330°), for which Warwick found the maximum proton-flare occurrence. It corresponds with the great complex of activity of 1957 to 1960 we already mentioned before, and one can even see an extension of the existence of this complex until 1964. But generally, and particularly on the Southern hemisphere, such a tendency of a grouping in prescribed heliographic longitudes is quite small. This is in agreement with the conclusion made by WILCOX and SCHATTEN (1967) that the analysis of Warwick is not statistically significant evidence for a long-term clustering of active regions. Nevertheless, it is clear that, due to the existence of the complexes of activity, such a clustering can be found statistically, if a shorter period is investigated, as has been done, e.g., by SAKURAI (1966) and by DODSON-PRINCE and HEDEMAN (1967) for the declining and minimum phases of the solar activity.

In this connection, I would like to call attention to the peculiar clustering of proton-flare regions on the Southern hemisphere. There seem to be two sources of activity, at a longitudinal distance of about 180° in agreement with Warwick's conclusion, which however move on the solar disk in the direction opposite to the solar rotation. If we unfold the diagram in several subsequent rotations (Figure 3), we can follow these two active areas on the Southern hemisphere from 1956 to 1962. If this were a real effect – and according to BUMBA (1967) there are some more indications that it is real – it would show that there were two sources of activity on the Southern hemisphere, which rotated slower than phenomena visible on the solar surface, making one rotation in about 27.8 days, thus shifting in the longitude at about 70 heliographic degrees per 10 solar rotations. When looking at the diagram, it is clear that as soon as an active region forms in the solar atmospheric layers, it rotates with the nor-

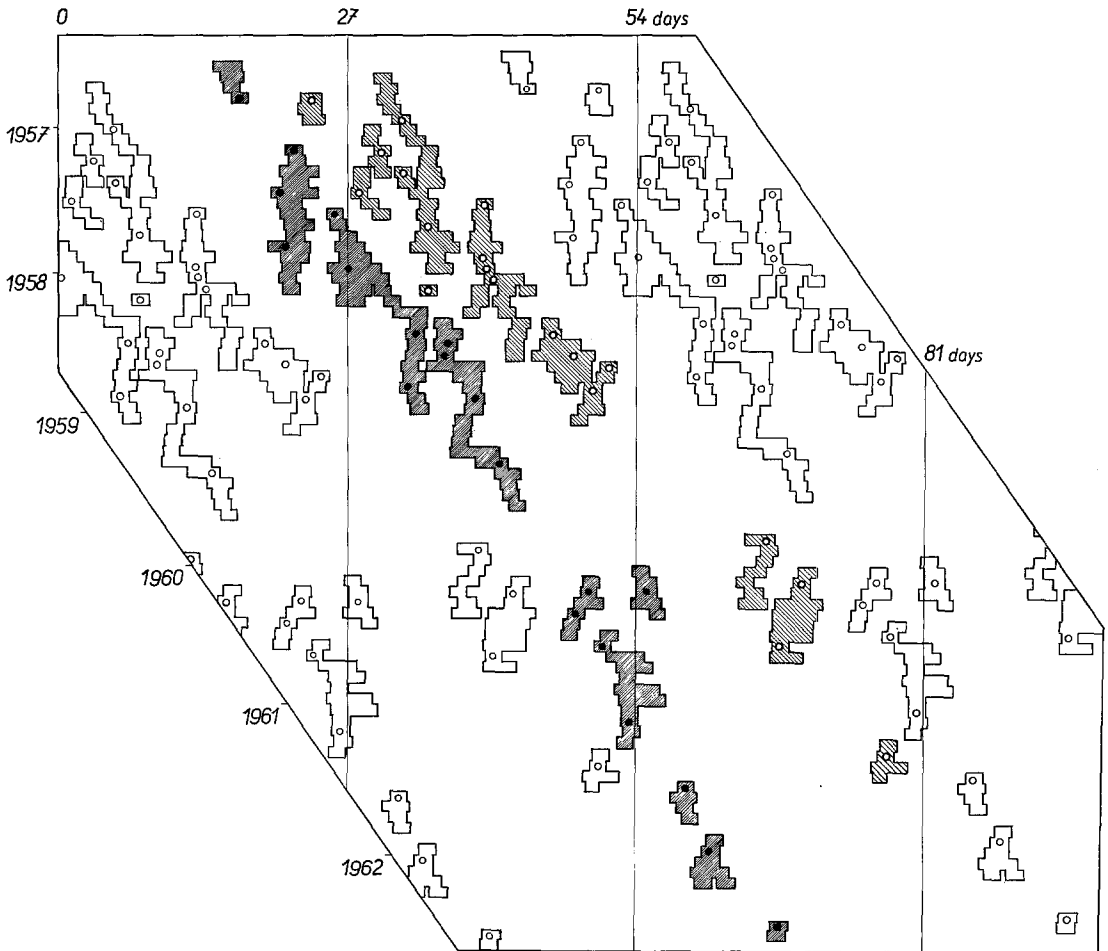


Fig. 3. The right part of Figure 1 unfolded in several subsequent rotations, in order to show the shift of two sources of activity on the Southern hemisphere from 1956 to 1962.

mal velocity of the solar rotation (cf. the vertical columns in the graph), but entirely new active regions or new complexes of activity always form in shifted positions, in accordance with the position of the source of activity which rotates slower.

One might tentatively look for a connection between this slower rotation and the fact that the activity on the Southern hemisphere was substantially lower during the whole investigated period, as compared with the activity in the Northern part of the solar disk. We do not know the reason for it. But one of the reasons might be that the source of the solar activity was located deeper at the Southern hemisphere than at the Northern one. In that case the result deduced from Figure 3 could be interpreted as due to a decrease of the rate of the solar rotation with the depth.

I do not intend to go into any more details here. My only intention has been to show that there are certain preferred areas on the sun, where the proton-flare regions develop, that several active regions producing proton flares can subsequently form in such an area and that there seem to be some rules which determine the positions of such areas on the sun. It is obvious that a detailed study of these rules can be very helpful for the problem of long-term forecasts of proton flares.

4. Proton-Flare Free Periods

But it is necessary to say that even if we knew the processes which lead to the formation of such a proton-flare complex of activity and could predict the positions of these complexes on the solar disk, long-term proton-flare forecasts would still meet with serious difficulties. The main task of these long-term forecasts is to find time-intervals, during which proton flares cannot occur on the visible hemisphere of the sun and no high-energy particles can appear in the space close to the earth or to a space-ship going, e.g., to the moon. In Figure 4 we have drawn both the solar hemispheres into one graph. That means this diagram shows the heliographic longitudes on the sun, on both the hemispheres, which are occupied by active regions suspected of a proton-flare activity. Their extension is fairly large, particularly in the maximum phase of the solar activity.

But, in fact, the situation is still worse. Our diagram only shows the date when such an active region passes through the central meridian. The active region, however, becomes dangerous for the surroundings of the earth, from about 2 days before the central meridian passage to 7 days after it, until it disappears behind the Western solar limb. Consequently, we must add to any dashed area in the graph 2 days to the left and 7 days to the right and only those empty areas which remain, are the fully safe time-intervals when we can be entirely sure that no proton flare can occur in the solar atmosphere. When we supplement our diagram in this way, the result is fairly disappointing (Figure 5).

We observe that during the maximum phase of solar activity, a proton-flare region can be formed at any time. The first gap, with a duration longer than one week, appears one year after the maximum, but it would be a masterpiece to predict it correctly. Thus, reasonable forecasts of quiet periods could be expected only at the end

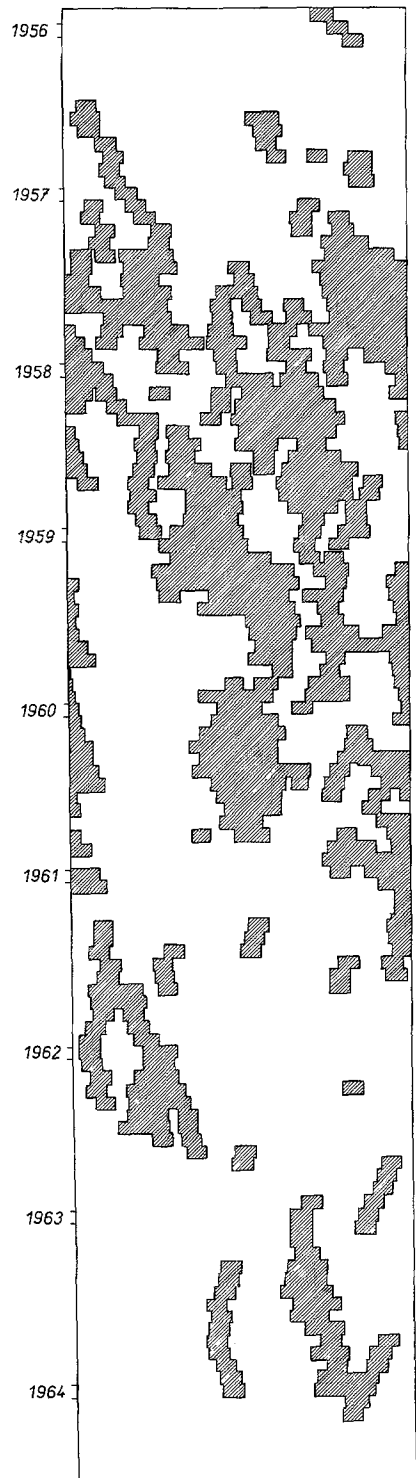
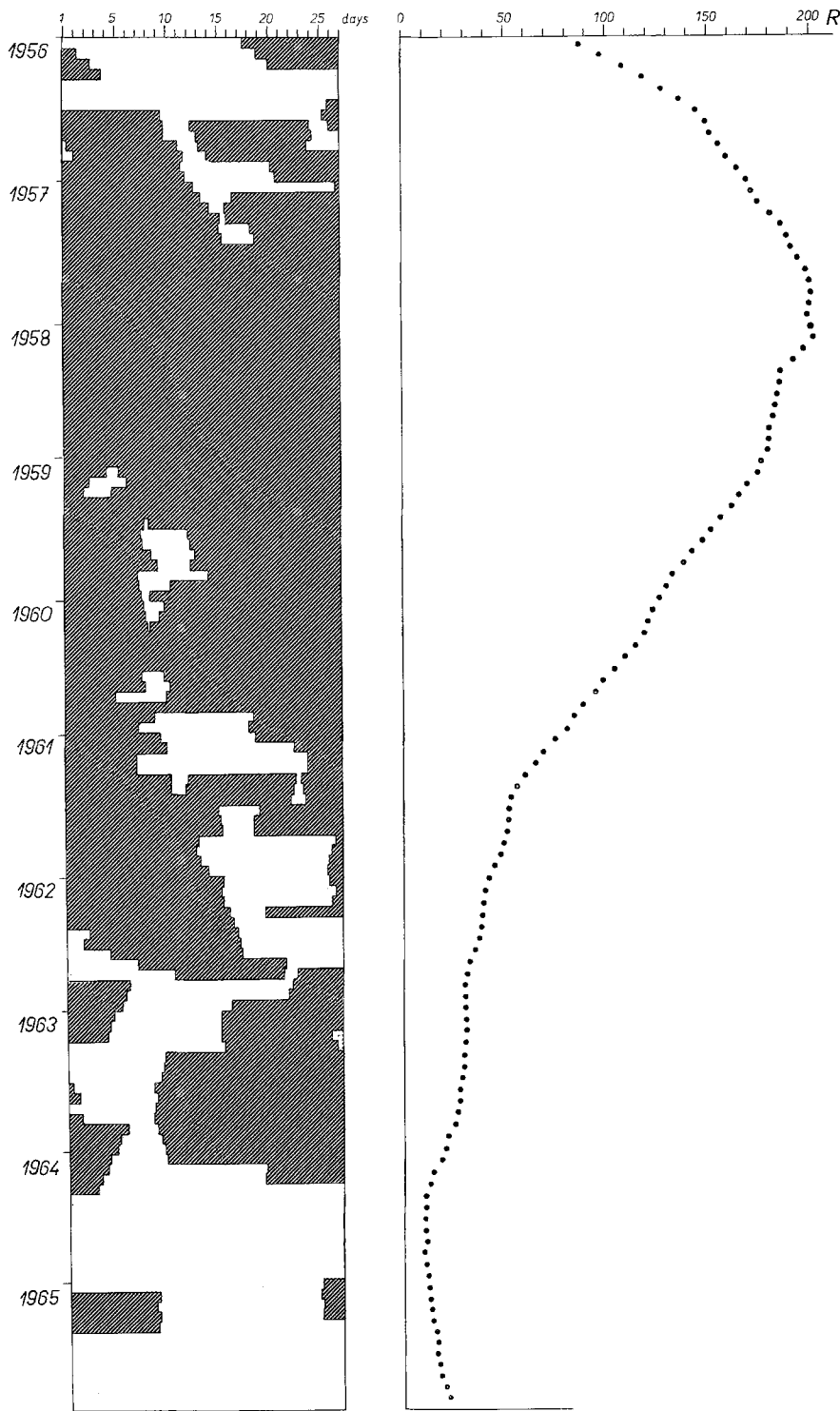


Fig. 4. Both parts of Figure 1 drawn into one graph, to show the heliographic longitudes on the sun occupied by proton-flare active regions including both hemispheres.



of 1960, i.e. more than 2 years after the solar maximum. Later on, the number of quiet periods increases, but they are rarely longer than 10 days until in 1964 the solar minimum begins. Therefore, it is quite obvious that any long-term forecasts of proton-flare free periods on the sun are entirely impossible for more than 3 years around the solar maximum, and this fact should be taken into account when planning the manned flights to the moon. In the present cycle, this hopeless period will probably start at the beginning of 1968 and it will last until the end of 1970. It is true that the present cycle will certainly be lower than the preceding one, which might somewhat improve the situation, but on the other hand, one has to bear in mind that in our considerations we have assumed a good knowledge of the formation and development of the complexes of activity, which in fact is not the case.

5. The Winter Deficiency of Proton Flares

There is one aspect, however, which perhaps might make the situation a little more favourable. When we look at our diagrams, we observe that the proton-flare regions do not form with the same intensity at any time. They seem to appear intermittently, as in the form of some impulses of activity. There are periods when the complexes of activity remain relatively quiet and then, after that, proton-flare regions are formed in several complexes at about the same time. When we make the sum of all proton-flare

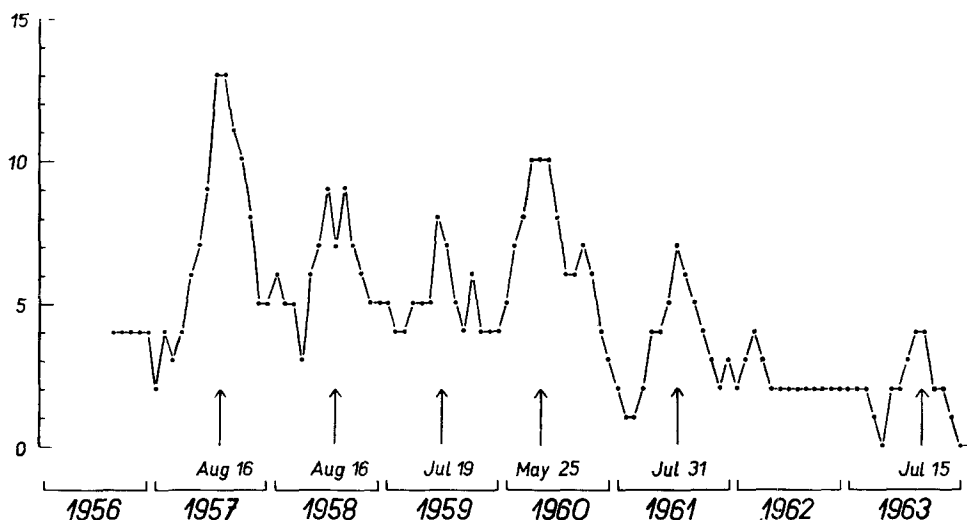


Fig. 6. Time variation of the sum of proton-flare active regions present on the sun. Individual dots are smoothed means of five rotations. The central dates of such smoothed means are written at the arrows which show the individual maxima of occurrence.

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Fig. 5. Figure 4, corrected for the 'proton-dangerous time' for each proton-flare active region. Everywhere inside the dashed part of the graph, a proton-flare region can form at any time. Only the empty areas are the fully safe time intervals when one can be entirely sure that no proton flare occurs in the solar atmosphere. The Wolf number R is added on the right-hand side.

regions at a given time, we find the curve which is shown in Figure 6. One can observe here several consequent maxima of the occurrence of proton-flare regions and these maxima always appear in summer months, with a fairly regular yearly period.

One could suspect that this is an effect of observation. Since the vast majority of solar observatories are located on the Northern hemisphere, some proton flares, and in consequence of it some proton-flare active regions as well, escape our observation in the winter time. But it is not easy to hold this explanation. Apart from the fact that since the beginning of IGY in 1957 the flare patrol has been almost complete all through the year, Figure 7 shows that this yearly period, characterized by the striking

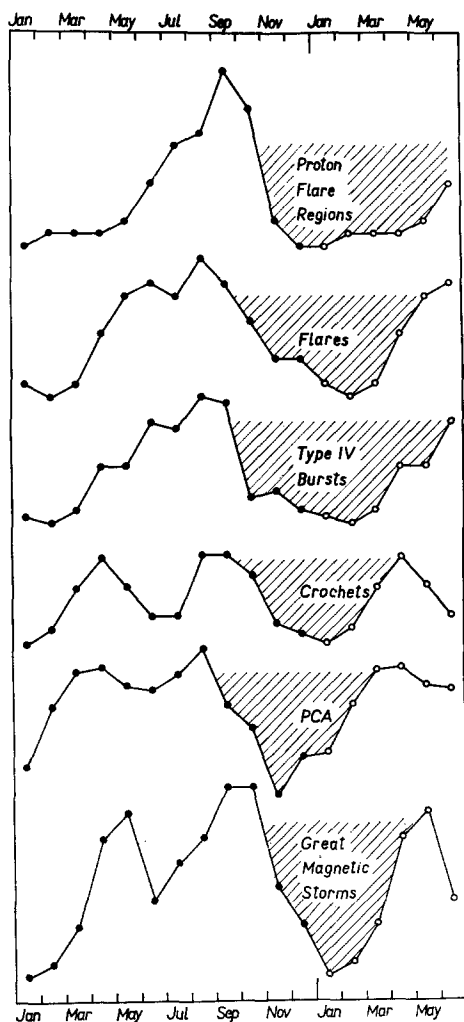


Fig. 7. The winter deficiency of solar activity and its geophysical effects. The first curve was constructed according to Figure 6; references to the other curves: flares and crochets by PINTÉR and KNOŠKA (1968), type-IV bursts by FRITZOVÁ and ŠVESTKA (1966), PCA by ŠVESTKA (1966) and, magnetic storms by JONAH *et al.* (1965).

deficiency of the flare activity in winter months, manifests itself in a variety of effects. The different curves in this figure refer to the proton-flare regions, flare number, type-IV bursts, magnetic crochets, polar-cap absorptions and great magnetic storms. It is very difficult to interpret the deficiency of all these phenomena in winter months as a seasonal effect on the earth. It is much more probable that the source of this yearly variation must be looked for on the sun. I do not intend to make any efforts of interpreting this 1-year period of solar activity, because it might lead us to some hypotheses of a modulation of the solar periodicity by the orbiting planets, which hardly can be understood from the physical point of view at the present time, but I would like to point out that this yearly variation of the proton-flare occurrence may help us in some way in the proton-flare forecasts.

6. Conclusions

Thus we can conclude that, according to the analysis presented here, it is practically impossible to make any safe long-term forecasts of proton-flare free periods on the sun during about three years around the solar maximum, with the knowledge we have at the present time. Later on, when the solar cycle declines, such forecasts may be possible as soon as we improve our knowledge of the formation and development of the complexes of activity, in which proton flares occur. The danger of a proton-flare formation seems to be significantly greater in summer months than in the winter season from November to February.

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