27-DAY RECURRENCE TENDENCY IN THE DAILY VARIATION OF COSMIC RAY MESON INTENSITY

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I. INTRODUCTION

In an earlier communication (Kane, 1955), it was shown that the daily variation of cosmic ray nucleonic component as revealed through the measurements of neutron intensity shows a recurrence tendency of a period of about 27 days. As a measure of the daily amplitude, the factor $D-N$ was considered where D represents the cosmic ray intensity during the 12-hourly day-time interval 0600 to 1800 hours local time and N represents the combined intensity for the two 6-hourly night intervals 0000 to 0600 hours and 1800 to 2400 hours local time on either side of the day interval. The main characteristics of the recurrence phenomena observed to be associated with the factor $D-N$ may be summarized as follows:—

(*a*) The $D-N$ values at different stations were fairly well correlated indicating a world-wide character of the daily variation.
(*b*) Chree analysis of the $D-N$ values revealed a 27-day recurrence tendency of the $D-N$ maxima.
(*c*) The recurrence tendency was more distinct during the year 1953 of low sunspot activity as compared to the previous two years 1951 and 1952 of comparatively higher sunspot activity.
(*d*) Chree analysis for the *minima* of $D-N$ values showed similar characteristics.
(*e*) The $D-N$ values did not show any unique phase relationship with the $D+N$ maxima, i.e. the maxima of the daily mean neutron intensity.
(*f*) The K_p indices of geomagnetic activity reveal prominent 27-day recurrence tendencies. A comparison of these with the $D-N$ maxima showed that every 27-day sequence of K_p maxima was not associated with $D-N$ maxima; but for some periods and for some of the sequences of K_p maxima, the $D-N$ maxima coincided with the K_p maxima.

In addition to the neutron intensity data, the Freiburg ionization chamber data for the same period were analysed in a similar way. The amplitude of the $D-N$ maxima of the meson intensity at Freiburg was smaller than for the neutron intensity. However, $D-N$ maxima of the meson intensity showed a 27-day recurrence tendency with the same characteristics as for the neutron intensity.

Yoshida and Kondo (1954) have harmonically analysed the daily variation of meson intensity at Huancayo for every day during the period 1936 to 1945 and have studied the 27-day recurrence tendency of the diurnal component. They show the 27-day recurrence of the amplitude of the diurnal component by means of a Bartel's diagram. Furthermore, Chree analysis has been conducted by them, taking for epochs (0 days) the commencement of magnetic storms during the period 1936 to 1940. Yoshida and Kondo find a clear 27-day recurrence extending to 2 or 3 cycles of solar rotation for the diurnal amplitude but not for the time of maximum. Since many authors (Ehmert and Sittkus, 1951; Sandstrom, 1955; Trumpy, 1955; Firor *et al.*, 1954; Elliot and Dolbear, 1951) have pointed out the increase of diurnal amplitude and change of its time of maximum on magnetically disturbed days, and since the 27-day recurrence in K_p is well established, it can be understood why a 27-day recurrence in the diurnal amplitude is brought out in Yoshida and Kondo's analysis. The surprising feature, however, is the absence of 27-day recurrence in the time of maximum as also the more persistent recurrence of the diurnal component as compared to the recurrence of the magnetic storms.

Yoshida and Kondo's analysis, however, suffers from the disadvantage that the amplitude and the phase of the daily variation cannot be taken into account simultaneously for the study of the recurrence tendency. Recently, Alfven (1954) has suggested that the diurnal variation could possibly be composed of two diurnal vectors, one along the earth-sun line and the other at right angle to it along the earth's orbit of rotation around the sun. With due consideration for the earth's direction of motion in its orbit and its rotation about its own axis, the two vectors may be termed as the noon vector and the 18-hour vector respectively. Allowance will have to be made, however, for the deflection of cosmic ray particles due to the earth's magnetic field.

In all standard procedures of harmonic analysis of a daily variation, the variation is supposed to be composed of mutually orthogonal vectors of different periodicities. Thus, in a 12 value scheme of harmonic analysis, one assumes the variation F to be of the form:—

$$F = a_0+a_1 \cos \theta+a_2 \cos 2\theta+a_3 \cos 3\theta+a_4 \cos 4\theta+a_5 \cos 5\theta+a_6 \cos 6\theta$$
$$b_1 \sin \theta+b_2 \sin 2\theta+b_3 \sin 3\theta+b_4 \sin 4\theta+b_5 \sin 5\theta \quad .. \quad .. \quad (1)$$

For the diurnal component, the two orthogonal vectors ($a \cos \theta$) and ($b \sin \theta$) give the resultant vector r given by

$$r \sin (\theta+\phi) = a \cos \theta+b \sin \theta \text{ where}$$
$$r = (a^2+b^2)^{\frac{1}{2}} \text{ and } \phi = \tan^{-1} (a/b). \quad .. \quad .. \quad .. \quad (2)$$

Thus, r and ϕ represent the amplitude and phase of the resultant vector while $-a$ and $-b$ are the amplitudes of the two vectors which can represent the noon-time and 18-hour vectors referred to above, if the 12-hourly values utilized for harmonic analysis start from midnight.

One may obtain the values of $-a$ and $-b$ directly by harmonically analysing a daily variation curve. However, for all variations composed mainly of a diurnal component, a simpler procedure is to evaluate two factors $D-N$ and $E-M$ defined as follows:—

D = Day-time intensity, i.e. the intensity observed during the daylit hours 0600 to 1800 L.T.

N = Night-time intensity, i.e. the addition of the intensities during the two night-time intervals 0000 to 0600 hours and 1800 to 2400 hours L.T. To eliminate errors due to long-time variation in cosmic ray intensity, the two night intervals should be preceding and succeeding the day-time interval.

E = Evening-time intensity, i.e. the intensity during the interval 1200 to 2400 hours L.T.

M = Morning-time intensity, i.e. the addition of the intensities during the two morning intervals 0600 to 1200 hours and 2400 to 0600 hours L.T. As in the case of night intervals, these two precede and succeed the evening-time interval.

The factor $D-N$ thus represents the excess of cosmic ray intensity during the day-time over the intensity during the night-time. Similarly $E-M$ represents the excess of cosmic ray intensity during the evening-time over the intensity during morning-time. A resultant vector $|r|$ can be calculated from these two factors as follows:—

$$(|r|)^2 = (D-N)^2+(E-M)^2 \qquad \ldots \quad \ldots \quad \ldots \qquad (3)$$

and would represent the total amplitude of the daily variation.

It can be easily shown that the factors $D-N$, $E-M$ and $|r|$ are directly proportional to the quantities $-a$, $-b$ and r referred to in equation (2).

It was proposed, therefore, to consider the factors $D-N$, $E-M$ and $|r|$ as representative of the noon-time vector, 18-hour vector and the total vector representing the diurnal variation of cosmic ray intensity and to study the recurrence tendencies in each of these by the Chree-analysis method taking for epoch the days of maxima of these factors themselves, instead of choosing some other criterion as the commencement of storm as done by Yoshida and Kondo.

II. Recurrence Tendencies in $D-N$, $E-M$ and $|r|$

For the purpose of studying the recurrence tendencies of the factors $D-N$, $E-M$ and $|r|$ defined above, the Carnegie Institution Data for cosmic ray meson intensity at Huancayo for the period 1937 to 1945 were utilized. For Huancayo,

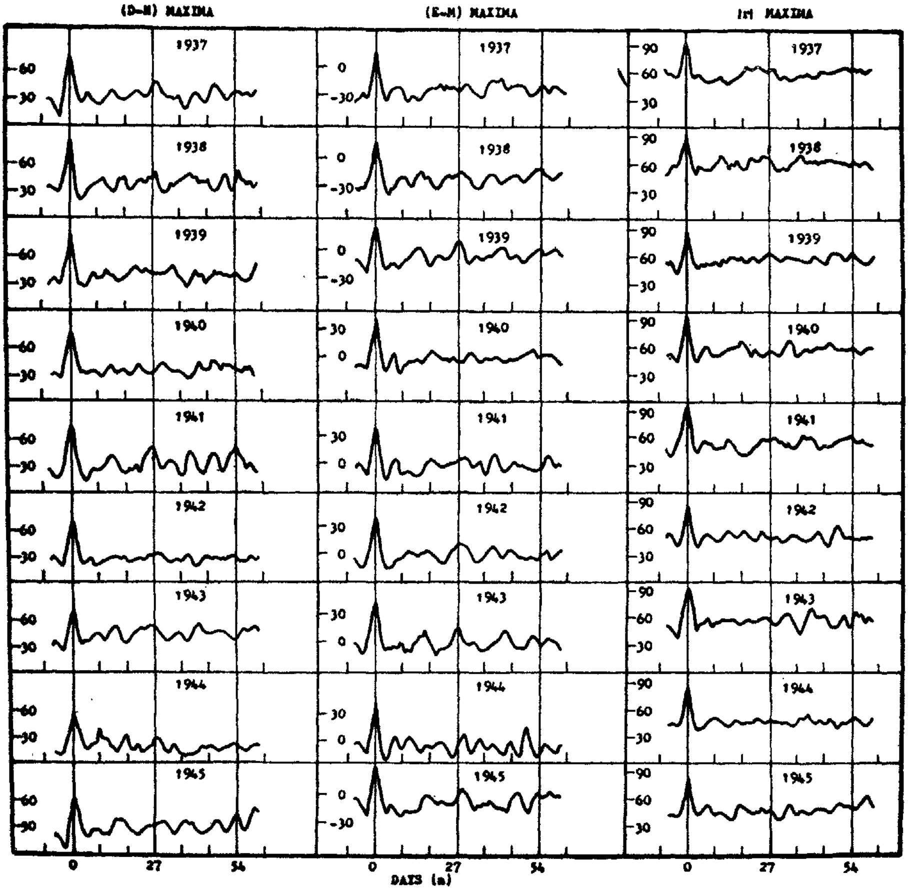

Fig. 1. Chree-type diagrams for $D-N$, $E-M$ and $|r|$ maxima.

the deflection of cosmic ray particles of average energy about 25 BeV would amount to about 90°. The factors $D-N$ and $E-M$ would, therefore, represent the 6-hour and 12-hour vectors respectively. The factors $D-N$ and $E-M$ were evaluated for each day during the 9-year period. A plot of these values, however, showed that the $D-N$ and $E-M$ values had large fluctuations from day to day and it was very difficult to choose the days of maxima. It was, therefore, necessary to make smooth the data. Moving averages over 3 consecutive days were evaluated for the two factors, even at the risk of reducing appreciably the amplitude of these fluctuations. This procedure greatly facilitated the selection of days of $D-N$ and $E-M$ maxima. The factor $|r|$ was calculated from the $D-N$ and $E-M$ values *after* the procedure of taking moving averages over three consecutive days.

Fig. 1 shows the Chree-type diagrams for $D-N$, $E-M$ and $|r|$ maxima for different years.

It seems that the recurrence tendency of a period of 27 days is prominent only in certain years, which are not always the same for $D-N$, $E-M$ and $|r|$. To determine whether the 27-day recurrence tendency was prominent in any particular Chree diagram, the following criterion was applied:—

A range R was defined as the difference between the maximum and minimum value of the ordinate in a particular Chree diagram. The maximum value was obviously at $n-0$. The average ordinate value for $n-26$, 27 and 28 was then evaluated and the minimum value of the ordinate in the Chree diagram was subtracted from this average value. The factor R' so obtained was required to be greater than $\frac{1}{3}R$ for the 27-day recurrence tendency to be considered as prominent. Table I indicates the prominences of the 27-day recurrence tendencies for the different factors for different years.

TABLE I.

Prominence of the 27-day recurrence tendency.
(o=*prominence*, x=*absence of prominence*)

Year	$D-N$ maxima	$E-M$ maxima	$\|r\|$ maxima
1937	o	x	o
1938	o	o	o
1939	x	o	o
1940	x	x	x
1941	o	x	o
1942	x	o	x
1943	o	o	o
1944	o	o	x
1945	x	o	x

III. Interrelation between $D-N$ and $E-M$ Maxima. Relationship with Solar Cycle

It can be seen from Table I that no definite correlation exists between the prominence of the recurrences and the sunspot cycle. Thus, the recurrences are pronounced in both the periods 1937 to 1939 and 1943 to 1945 when the sunspot activity was respectively high and low. In the years 1940 to 1942 of moderate sunspot activity, the recurrence tendency is almost absent.

Fig. 2 shows the average Chree-type diagrams for $D-N$, $E-M$ and $|r|$ maxima for the years in which the recurrence tendency was prominent and for years in which it was not prominent. The former group includes the years

1937, 1938, 1941, 1943, 1944, 1945,	for $D-N$ maxima,
1938, 1939, 1942, 1943, 1944, 1945,	for $E-M$ maxima and
1937, 1938, 1939, 1941, 1943,	for $\|r\|$ maxima.

The other group includes the years

1939, 1940, 1942,	for $D-N$ maxima,
1937, 1940, 1941,	for $E-M$ maxima and
1940, 1942, 1944, 1945,	for $\|r\|$ maxima.

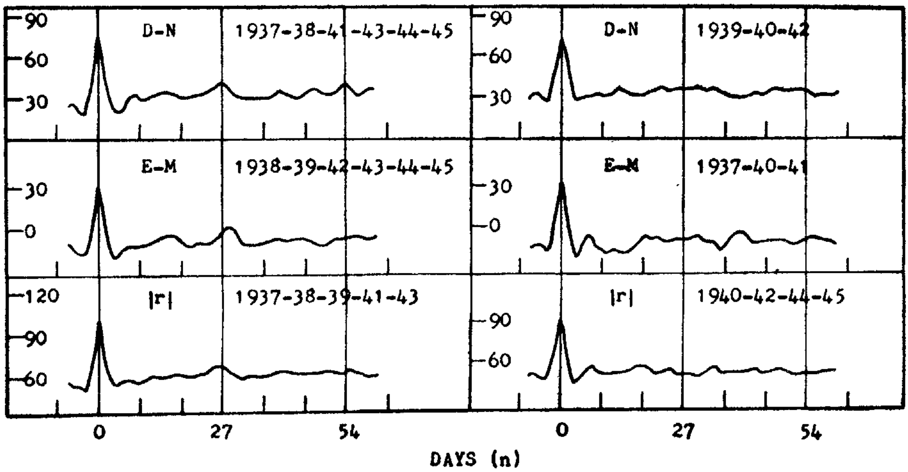

FIG. 2. Average Chree-type diagrams for $D-N$, $E-M$ and $|r|$ maxima for the years in which the 27-day recurrence tendency was prominent and for years in which it was not prominent.

It seems from Fig. 2 that, in general, recurrence tendencies of periodicities other than 27 ± 1 days do not exist in the $D-N$, $E-M$ and $|r|$ maxima.

Fig. 3 is a Bartel's diagram or a 27-day calendar for the period 1937 to 1945. The $D-N$ and $E-M$ maxima are indicated on the same as dots and crosses respectively.

It can be seen that many of the maxima reveal a tendency to repeat after one cycle of 27 ± 1 days and some of them persist for more than one cycle. However, the $D-N$ and $E-M$ maxima do not seem to occur on the same day nor do they seem to bear any unique phase relationship with respect to each other. From Fig. 2, it is also evident that the 27-day recurrence tendency is not so prominent in $|r|$ as it is in $D-N$ and $E-M$ individually. These facts seem to indicate that the $D-N$ and $E-M$ vectors are independent of each other.

In spite of the tendency of many of the $D-N$ and $E-M$ maxima to recur after 27 days, one finds from Fig. 2 that even for the group of years for which the recurrence tendency is prominent for any one of the two factors, the magnitude of the maximum at $n = 27$ is rather small as compared to the maximum at $n = 0$. This could be due to various reasons:

(a) From Fig. 3 one finds that some of the maxima do not repeat after 27 days. This will have a tendency to minimize the height of the peak at $n = 27$.

(b) In some cases, the maxima seem to repeat after 26 or 28 days. This would have a broadening and reducing effect on the peak at $n = 27$ days.

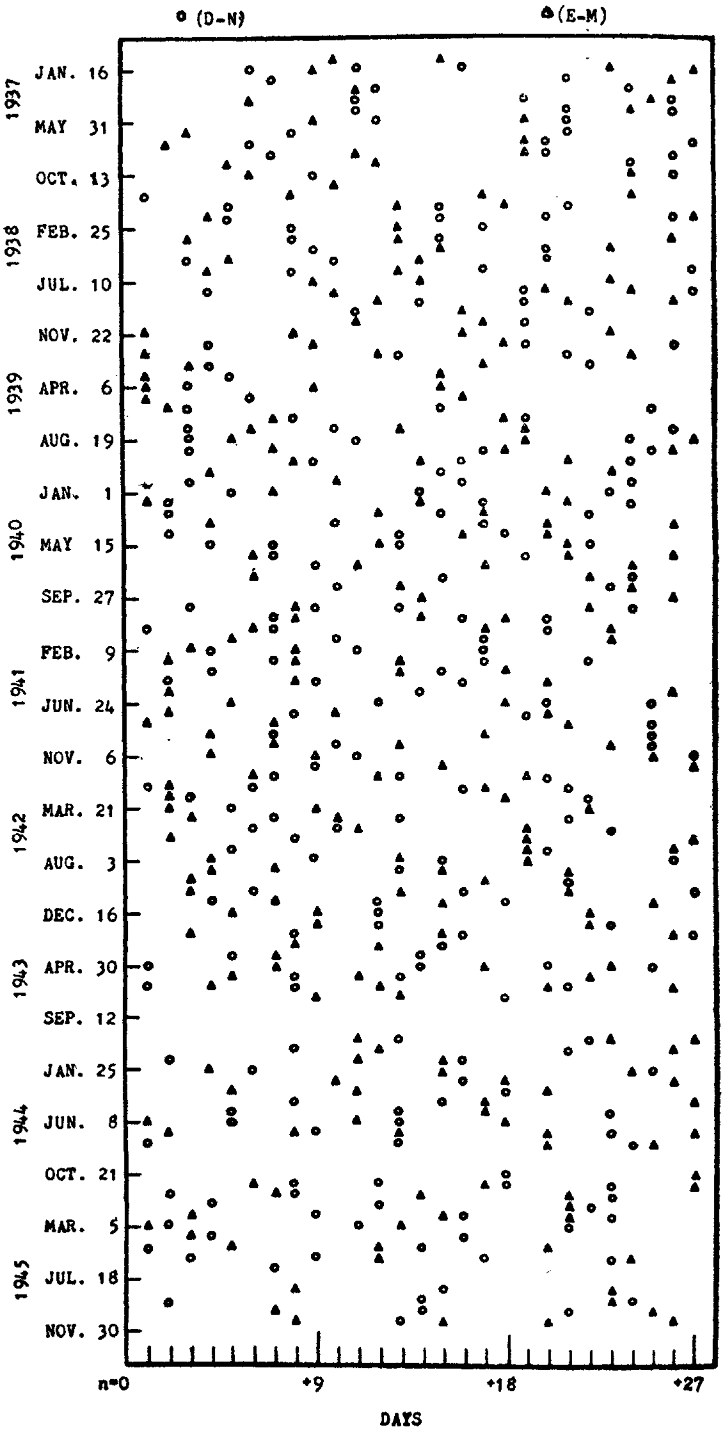

FIG. 3. Bartel's diagram for the $D-N$ and $E-M$ maxima.

(c) The values of $D-N$ and $E-M$ used in the present analysis are moving averages over three consecutive days. This procedure, which was necessitated by the fact that the original values of $D-N$ and $E-M$ had a large scatter making the task of picking out their maxima very difficult, would tend to broaden the peak at $n = 27$ and to reduce its size.

(d) The fact that the maximum at $n = 27$ is smaller than the one at $n = 0$ is observed even in the Chree diagrams for the individual years. A study of the original plot of $D-N$ and $E-M$ values against the time as abscissa has shown that a $D-N$ or $E-M$ maximum on repeating after 27 ± 1 days is usually reduced in size. The reduction is found to be still greater after 54 days.

IV. Relationship with Geomagnetic Activity

It is interesting to study the behaviour of geomagnetic activity during the period under consideration. For this purpose, the geomagnetic indices C_p, for which the daily values are available from 1940 onwards, are utilized. Moving averages over three consecutive days are evaluated to maintain similarity with the previous procedure. Chree-type diagrams for the C_p maxima for various years are shown in Fig. 4.

It is clear that the recurrence tendency in the maxima of C_p is prominent for all years between 1940 and 1945 and even the peak at $n = 54$ is substantial.

An idea of the relative magnitudes of the recurrence tendencies of period 27 days in the factors $D-N$, $E-M$, $|r|$ and C_p can be obtained from Table II which gives the number of maxima (expressed as percentages of the total number of maxima) for each of the above factors for frequency values $f = 1$ and 2 or more. Frequency $f = 1$ gives the number of maxima that are not followed or preceded by other maxima at an interval of 27 ± 1 days. Frequency $f = 2$ or more gives the number of maxima which occur in groups of two or more at a time on the Bartel's diagram.

It is clear that the recurrence tendency in the C_p maxima is much more prominent than the recurrence tendency in any of the other three factors. One can also see that among the maxima of the factors $D-N$, $E-M$ and $|r|$, almost 50 per cent do not recur at all after a 27-day interval. The other 50 per cent do recur and sometimes continue to do so for 3 or 4 cycles. As the interval of 27 days happens to be approximately the rotation period of the sun about its axis, an hypothesis of a solar origin of the 27-day recurrence tendency in the daily variation of cosmic ray intensity would require that,

(1) the region responsible for the $D-N$ and $E-M$ vectors are not identical,

(2) some of these regions are short-lived and do not survive one solar rotation period. There are others, however, which survive more than two cycles of solar rotation.

To study, further, the relationship between the C_p maxima and the maxima of the cosmic ray factors, a Chree analysis was carried out for each one of them with the days of C_p maxima as $n = 0$ days. Fig. 5 shows the Chree-type diagrams for the periods 1940-41-42 and 1943-44-45.

It seems from Fig. 5 that the $D-N$ and $|r|$ maxima precede the C_p maxima ($n = 0$) in the period 1940-41-42 and coincide with them in the period 1943-44-45, while the $E-M$ maxima do not show any unique relationship with the C_p maxima. Also, for $D-N$ and $|r|$, the magnitude of the peak preceding or coinciding with $n = 0$ in Fig. 5 is rather small. One may say, however, that the effect is more pronounced in $|r|$ than in $D-N$. This could be due to the fact that the values of $|r|$ are a measure of the departures from means of $D-N$ and $E-M$ values, irrespective of whether the departures are positive or negative. One may recall that the index

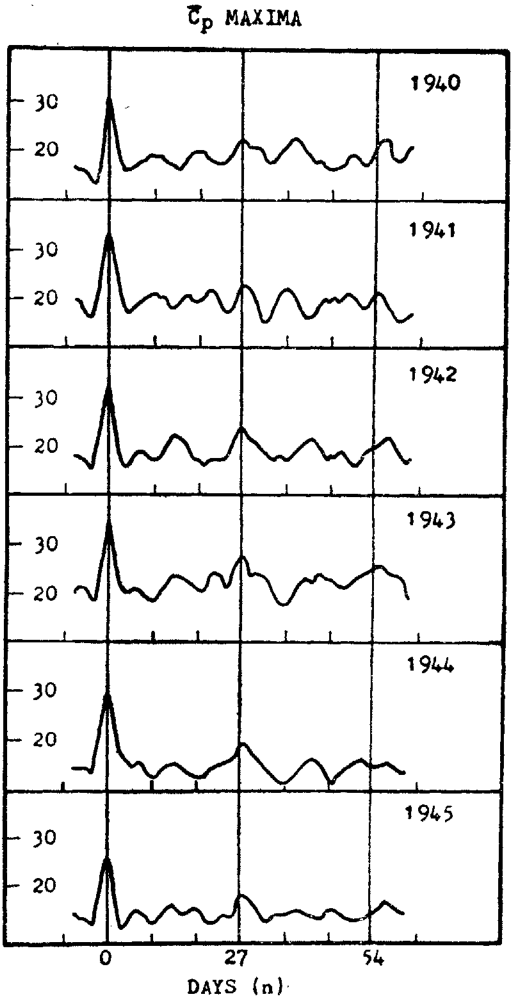

FIG. 4. Chree-type diagrams for C_p maxima.

TABLE II.

Percentage frequency distribution of the $D-N$, $E-M$, $|r|$ and C_p maxima.

Period	1937-38-39		1940-41-42		1943-44-45	
Frequency f	1	2 or more	1	2 or more	1	2 or more
$D-N$ maxima	47	53	52	48	60	40
$E-M$ maxima	39	61	52	48	47	53
$\|r\|$ maxima	47	53	46	54	52	48
C_p maxima	..	..	34	66	28	72

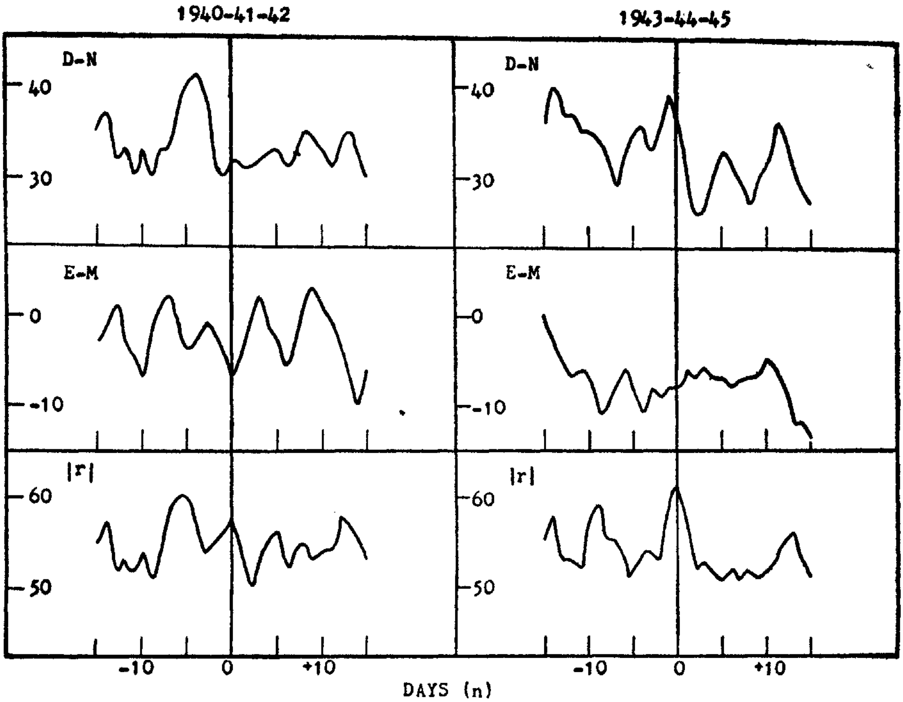

Fig. 5. Chree-type diagrams for $D-N$, $E-M$ and $|r|$ values. ($n = 0$ corresponds to C_p maxima.)

C_p of geomagnetic activity also represents a departure from mean in a similar way. Thus, an increased geomagnetic activity could cause large fluctuations in $D-N$ and $E-M$ values but would still remain undetected in a Chree-type analysis where the positive and negative values add up algebraically. It would, however, show in the values of $|r|$ which are obtained by squaring the values of $D-N$ and $E-M$.

V. Conclusion

In conclusion, one may summarize the results of the present investigation as follows:—

(1) At Huancayo, the maxima of $D-N$ and $E-M$ which represent the components of the vector representing the daily variation of cosmic ray intensity, in the 6-hour and 12-hour directions, indicate a recurrence tendency of a period of about 27 days.

(2) The two vectors $D-N$ and $E-M$ are not interrelated. The 27-day recurrence tendency in their maxima is not revealed at all times. But in case of some maxima, the recurrences continue for more than one solar rotation.

(3) The recurrence tendency is not equally prominent in all years. No definite relationship with the sunspot cycle can be established.

(4) A phase relationship between the $D-N$ and $|r|$ maxima and the maxima of geomagnetic activity is indicated. The magnitude of the effect is, however, very small, and the phase seems to shift during the course of years. During the sunspot minimum, the maxima of geomagnetic activity appear to coincide with the maxima of the amplitude of the daily variation of cosmic ray intensity.

In a previous communication (Kane, 1955) the author has shown that the recurrence tendency in the daily variation of the nucleonic component of cosmic ray intensity was more prominent in 1953, a year of very low sunspot activity, as compared to that in the previous two years 1951 and 1952. A similar result was obtained for the ionization chamber data from Freiburg. The result of the present analysis is apparently in contradiction with those results. There is reason (Sarabhai *et al.*, 1955) to believe, however, that the form of the daily variation of cosmic ray intensity has changed radically during the period after 1945. In fact, the form of the variation of the amplitude of cosmic ray intensity during the last 18 years is suggestive of a 22-year cycle rather than a 11-year cycle. The present analysis is, therefore, being extended to the Huancayo data for the period after 1945.

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Abstract

The Carnegie Institution data for Huancayo for the period 1937 to 1945 have been analysed for the study of a 27-day recurrence tendency in the daily variation of cosmic ray meson intensity. Quantities $D-N$ and $E-M$ which represent the 6-hour and 12-hour components of the daily variation at Huancayo after allowing for the deflection of cosmic ray particles in the earth's magnetic field are studied separately. Each of the two factors reveals a 27-day recurrence tendency which is not equally prominent in all years and is apparently unconnected with the sunspot cycle. The maxima of $D-N$ and $E-M$ do not seem to be related to each other. A relationship with C_p indices, representative of geomagnetic activity, is also investigated.

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