Changes in Amplitude of the 27-day Variation in Cosmic Ray Intensity during the Solar Cycle of Activity

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Abstract

The 27-day recurrence tendency in the cosmic ray intensity has been studied by the Chree method of analysis for the period 1937—55, using the ionisation chamber records at Huancayo. The amplitude of the 27-day variation changes from year to year. The variation in the amplitude is in general agreement with the changes in solar activity as revealed by the sun-spot number only for the years 1937—46 and 1952—55. This is in agreement with the results of Meyer and Simpson for the same periods, obtained from a slightly different method of analysis. The correlation breaks down for the period 1946—52 and this is discussed in terms of possible changes in the electromagnetic conditions in the interplanetary space during the solar cycle.

1. Introduction

The quasi-periodic variation in the intensity of cosmic rays with a recurring tendency of about 27 days has been studied by MONK and COMPTON (1939), BROXON (1949), LANGE and FORBUSH (1949), SIMPSON (1954) and others.

Since the synodic period of rotation of the sun is about 27 days and since SIMPSON et al. (1952) had observed in 1951 that individual solar regions could be associated with the 27-day variation in cosmic rays, they have searched for an association between the amplitude of the 27-day variation and the changes in solar activity as revealed by the sunspot number. They have studied the ionisation chamber data for the period 1937—46, and neutron data for the period 1951—53. It would be worth-while comparing the results of their analysis with the present analysis.

The 27-day variation in cosmic ray intensity could be interpreted as modulation effects in the interplanetary space produced by the deceleration in the electric field associated with the beams of rarified ionised gas emitted from the sun, as pointed out by BRUNBERG and DATTNER (1954), ALFVÉN (1956), and VENKATESAN (1957). The beams with the frozen magnetic field and the electric field arising from polarisation effects were invoked by ALFVÉN (1950, 54, 55) to explain the essential features of magnetic storms and aurorae.

It is reasonable to suppose that the beams which are expected to govern and regulate the electromagnetic conditions in the interplanetary space to a large extent, would be affected by the changes in solar activity occurring during its eleven year cycle. In view of the general dependence of the beams on solar activity, it would be of interest to study one of the effects attributed to the electric field, namely the cosmic ray intensity decreases, to see whether there is any association between them.

Since the recurrence phenomena are attributed to the beams, it would therefore not be surprising if a relation, for example between the amplitude of the 27-day variation and

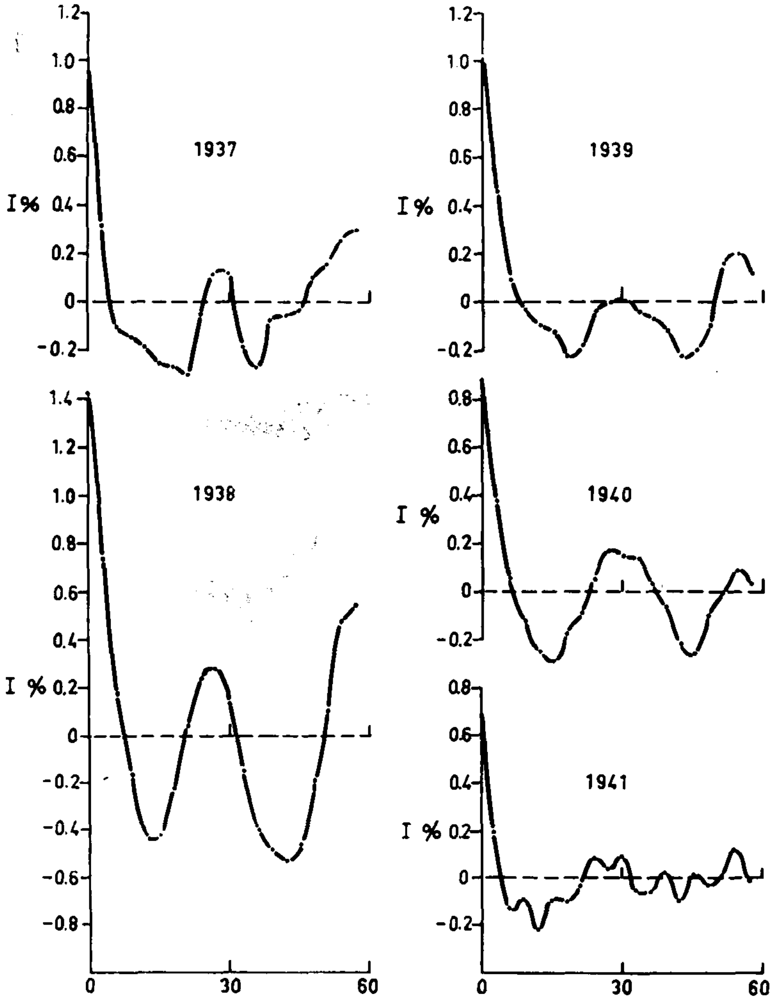

Fig. 1. The Chree analysis of the daily mean cosmic ray intensities at Huancayo for the years 1937—41. The ordinate gives the intensity and the abscissa, the days.

solar activity were observed. MEYER and SIMPSON (1954) from a study of the neutron intensity data over the years 1951, 52 and 53 find a progressive decline in the amplitude, which is consistant with the decreasing solar activity.

2. Data and Method of Analysis

The data chosen for study are the daily mean intensities of the ionisation chamber at Huancayo for the years 1937 to 1955. This covers a period corresponding to more than one complete cycle. The years 1937 and 1947 were ones of high solar activity and 1944 and 1954 were ones of low activity.

The method of analysis is the one originally devised by CHREE (1913) in connection with the study of recurrence phenomena in geomagnetic character figures. It should be pointed out that the method is free from any preconceived notions about the length and significance of the recurrence tendency. The method consists in summing up the intensity values on all days exhibiting a minimum (or a maximum) tendency by choosing, say, five days per month. This is designated as the zero day. Similarly the same procedure is carried out for, say, 60 days preceding and following the selected zero days. It is possible that the recurrence tendency is obscured to some extent either by seasonal effects or by

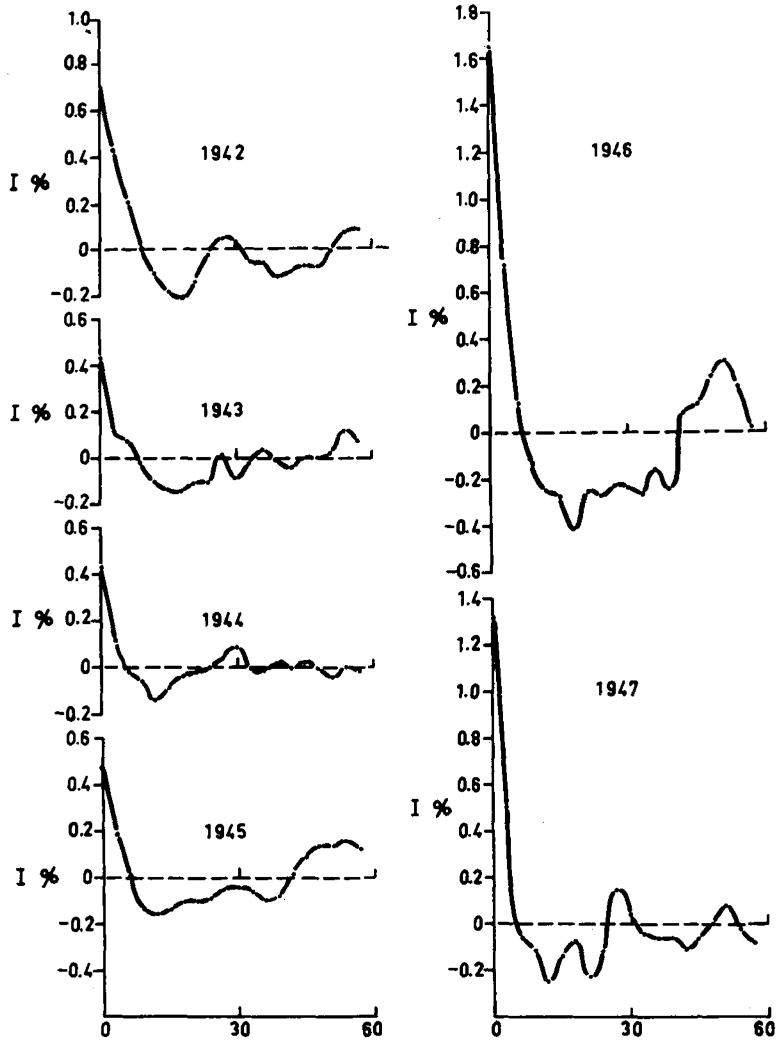

Fig. 2. The Chree analysis of the daily mean cosmic ray intensities at Huancayo for the years 1942—47. The ordinate gives the intensity and the abscissa, the days.

systematic drifts in the measuring instrument. As these effects would be nearly the same for both the analyses corresponding to minimum and maximum intensity days, it could be removed by subtracting the sums of the former from the sums of the corresponding day in the latter. The difference curve is plotted with each point representing the average intensity over three days as is usually done in such analyses. The final results are obtained by folding the difference curve about the zero day so that values corresponding to the preceding and following days are combined.

3. Results and Discussions

Figures 1—4 give the final results for Huancayo for the years 1937—55. It can be seen from the figures that the recurrence tendency undergoes changes during the solar cycle. The recurrence tendency near the 27th day is most pronounced in the years 1938, 1948, 1951 and 1952. While the years 1938 and 1948 correspond to periods when the solar activity was high, the other two years correspond to epochs when the solar activity was near the end of the cycle. It should be pointed out that 1954 was the year of minimum solar activity.

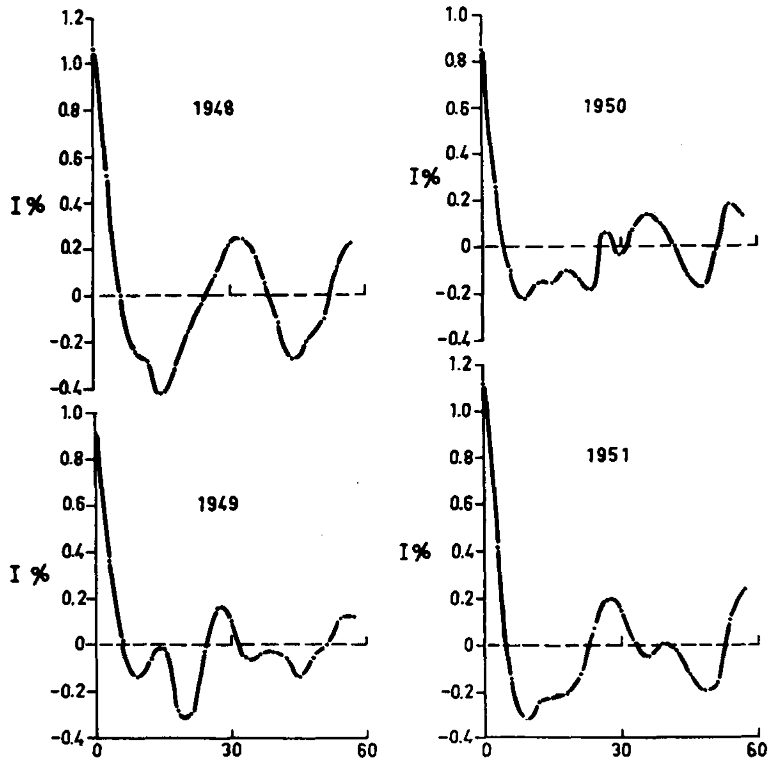

Fig. 3. The Chree analysis of the daily mean cosmic ray intensities at Huancayo for the years 1948—51. The ordinate gives the intensity and the abscissa, the days.

In fig. 5, a comparison is made between the changes in solar activity as revealed by the sunspot numbers and the amplitude of the 27-day variation. R is the mean annual sunspot number for the year, while 'a' refers to the value of the intensity corresponding to the zero day measured from the mean level for each year. 'a' could be considered as a measure of the amplitude. On the same fig. are also given the values of σ for each year, which is defined by MEYER and SIMPSON (1954) as a quantitative measure of the 27-day amplitude. σ_H refers to Huancayo while σ_{Cl} refers to Climax. σ_{Cl} is plotted for the station Climax using neutron intensity instead of ionisation chamber data. The scale ratio for neutron/ionisation chamber is taken to be approximately 5.

$\sigma = \langle \delta \rangle^{\frac{1}{2}}$ is the standard deviation of a set of δ^s, where $\delta = [I(t) - I(t+\tau)]/\langle I \rangle$. $\langle I \rangle$ refers to the average intensity, $I(t)$ and $I(t+\tau)$ refer to the intensities at Huancayo on day t and $t+\tau$, where $\tau = 14$. This is a consequence of the existence of recurrence tendency of 27—28 days in the intensity variations. They have pointed out that this selection preferentially chooses those variations which have a quasi-periodicity of 27 days.

In fig. 6 also a comparison is made between the changes in solar activity as revealed by the sunspot numbers and the amplitude of the 27-day variation defined in a slightly different way. R as before is the mean annual sunspot number, while 'A' is half the difference between the values on day 0 and day 14, and which could be taken as a measure of the amplitude. It should be pointed out that there could be a certain measure of uncertainty in 'A' since another sequence of 27-day variations which is often found showing up after 14 days, would reduce it. This has to be borne in mind, as it could very well happen that these secondary series are more prominent in one year than in others. On the same fig. are also given σ (tracking), defined by MEYER and SIMPSON (1954) as a measure of the ampli-

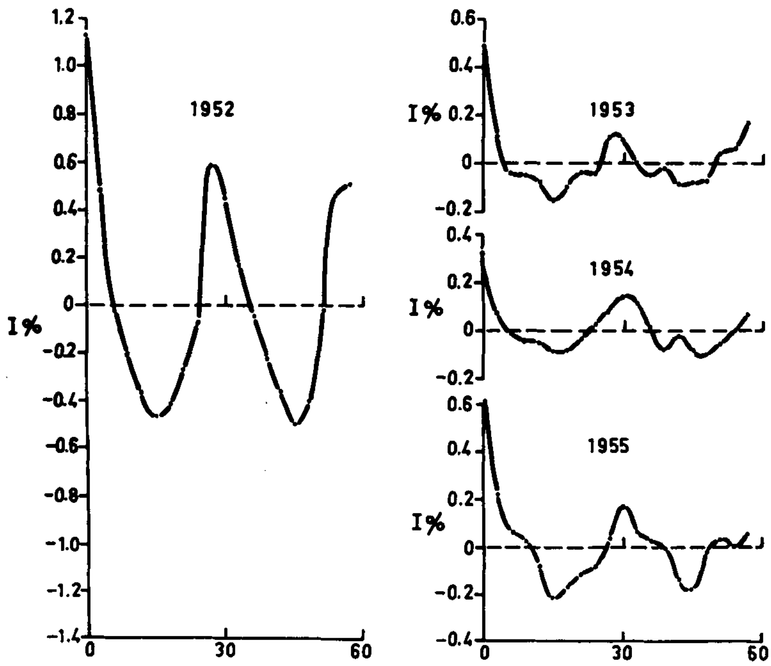

Fig. 4. The Chree analysis of the daily mean cosmic ray intensities at Huancayo for the years 1952—55. The ordinate gives the intensity and the abscissa, the days.

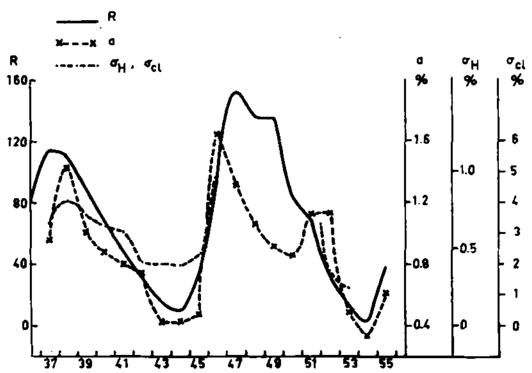

Fig. 5. The variation of the amplitude of the 27-day variation in cosmic ray intensity during the years 1937—55. R refers to the mean annual sunspot number, 'a' to the amplitude of the 27-day variation at Huancayo as measured in the present investigation, from the mean level of intensity, σ_H, σ_{Cl} to the amplitude of the 27-day variation as defined by Meyer and Simpson, at Huancayo and Climax.

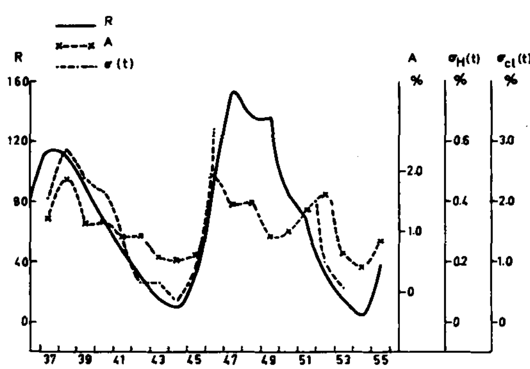

Fig. 6. The variation of the amplitude of the 27-day variation in cosmic ray intensity during the years 1937—55. R refers to the mean annual sunspot number, 'A' to the amplitude of the 27-day variation at Huancayo as measured in the present investigation and equal to half the difference between the values on zero day and 14th day, $\sigma(t)$ to the worldwide amplitude of the 27-day variation as defined by Meyer and Simpson, at Huancayo and Climax.

tude of the worldwide 27-day variation. It is the product of σ_H and γ, the correlation between the δ^s for Huancayo and some other station.

In their analysis Meyer and Simpson remove some periods from the data, namely those containing temporary increases due to solar flare and Forbush decreases which they consider to be different from the 27-day variations.

We have not deleted the flare period data corresponding to 28th Feb., 1942 and 26th July, 1946 since we do not find any increase at Huancayo and since we do not use the data of any other station. Since we consider the so-called non-recurring Forbush decreases differ only in the matter of degree, we have not deleted these periods. We attribute both the 27-day variation as well as Forbush decreases to be the effect of deceleration in the beams from the sun. In this connection, it should be pointed out that SINGER (1946) holds a similar view about the two effects. He has further referred to a case of recurrence in Forbush decreases. GALLI and GALLI (1956) have pointed out the 27-day recurrence in Forbush decreases.

MEYER and SIMPSON (1954) have determined a measure of the amplitude of the 27-day variation in cosmic ray intensity for the periods 1937—46 and 1951—53. As their result for 1951 is only for six months we have not considered that for the comparison with our results. It can be seen from figs. 5 and 6 that the measure of amplitude as defined by them and as given here reveal a good agreement for the period for which their data is available in spite of certain differences in the mode of selection of the data and the method for analysis. This close agreement for 1937—46 and 1952—53 leads one to expect that the same agreement is likely to be there for the intervening period also.

The close agreement between the amplitude of the 27-day variation in cosmic ray intensity and the solar activity as revealed by the sunspot number, is clearly seen from figs. 5 and 6 for the periods 1937—46 and 1952—55. The departure from this behavior during 1946—52 stresses the importance of a careful study needed for this period before one can draw any general conclusions about the whole solar cycle.

The correlation between sunspot number and the amplitude of the 27-day variation does not mean that the sunspots are the underlying cause of the cosmic ray changes. It is only an index of solar activity with which one can reasonably associate the emission of beams. For example, one could say that with increased activity of the sun, the number of beams emitted would be greater and perhaps that the beams extend to a larger extent. The departure from the expected correlation during 1946—52 could be reasonably accounted for by an interpretation in terms of possible changes in the characteristics of the beams. Since the solar activity has increased even after 1946, the number of beams could not have decreased. In this connection it is worth-while pointing out that the years 1947—49 had the highest sunspot numbers since the last seventy years, and moreover the year 1947 had the highest value since 1778, indicating an unusually heavy activity.

The amplitude of the 27-day variation is governed by the voltage across the beams, which in turn depends on a number of factors. It is not possible to say at this juncture, from the cosmic ray evidence alone, whether there is any systematic variation in the characteristics of the beam like the value of the magnetic field frozen in the beam, the velocity of the particles in the beam, the width of the beam etc., with the changes in solar activity. It is necessary to look into geomagnetic and auroral data also before one can arrive at unambiguous conclusions.

It can be seen from fig. 6 that the amplitude of the 27-day variation in 1946 does not reach a value much higher than in 1938 although solar activity is very much higher. It is worth-while to point out that in 1946, there were a series of heavy Forbush decreases starting from Feb. and lasting for nearly six months. If it is reasonable to assume that the beams, to which could be attributed this unusually heavy activity, had transported a major quantity of the flux available, there would be a relatively weaker magnetic field for new beams to freeze. Hence it would be reasonable to expect these beams not to produce heavy geomagnetic disturbances or heavy cosmic ray decreases. This would reduce the amplitude of the 27-day variation. It can be seen from fig. 6 that the amplitude of the 27-day variation decreases from 1946 although the solar activity goes up and remains high. In other words some sort of saturation of the electromagnetic state of the interplanetary space is reached.

It is of importance to find out whether the breakdown in the relationship between the amplitude of the 27-day variation in cosmic ray intensity and solar activity during 1946—52 is reflected in any other effects attributed to the electric field of the beams emitted from

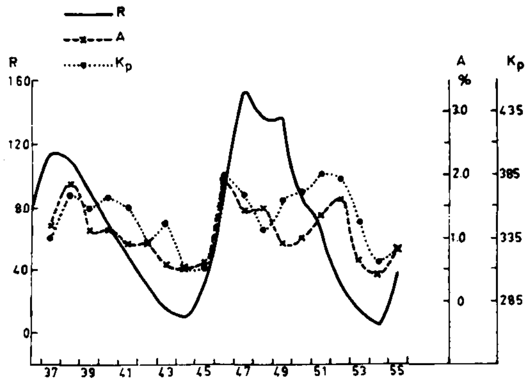

Fig. 7. The variation of the amplitude of the 27-day variation in cosmic ray intensity and a measure of the geomagnetic disturbance during the years 1937—55. R refers to the mean annual sunspot number, 'A' to the amplitude of the 27-day variation at Huancayo as measured in the present investigation and equal to half the difference between the values on zero day and 14th day, and K_p to the sum of K_p maximum values for the 60 most disturbed days in each year.

the sun. For example, we could consider the geomagnetic disturbances. The planetary index, K_p, is a reliable though arbitrary measure of geomagnetic disturbance. One could choose either the maximum value of K_p or the sum of the eight K_p values available for each day. We use the former. Instead of using the elaborate method adopted above for cosmic rays, one could obtain an idea of the behavior of geomagnetic disturbances during a solar cycle by the following method. The 60 most disturbed days in each year are selected and the sum of the K_p maximum values for these 60 days is determined and plotted against time as in fig. 7. It can be seen from that fig. that the geomagnetic disturbances as revealed by K_p also show changes from year to year in fair agreement with the changes in sunspot number for 1937—46 and 1952—55, just as the cosmic rays behaved. But, for the period 1946—52, they show the same departure from sunspot number as is observed in the case of cosmic rays. This supports the earlier observation pointing out the necessity of looking into this period carefully.

If it is reasonable to assume some sort of saturation of the electromagnetic conditions in the interplanetary state is reached in 1946, then the absence of the occurrence of heavy geomagnetic disturbances immediately after 1946 is understandable although the solar activity goes up and remains high. The gradual resetting of the pre-saturation conditions takes place by about 1948. Further emission of beams thereafter would result in the occurrence of comparatively heavier geomagnetic activity as can be observed from fig. 7.

Fig. 8 shows 'A' the amplitude of the 27-day variation in the intensity of cosmic rays and the sum of the K_p maximum values for the 60 most disturbed days in each year against R the sunspot number. It can be observed from this figure that they both appear to reach a maximum value corresponding to the value of sunspot number in about the range 80 to 100. The figure also seems to indicate a decline

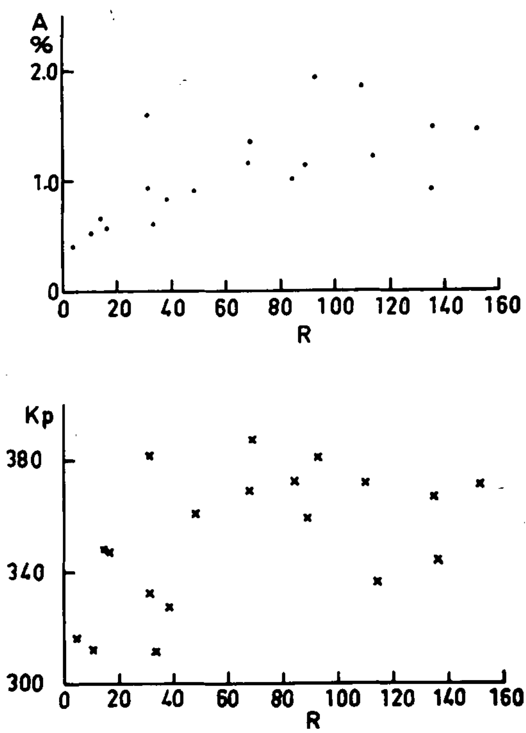

Fig. 8. The relation between the amplitude of the 27-day variation in cosmic ray intensity and sunspot number; and the relation between the geomagnetic disturbances and the sunspot number. R refers to the mean annual sunspot number, 'A' to the amplitude of the 27-day variation at Huancayo as measured in the present investigation and equal to half the difference between the values on zero day and 14th day, and K_p to the sum of K_p maximum values for the 60 most disturbed days in each year.

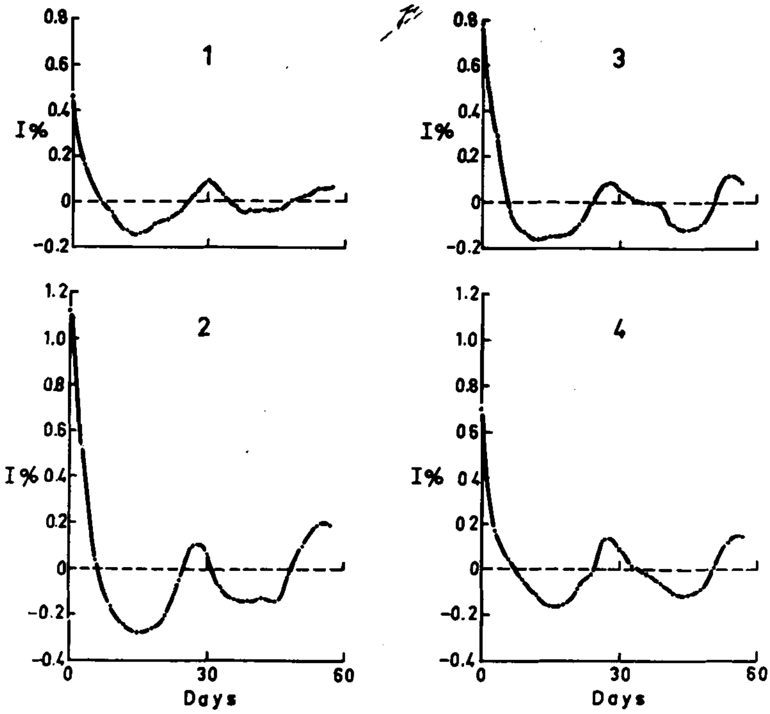

Fig. 9. Changes in the periodicity of the recurrence tendency in the variation of the cosmic ray intensity. The four curves correspond to recurrence during various stages in the solar cycle of activity.

with further increase of sunspot number. This indicates that some sort of saturation of the electromagnetic state is reached at a particular level of solar activity.

If changes in the electric field of the beams during the solar cycle do take place, then it could very well be due to changes in any of the three parameters governing the same, namely the frozen magnetic field, the velocities of the particles in the beam and the width of the beam. This would also raise the question whether it is the general dipole field of the sun that is frozen in the beam or whether at least at times the local high regional magnetic field could be frozen in the beam. The latter possibility would easily allow for a wide range in the variation of the frozen field from year to year. The shrinking of the auroral zone during the minimum solar activity years would support the view that the electric field gets weaker.

The recurrence period also seems to vary during the solar cycle. It is of course not definite whether on the evidence available one could point out a definite systematic variation with solar activity. It would therefore be worth-while to look at other data in addition to cosmic rays to arrive at an unambiguous conclusion. It appears from table 1 that the period of recurrence is larger for the years when the new cycle starts. A combination

Table 1. Recurrence period for years grouped according to solar activity.

No.	Group corresponding to	Years combined	Recurrence interval days
1	beginning of new cycle	1944, 1945 1954, 1955	30
2	maximum of activity	1937, 1938 1946, 1947 1948, 1949	Between 27 and 30
3	fall of activity	1939, 1940 1941, 1950, 1951	Between 27 and 30
4	end of cycle	1942, 1943 1952, 1953	27

of the data for the whole period into 4 groups, (a) rising part of solar cycle, (b) period of maximum activity, (c) fall of activity, and (d) end of cycle, reveals that at least for group (a) the recurrence period is greater than for the other groups. This is seen from figure 9. Such a behavior, if it is definite, would be understandable. The 'butterfly pattern' of the distribution of the sunspots is wellknown. If the region of origin of the beams changes during the solar cycle in a systematic way such a behavior could be expected. The problem needs further study.

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