are interpreted as follows:

$$\pi^- + p \to \Lambda^0 + \theta^0 \quad \text{Cases } D \text{ and } H,$$
$$\to \Sigma^0 + \theta^0 \quad \text{Cases } A, B, G, \text{ and } I,$$
$$\to \Sigma^- + \theta^+ \quad \text{Cases } E, J, \text{ and } K.$$

The positions of observed decay events and the fraction of cases in which both Y and K decays are observed are consistent with previous information on the mean lifetimes of Λ^0 and θ^0.

To determine the total cross section for V-production, it is necessary to estimate the number of V-production cases where the decays were not seen either because they were outside the sensitive region or involved only neutral secondaries. This estimate is very uncertain, but leads to a cross section of $\sim$0.9 millibarn.

Data on angular correlations might be expected to provide some information on the spins of the particles involved. Three effects have been observed: (1) The angle between line of flight of the hyperon and incident π^- in the c.m.s. of the π^--p system (β) shows that the Λ^0 and Σ^0 prefer to travel backward in the c.m.s. The same backwards preference was noted[4] for nucleons from π^--p interactions which lead to emission of pions. (2) For Λ^0 and $Y^\pm$, the angle between production and decay planes (α) is less than 45° in all cases. (3) The angle between incident pion and nucleon from the hyperon decay in the hyperon rest system (γ) has been calculated, but the data are inconclusive because of insufficient statistics. However, the rather striking correlation shown by α may indicate that the spin of the hyperon is at least $\frac{3}{2}$.

We wish to acknowledge the continuing cooperation of the Cosmotron staff and of the other members of the cloud chamber group, without whose support this work would not have been possible.

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Recurrence Phenomenon in the 24-Hour Variation of Cosmic-Ray Intensity*

R. P. KANE†
Institute for Nuclear Studies, The University of Chicago, Chicago, Illinois
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Changes of cosmic-ray intensity in 24-hour intervals were studied at four neutron monitor stations and for one ionization chamber in the geomagnetic latitude range 0°–52° N. There is evidence that the fluctuations in the 24-hour variation of cosmic-ray intensity have a recurrence tendency of 27–28 days. There does not appear to be, however, any unique relationship between this recurrence and the well-known recurrence in the amplitude of the mean daily intensity. The association of this phenomenon with 27 day recurring disturbances in the geomagnetic field is also investigated.

I. INTRODUCTION

IT is now well established that the amplitude and phase of the daily variation of cosmic-ray intensity are not constant. For example, the amplitude and phase of the 24 hourly variation of the nucleonic component undergo large day-to-day changes.[1] The purpose of the present investigation is to determine whether the amplitude of this variation possesses any recurrence characteristics. Also, since the 27-day daily mean intensity variation has been associated with solar processes and since there is evidence[2] that the amplitude of the daily variation follows roughly the pattern of the solar activity cycle, it is further proposed to investigate whether a 27-day recurrence of the daily variational intensity exists and to explore its association with solar induced geophysical phenomena.

II. NATURE OF THE PROBLEM

The principle difficulty in approaching this question is the measurement of the daily amplitude for a single day. Usually, an harmonic analysis is obtained for 24 hourly values (or 12 bi-hourly values) so as to determine the amplitude and phase of the best fitting sine curve. Such a procedure may, however, be incorrect and unreliable due to both the large statistical errors involved in counting rate and the presence of prominent day-to-day variations, e.g., a large 27-day recurrence in the mean daily cosmic ray intensity. Consider, for example, the arbitrary plot in Fig. 1 of cosmic-ray intensity over a period of 5 consecutive days. A, B, C, and D represent respectively the four 6 hourly intervals, 0000 to 0600, 0600 to 1200, 1200 to 1800, and 1800 to 2400 hours local time. An harmonic analysis for the 24 hourly values of day 1 and 2 would yield an hour of maximum late at night, and, for days 4 and 5, early in the morning. The amplitudes would be greatly affected by the average slopes of the day-to-day variation. Clearly, the essential features of the daily variation

* Assisted by the Office of Scientific Research, Air Research and Development Command, U. S. Air Force.
† Fulbright and U. S. Government scholar from India.
[1] Firor, Fonger, and Simpson, Phys. Rev. 94, 1031 (1954).
[2] V. Sarabhai and R. P. Kane, Phys. Rev. 90, 204 (1953).

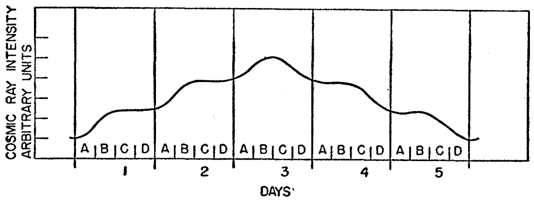

FIG. 1. Arbitrary plot of hourly values of cosmic-ray intensity for five consecutive days.

would thus be greatly distorted by the presence of a prominent systematic variation of the mean daily intensity.

However, for study of the recurrence phenomenon in the amplitude of daily variation in this paper, a precise determination of the hour of maximum intensity is not required. As a first approximation, it is sufficient to know whether the maximum occurred in the daytime or in the night time. This can be determined by taking the difference between the total counting rates of the day hours and night hours. The magnitude and sign of the "day minus night" intensities may be taken as representative of the amplitude and phase, respectively, of the daily variation.

To avoid distortions due to systematic day-to-day variations of mean daily intensity, the following procedure was adopted:

(a) The day intensity was defined as the 12-hour interval $B+C$, i.e., 0600 to 1800 hours local time and designated as D. The night intensity was defined as the sum of the two 6 hour intervals A and D, on either side of the day interval, and designated as N. Thus the difference, $D-N$, would be independent of any straight slope of the day-to-day variation such as for day 1 and 2, or 4 and 5. A dependence on slope would still persist in day 3 which happens to be at the peak of the mean daily variation.

(b) The value of $D-N$ for each day was expressed as a percentage of the $D+N$ value of the same day, for the following reason. The mean daily intensity $D+N$ is known to undergo fluctuations with a 27-day recurrence tendency. If the fractional changes during the day and night are the same at all times, the $D-N$ values would tend to increase for days at the maximum of the mean daily intensity $D+N$. This effect would be reduced by using the percentage $100(D-N)/(D+N)$.

If the $D-N$ values are independent of the $D+N$ variations, this procedure would introduce false recurrence tendencies in the $(D-N)/(D+N)$ values. However, the magnitude of the false recurrences would be about the same as the magnitude of the fluctuations in $D+N$ values, which is about ± 5 percent or less. The percentage amplitude of the 24 hour variation varies in the limits of about $+1$ percent to -1 percent. The maximum errors involved would, therefore, be about ± 0.05 percent. During years of low solar activity, this error will be still reduced, since the fluctuations in $D+N$ values hardly exceed ± 1 percent, as shown later in this paper.

(c) Averages over three consecutive days were evaluated and taken as representative of the middle day. Thus for any day 0, the percentage daily amplitude was represented by

$$\frac{1}{3}\sum_{n=-1}^{n=+1}\left\{\frac{100(D-N)}{D+N}\right\}_n.$$

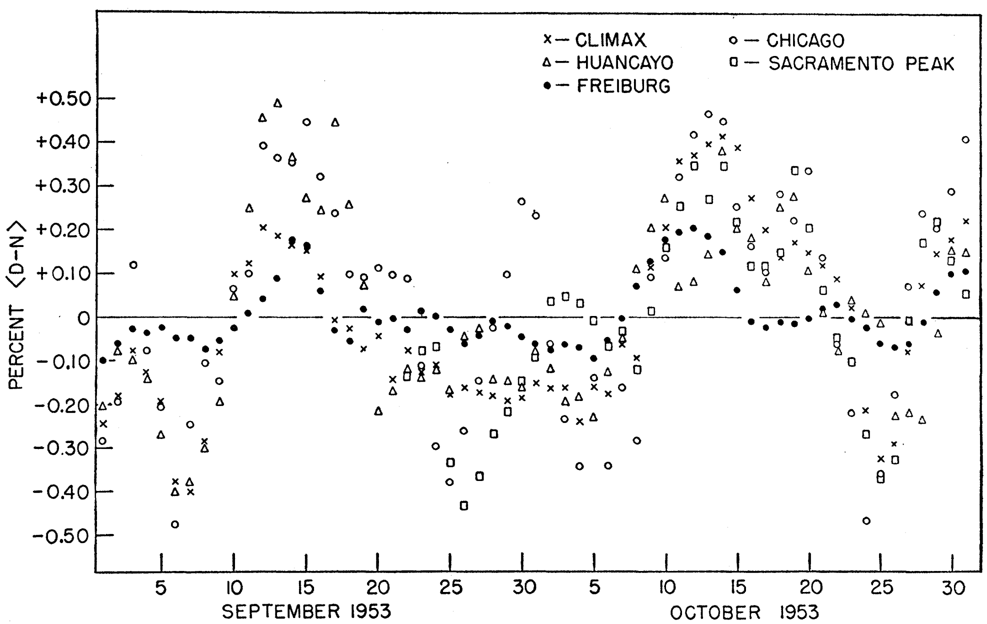

FIG. 2. $\langle D-N\rangle$ values for the neutron piles at Climax, Chicago, Sacramento Peak, and Huancayo, and the ionization chamber intensity at Freiburg, for September and October, 1953.

TABLE I. Correlation coefficients among the $\langle D-N\rangle$ values at various stations.

Year and months	Climax and Sac. Peak	Climax and Chicago	Climax and Huanc.	Climax and Freib.	Sac. Peak and Chicago	Sac. Peak and Huancayo	Sac. Peak and Freiburg	Chicago and Huanc.	Chicago and Freib.	Huanc. and Freib.
1951										
May–Jun.	+0.54	+0.13		+0.54	−0.14		+0.66		−0.09	
Jul. –Aug.	+0.67	+0.33		+0.44	+0.20		+0.36		−0.01	
Sep. –Oct.	+0.24	+0.24		+0.23	+0.11		−0.27		−0.25	
Nov.–Dec.	+0.60	+0.47		+0.33	−0.12		+0.53		+0.12	
1952										
Jan. –Feb.	+0.51	+0.32	+0.62	+0.70	+0.04	+0.33	+0.28	+0.24	+0.41	+0.64
Mar.–Apr.	...	+0.28	+0.41	+0.45	...	...	...	+0.14	+0.27	+0.57
May–Jun.	+0.70	+0.69	+0.46	+0.77	+0.38	+0.33	+0.59	+0.35	+0.57	+0.50
Jul. –Aug.	+0.59	+0.27	+0.68	+0.51	+0.32	+0.38	+0.21	+0.11	+0.32	+0.48
Sep. –Oct.	+0.61	+0.48	+0.49	+0.50	+0.50	+0.61	+0.58	+0.25	+0.43	+0.62
Nov.–Dec.	+0.56	−0.15	+0.37	+0.28	−0.15	+0.31	+0.36	−0.08	0	+0.40
1953										
Jan. –Feb.	−0.32	+0.44	+0.44	+0.50	+0.05	+0.26	+0.14	+0.36	+0.31	+0.52
Mar.–Apr.	+0.56	+0.66	+0.57	+0.60	+0.36	+0.45	+0.28	+0.26	+0.52	+0.33
May–Jun.	+0.31	+0.47	+0.34	+0.54	+0.15	+0.21	+0.60	+0.28	+0.33	+0.65
Jul. –Aug.	...	+0.61	+0.69	+0.79	...	...	...	+0.40	+0.32	+0.48
Sep. –Oct.	+0.92	+0.84	+0.77	+0.83	+0.83	+0.50	+0.58	+0.66	+0.62	+0.60
Nov.–Dec.	+0.56	+0.58	+0.17	+0.50	+0.21	+0.11	−0.04	+0.18	+0.49	−0.08

This reduces statistical errors and reduces distortions in days at the maxima (e.g., day 3 in Fig. 1) or minima of variations in the mean daily intensity.

The quantity

$$\frac{1}{3}\sum_{n=-1}^{n=+1}\left\{\frac{100(D-N)}{D+N}\right\}_n$$

will be designated, hereafter, as $\langle D-N\rangle$ for convenience. $\langle D-N\rangle$ values have been obtained for the neutron detector stations at Climax, Chicago, and Sacramento Peak (for May, 1951 to December, 1953), and Huancayo, Peru (for January, 1952 to December, 1953). To investigate the problem at higher mean primary particle energy, the ionization chamber data[3] from Freiburg, Germany, have also been analyzed in the same way.

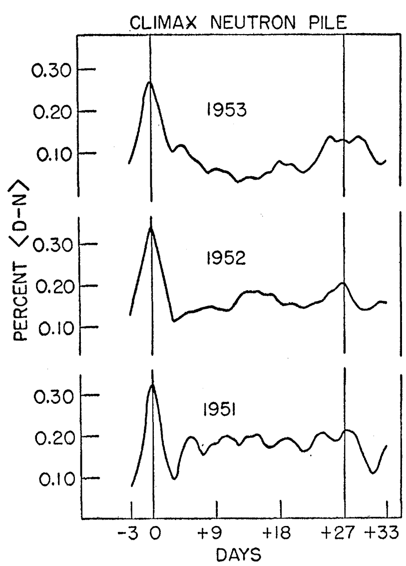

FIG. 3. Chree type diagram for Climax $\langle D-N\rangle$ maxima.

III. EXPERIMENTAL RESULTS

(a) Recurrence Properties of the Amplitude of the 24-Hour Variation

Any recurrence phenomenon in a cosmic-ray intensity variation which is to be attributed to a variation in the total primary cosmic radiation must satisfy the condition that the variation is observed throughout the world. There has been increasing evidence over the past few years that this condition is satisfied for the amplitude changes in the daily intensity variation, provided the observations are compared in local time. Additional evidence will be presented here to demonstrate that the data used in this paper fulfill these requirements.

For example, Fig. 2 shows the $\langle D-N\rangle$ values for the neutron piles at Climax, Chicago, Sacramento Peak, and Huancayo, and the ionization chamber at Freiburg for the period September through October, 1953. This is an interval of rather good agreement.

To investigate this point further, a correlation analysis was carried out between the $\langle D-N\rangle$ values for the different pairs of observing stations using successive bi-monthly periods. Table I gives the values of the correlation coefficients between pairs of observing stations.

Although there is good evidence that the 24-hour variations are worldwide in character, it is obvious from Table I that the tracking between pairs of the various stations is not perfect. This imperfect tracking is associated with the following difficulties:

[3] Data obtained by A. Sittkus of the University of Freiburg are published quarterly in "Sonnen-Zirkular" of the Fraunhofer Institute, Freiburg I.B., Germany.

(1) In 1951, both Chicago and Climax neutron piles had low counting rates.

(2) Since it is well established that the amplitude changes day by day, stations at different geomagnetic longitudes observe slightly different amplitudes due to different local times. The fact that the 24-hour variation is principally due to charged particles enhances these differences for stations at different geomagnetic latitudes.

To investigate the main problem of searching for a recurrence tendency in the $\langle D-N\rangle$ maxima at any station, the Chree type of analysis was adopted.[4] It consists in designating a day of $\langle D-N\rangle$ maximum as day 0, and writing down the $\langle D-N\rangle$ values for days $n=-3$ or less to $n=+33$ or more. All maxima within the period under study are superposed on $n=0$ and the values for each of the other days are added separately. The superposition of data for days -3 to $+33$ gives the Chree diagram where the maximum value is at $n=0$ and the day of any *other* maximum (if any) indicates the recurrence period in days.

Since the correlations among the various stations are not always high, it has not been possible to select individual days on which all the stations simultaneously display $\langle D-N\rangle$ maxima. Hence the selection of $\langle D-N\rangle$ maxima to form the set of $n=0$ days has been carried out independently for each cosmic-ray station. The total number of maxima in any year for each of the stations was about 30.

Figures 3, 4, 5, 6, and 7 show the Chree type diagrams for each of the observing stations for different years.

The principle features of the Chree diagrams for $\langle D-N\rangle$ maxima may be summarized as follows:

(1) The $\langle D-N\rangle$ values show a 27–28 day recurrence tendency at all stations.

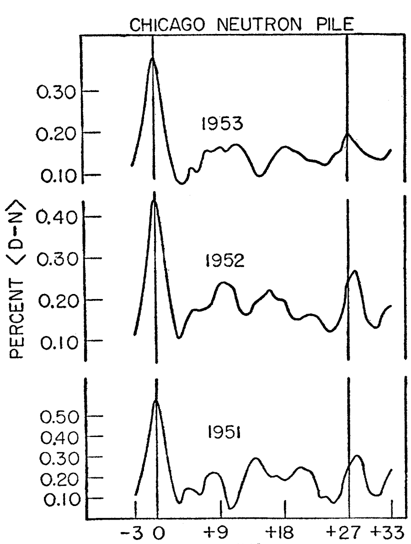

FIG. 4. Chree type diagram for Chicago $\langle D-N\rangle$ maxima.

[4] C. Chree, Trans. Roy. Soc. (London) **A212**, 75 (1913).

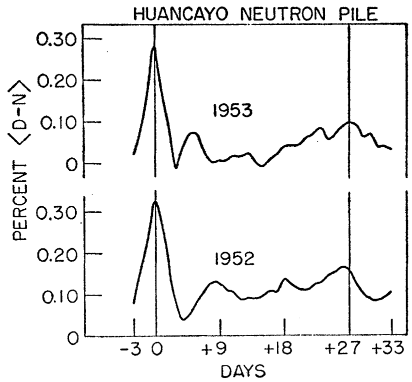

FIG. 5. Chree type diagram for Huancayo $\langle D-N\rangle$ maxima.

(2) The range of the $\langle D-N\rangle$ values, i.e., the difference between the maximum and minimum values of $\langle D-N\rangle$ in the 27-day recurrence, is about the same for 1951, 1952, and 1953. Thus, the magnitude of the changes in $\langle D-N\rangle$ values seems to remain about the same over the three year period.

(3) The maximum values of $\langle D-N\rangle$ at $n=0$ seem to be smallest in absolute magnitude in 1953. Also, the average $\langle D-N\rangle$ value for a 27-day cycle is smaller in 1953 than in 1951 or 1952.[5]

(4) The observed 27-day recurrence in 1953 seems to be more pronounced than in 1951 or 1952.

Whether the *maxima* of $\langle D-N\rangle$ values or the *minima* are more important for a physical interpretation of this 27-day recurrence, depends upon which particular hypothesis is invoked to account for the origin of these variations. To check whether one could give more im-

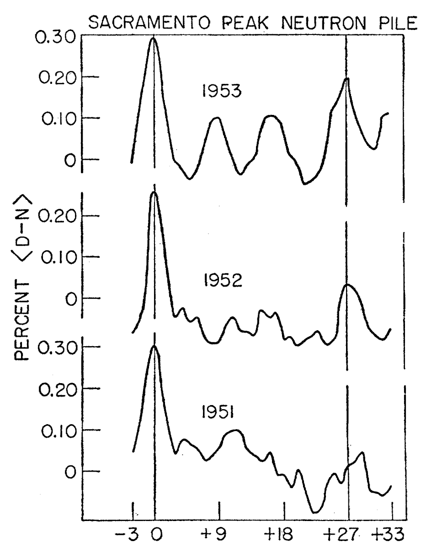

FIG. 6. Chree type diagram for Sacramento Peak $\langle D-N\rangle$ maxima.

[5] This is in agreement with the results of Sarabhai and Kane (see reference 2) who report a tendency of the daily amplitude to be smaller at the time of sunspot minimum.

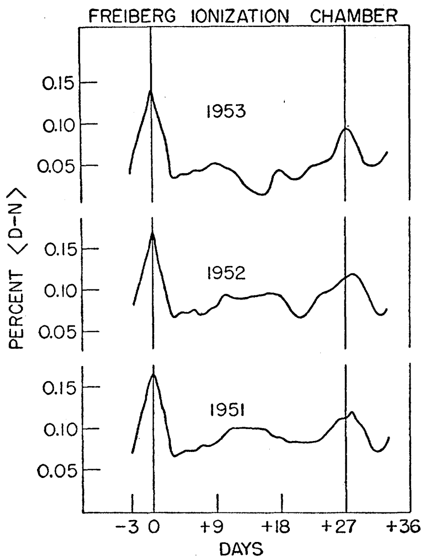

FIG. 7. Chree type diagram for Freiburg ⟨D−N⟩ maxima.

portance to the maxima or the minima from the experimental data alone, a Chree analysis was also carried out for the *minima* of ⟨D−N⟩ values using data from the Climax neutron pile. Figure 8 shows the Chree diagrams for the Climax neutron pile with ⟨D−N⟩ minima as $n=0$ days. Since all minimum values are at $n=0$, the sign of the ordinate scale is reversed.

Clearly, the ⟨D−N⟩ minima show similar characteristics to the ⟨D−N⟩ maxima.

(b) Association with Geophysical and Solar Phenomena

The daily mean intensity of cosmic rays is known to have a recurrence tendency of about 27 days. This is shown in Fig. 9 for the mean daily intensity of $D+N$ obtained from the data used in this paper. The recurrence tendency decreases in successive years 1951, 1952, 1953. Since the ⟨D−N⟩ values also possess a 27-day recurrence, the question arises as to whether the two variations are related in some way. Since, as pointed out in Sec. II above, the ⟨D−N⟩ values used in the present analysis are expressed as percentages of the $D+N$ intensity, the 27-day recurrence tendency in ⟨D−N⟩ values is not the induced effect of a 27-day recurrence in $D+N$ intensity.

To determine whether there was any meaningful phase relationship between the two variations, a Chree analysis was carried out for the Climax neutron pile. The days for which the mean daily intensity $D+N$ had maximum values were selected as $n=0$ days. The ⟨D−N⟩ values were written down for $n=-3$ to $n=+33$ and the superposition was carried out for all the $n=0$ days of $D+N$ maxima in any particular year. These Chree diagrams are shown in Fig. 10.

It is obvious from Fig. 10 that the ⟨D−N⟩ values do not show any unique phase relationship with the $D+N$ maxima for any year.

Geomagnetic disturbances are known to possess a pronounced 27-day recurrence as a consequence of their association with solar phenomena. The K_p index of geomagnetic activity has been established to represent the degree of the worldwide disturbance. This recurrence is illustrated for the period 1951 through 1953 in Fig. 11 as a 27-day calendar. Each row represents a period of 27 days between the vertical lines $n=0$ and $n=27$. Starting in January, 1951, successive 27-day intervals are represented by successive rows in Fig. 11. The dates corresponding to days $n=0$ are given at the left of the diagram. The days on which the K_p index

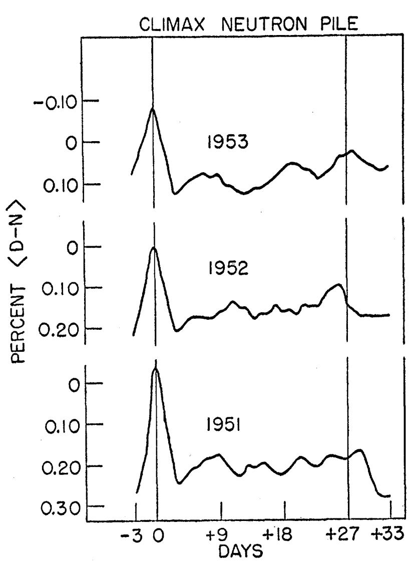

FIG. 8. Chree type diagram for Climax ⟨D−N⟩ minima.

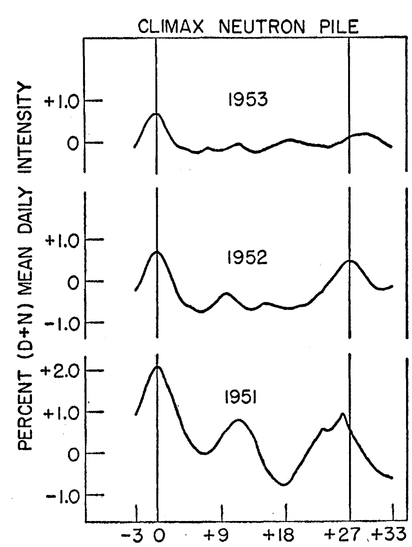

FIG. 9. Chree type diagram for Climax mean daily neutron intensity $D+N$ maxima.

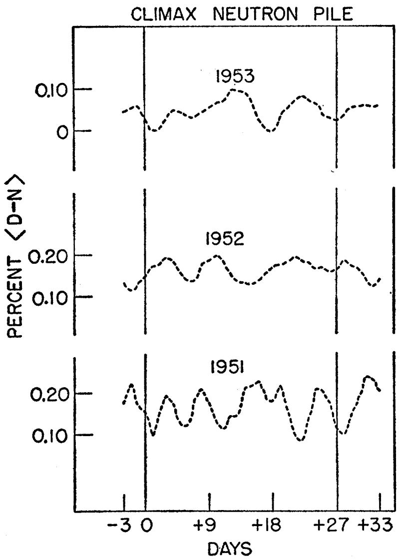

Fig. 10. Chree type diagram for Climax $\langle D-N \rangle$. The "0" day corresponds to Climax mean daily intensity maxima.

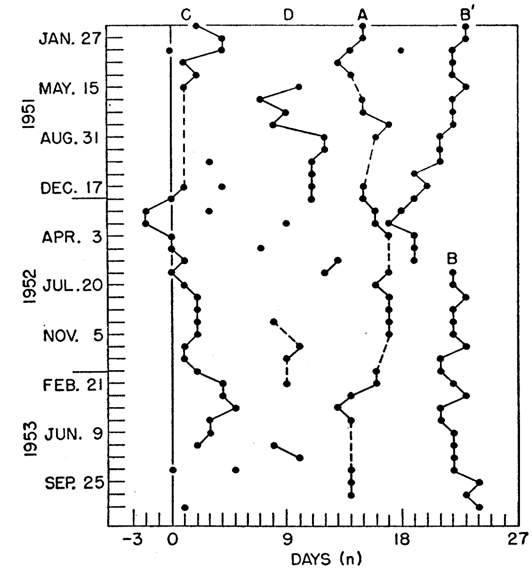

Fig. 11. Location of K_p maxima on a 27-day calendar.

attained maximum values are denoted by circular dots. In general, five 27-day sequences may be identified for the period under consideration. These are indicated as A, B', B, C, and D in Fig. 11. Sequence B may be a continuation of sequence B'.

To study the phase relationship between these 27-day sequences of K_p maxima and the $\langle D-N \rangle$ and $D+N$ values of cosmic-ray intensity, a Chree analysis was carried out separately for $\langle D-N \rangle$ and $D+N$ values, selecting for $n=0$ the days of K_p maxima belonging to one 27-day sequence at a time for 1951, 1952 and 1953 separately.

The results may be summarized as follows:

In general: (1) Not every 27-day sequence of K_p maxima is preceded by $D+N$ maxima. (2) Not every 27-day sequence of K_p maxima is associated with $\langle D-N \rangle$ maxima.

However, for some periods and for some of the sequences of K_p maxima: (1) The K_p maxima are preceded by $D+N$ maxima by about three days. (2) The maxima of $\langle D-N \rangle$ coincide with the maxima of K_p values.

These latter statements are specially borne out for sequence D in 1951, sequence C in 1952, and sequence B in 1953 for data from the neutron monitor stations at Climax and Huancayo.

IV. CONCLUSION

There is evidence that the fluctuations in the amplitude of the 24-hour variation of cosmic-ray intensity have a recurrence tendency of 27–28 days. Recurrence tendencies of the same period are known to exist in the mean daily intensity of cosmic rays. However, at present there does not appear to be any unique relationship between the mean daily intensity and the amplitude of the 24-hour variation.

Phase relationships with the 27-day recurrence phenomenon in the intensity of geomagnetic disturbances, represented by worldwide K_p indices, have also been studied. Though, in general, it is not possible to identify a phase relationship of *all* the K_p maxima with either the daily mean cosmic-ray intensity or the amplitude of the 24-hour variation, it seems to be true for particular 27-day sequences of K_p maxima that the maxima of the daily mean cosmic-ray intensity precede the K_p maxima by about three days whereas the maxima of the amplitude of the 24-hour variation of cosmic-ray intensity coincide with the maxima of K_p values. This latter relation is in agreement with the reports of some observers who find increases in the amplitude of the 24-hour variation of cosmic-ray intensity on magnetically disturbed days.[6,7]

The author is deeply grateful to Professor J. A. Simpson for guidance and helpful discussions during the course of this investigation. Thanks are due to the computation group for computational help. The author is also indebted to the Department of State (U. S. A.), the U. S. Educational Foundation and the Institute of International Education for the grant of a scholarship.

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[7] H. Elliot and D. W. N. Dolbear, J. Atm. and Terrest. Phys. **1**, 205 (1951).