Recurrence Tendency of Geomagnetic Activity during the Current Sunspot Minimum

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(*Received 17 August 1954*)

ABSTRACT. Geomagnetic activity during the three year period June 1950—June 1953, has been analysed and found to consist mainly of two very long sequences of recurrent (27-day period) moderate geomagnetic storms. During the three year period there have been 40 recurrences of one of these sequences (called the *A* sequence) and 21 recurrences of the other sequence (called the *B*-sequence). Moreover these sequences have continued beyond the period studied. Each sequence exhibits a periodic variation in its activity with a period of one year. For the *A*-sequence the maxima lie near September and minima near March; whereas for the *B*-sequence the maxima lie near March and minima near September. The explanation of this variation is found to lie in the tilt of the solar axis of rotation to the ecliptic; the heliographic latitude of the earth attains its maximum positive and negative values on 7 September and 5 March respectively. The *M*-region responsible for these long sequences are located above $7°·2$ heliographic latitude and separated by about 130° in longitude. The *M*-region associated with the *A*-sequence lies in the northern hemisphere and the other one in the southern hemisphere.

1. Introduction

It is well known (Chree and Stagg 1927, Greaves and Newton 1928) that moderate geomagnetic storms tend to recur after 27 days. Such storms are not related to sunspots, are almost always of gradual commencement type, and are usually well-marked only during the few years immediately preceding the minimum of sunspot activity. On days which are commonly termed "magnetically disturbed", the activity of the earth's field as denoted by the international character figure C, lies between 1 and the maximum activity of 2, although the days for which the C-figure is not much lower than 1 are far from quiet. A number of sequences of moderate geomagnetic storms, sometimes consisting of as many as seven or eight individual storms separated by 27 days have been reported in the literature. Since the 27-day period corresponds to the sun's synodic period of rotation, Bartels (1932) suggested that the storms are caused by the emission of a continuous stream of particles from certain hypothetical disturbed regions on the sun which he called *M*-regions. Several attempts have been made to identify the *M*-regions with visible phenomena in the solar corona and on the disc, such as coronal *C*-regions (Waldmeier 1939, 1942, 1950; Shapley and Roberts 1946; Smyth 1952) coronal streamers (Allen 1944; Kiepenheuer 1952), bright hydrogen and calcium flocculi as sources of ultra-violet light (Richardson 1951), Wulf and Nicholson 1948), prominences and dark filaments (Kiepenheuer 1947, Waldmeier 1947), and sunspot groups associated with intense radio emission in the metre wave length band (Maxwell 1952). Most workers agree that the recurrent storms are caused by a stream of corpuscles sweeping the earth. It has also been believed generally that after about seven or eight recurrent storms of moderate activity have taken place, the sequence

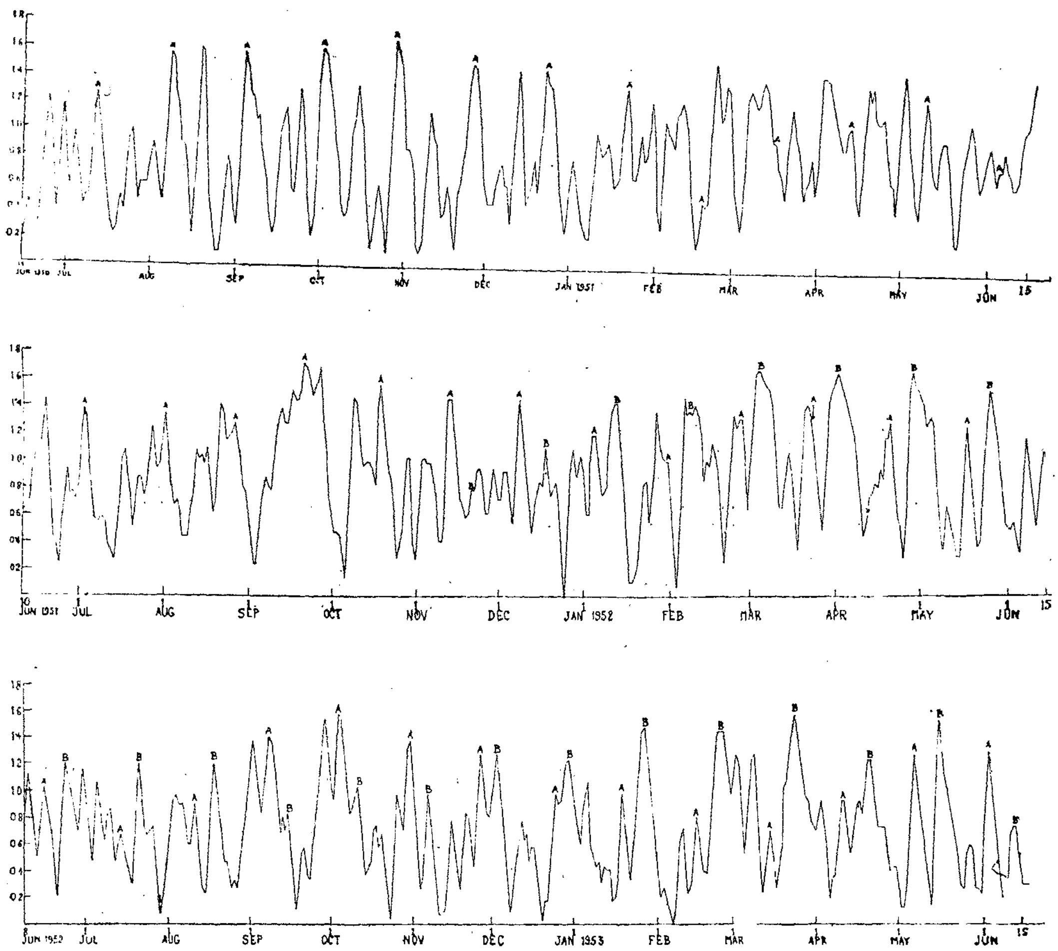

Fig. 1

terminates and the M-region responsible for the recurrent disturbances becomes inactive. As a result of the investigation reported here, we find that M-regions are very much longer lived than it has hitherto been supposed. The recurrent type of geomagnetic activity after remaining well-marked for a few recurrences diminishes to such proportions that it can no longer be classified as a storm, although it may still remain appreciable. Furthermore, after a few 27-day recurrences of rather low activity, the storm-like conditions appear again and the continuity of the sequence is maintained.

2· Analysis of Geomagnetic Activity

The 3-day running means of the C-figures of geomagnetic activity for the 3 year period 1950-53 have been plotted in Fig. 1. The C-figure values have been taken from the C.R.P.L.F-Series bulletins published by the National Bureau of Standards, Washington D. C. Prior to June, 1950, the sunspot activity was comparatively high and no well marked periodicity was discernible. The period prior to June 1950 is, therefore, omitted from the present discussion. The 3-day running means are plotted because the day to day variations of the activity are appreciable and tend to mask to some degree

TABLE 1

Dates of maximum activity of *A*-sequence

S. No.	Date	*C*-figure	Days
1	15- 6-50		..
2	12- 7-50	1.4	27
3	8- 8-50	1.8	27
4	5- 9-50	1.6	28
5	2-10-50	1.7	27
6	28-10-50	1.8	26
7	26-11-50	1.6	29
8	24-12-50	1.5	28
9	22- 1-51	1.6	29
10	18- 2-51	0.6	27
11	16- 3-51	1.0	26
12	13- 4-51	1.4	27
13	10- 5-51	1.4	27
14	6- 6-51	1.1	27
15	2- 7-51	1.7	26
16	28- 7-51	1.3	26
17	25- 8-51	1.4	28
18	21- 9-51	1.7	27
19	17-10-51	1.7	26
20	13-11-51	1.6	27
21	8-12-51	1.6	25
22	5- 1-52	1.3	28
23	1- 2-52	1.4	27
24	27- 2-52	1.4	26
25	25- 3-52	1.0	27
26	21- 4-52	1.8	27
27	18- 5-52	1.4	27
28	14- 6-52	1.3	27
29	14- 7-52	0.7	30
30	12- 8-52	1.0	29
31	8- 9-52	1.5	27
32	4-10-52	1.7	26
33	31-10-52	1.6	27
34	27-11-52	1.5	27
35	24-12-52	1.3	28
36	19- 1-53	1.2	26
37	16- 2-53	1.0	26
38	15- 3-53	0 7	27
39	11- 4-53	1.1	27
40	6- 5-53	1.4	25
41	2- 6-53	1.5	27

TABLE 2

Dates of maximum activity of *B*-sequence

S. No.	Date	*C*-figure	Days
1	22-11-51	..	..
2	19-12-51	1.2	27
3	13- 1-52	1.5	25
4	8- 2-52	1.4	26
5	5- 3-52	1.7	26
6	3- 4-52	1.7	29
7	29- 4-52	1.7	26
8	27- 5-52	1.6	28
9	23- 6-52	1.3	27
10	21- 7-52	1.4	28
11	17- 8-52	1.4	27
12	14- 9-52	1.2	28
13	11-10-52	1.2	27
14	7-11-52	1.0	27
15	4-12-52	1.4	27
16	30-12-52	1.3	26
17	26- 1-53	1.6	27
18	23- 2-53	1.5	28
19	24- 3-53	1.8	29
20	20- 4-53	1.3	27
21	16- 5-53	1.8	26
22	12- 6-53	0.9	27

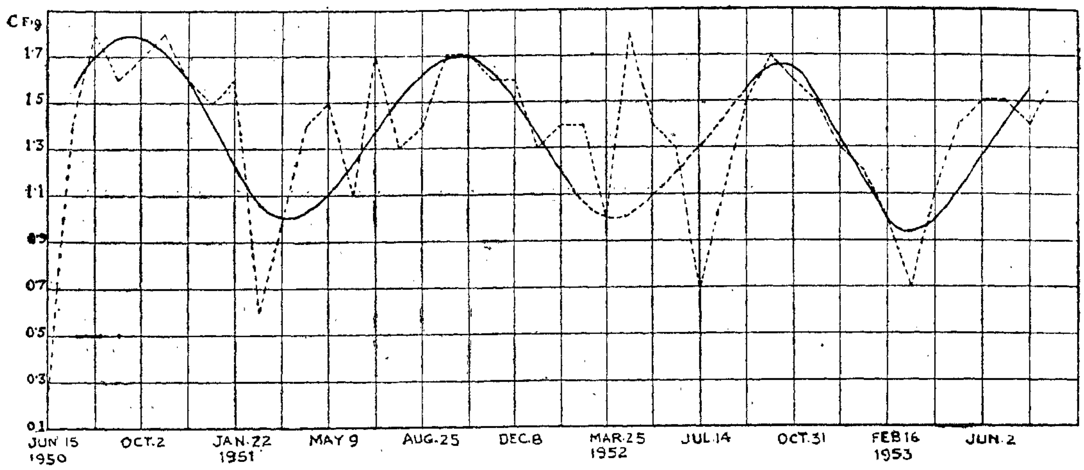
C Fig
1·7
1·5
1·3
1·1
0·7
0·5
0·3
0·1
JUN 15
1950
OCT. 2
JAN. 22
1951
MAY 9
AUG. 25
DEC. 8
MAR. 25
1952
JUL. 14
OCT. 31
FEB 16
1953
JUN. 2

Fig. 2

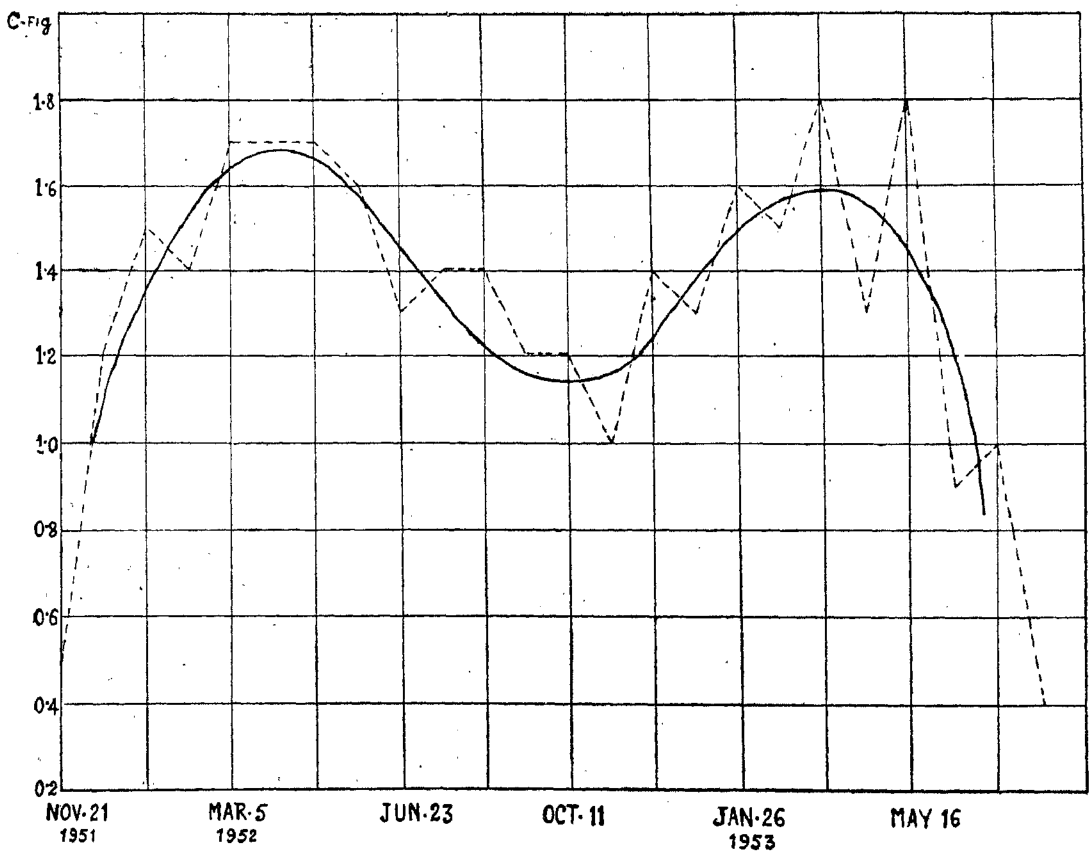
C-Fig
1·8
1·6
1·4
1·2
1·0
0·8
0·6
0·4
0·2
NOV. 21
1951
MAR. 5
1952
JUN. 23
OCT. 11
JAN. 26
1953
MAY 16

Fig. 3

the periodic recurrence of activity. The result of this process of smoothing out is that a certain day of maximum activity may be shifted by one day on either side, large maxima slightly reduced and minima slightly increased. We have verified that beyond the above mentioned effects, the 3-day running means do not introduce any error of a substantial nature. In our subsequent discussion, where we consider the variation of activity within a sequence, we have used the actual *C*-figures rather than the running means. From Fig. 1 we have been able to draw the following conclusions—

(*a*) The 27-day recurrence tendency exists throughout the three year period,

(*b*) The recurrent type of activity consists primarily of only two long sequences which are indicated in Fig. 1 by A and B,

(*c*) There are a few short-lived sequences corresponding to two or more 27-day recurrences,

(*d*) There are a few individual peaks of high magnetic activity.

Many of these isolated peaks are associated with sudden commencement type of storms.

In order to determine the continuity of the long sequence, the following procedure was adopted. When a well-marked increase in the activity was followed after approximately 27 days by a similar increase, the latter has been regarded as part of the sequence to which the former increase belongs. It does not appear necessary that one peak follows another exactly 27 days later as long as the mean periodicity does not differ from 27-days. We have come to this conclusion because of the fact that geomagnetic disturbances are superposed over one another. Moreover, use of 3-day running means may displace a certain peak ± 1 day. The *A* and *B* sequences so obtained will be considered below.

The A-sequence : This sequence starts with the moderate storm of 11-12 July, 1950. Prior to this date, there does not seem to be any trace of this sequence. The first eight peaks of this sequence, between July and December, 1950 have been discussed by Maxwell who associates the *M*-region responsible for these storms with an active coronal region overlying a sunspot group of unusual radio characteristics. The sequence appears to have continued until November 1953, the time of preparation of this paper. The dates of maximum activity for each recurrence of this sequence are tabulated in column 2 of Table 1. Column 3 gives the actual *C*-figures (not the running means) for these dates. Column 4 gives the number of days between successive recurrences.

From Table 1 it can be seen that in most cases the peaks are separated by 27 $\pm$ 1 days. In five cases they are separated by 25 or 29 days and in one case by 30 days. The mean period for 40 recurrences of this sequence is 27.05 days. The data in Table 1 are given upto June 1953 upto which time the international *C*-figures were available when this paper was prepared. Kodaikanal magnetograms, however, indicate that the sequence was well marked upto November, 1953. The dates of the disturbances for the months of June to November, 1953 from Kodaikanal magnetograms are as follows :—

42	29-6-53	45	19-9-53
43	26-7-53	46	16-10-53
44	23-8-53	47	12-11-53

The B-sequence : This sequence of magnetic storms which is shorter than the *A*-sequence, began on 21 November, 1951 and has also continued upto the time of preparation of this paper. The data for this sequence are given in Table 2. As in the case of the *A*-series, the days of maximum activity for the *B*-sequence also fall at intervals of 27 ± 1 days, there being only three occasions when the interval was 25 or 29 days. The mean period for 21 recurrences of this sequence is also 27.05 days. From Kodaikanal magnetograms, there is indication that this sequence also continued beyond June 1953. The activity associated with subsequent peaks was, however, comparatively low.

3. Annual Variation of Geomagnetic Activity

It has been known for a long time that the monthly means of all types of geomagnetic activity exhibit two maxima, in March and September. Bartels (1932) studied this effect for an extensive period of 59 years and confirmed that this type of variation exists for years of high, medium, as well as low sunspot activity. It was, however, difficult to decide conclusively whether the six-monthly periodicity is real, or whether it is made up of two superimposed twelve-monthly periodicities, one having maxima in March and the other in September. Bartels by his harmonic dial method concluded that the six-monthly rather than the twelve-monthly periodicity is physically significant.

A glance at Fig. 1 will show that magnetic disturbances belonging to either sequence exhibit periodic variations. In Figs. 2 and 3 we have plotted the *C*-figures given in Tables 1 and 2 for the *A* and *B*-sequences respectively. These points do not lie on a smooth curve. A geomagnetic disturbance usually lasts two to four days, and there are undoubtedly frequent superpositions of other disturbances which are due to different causes. When such superpositions occur, they may cause two fold errors in our investigation because sometime we may erroneously choose the superposed spurious disturbance for the correct one or because the latter may be completely masked. First there may be an error of $\pm$ 1 or even $\pm$ 2 days in the date of maximum activity. Second the value of the maximum activity, if it belongs to the spurious disturbance, may be quite different from the true value for the sequence. These spurious disturbances seem, however, only to distort the real annual variation effect, and not to obliterate it completely. In order to illustrate the annual trend, a smoothed line has been drawn in Figs. 2 and 3. It has been found that most of the larger deviations between the smoothed and the true curves were due to high magnetic activity resulting from the occurrence of S.C. type of storms almost simultaneously with the recurrent disturbances considered here.

Let us now consider each sequence separately. For the *A*-sequence it can be seen that the activity is high in the months of August, September and October, and low in the months of February, March and April. There seems to be abnormally low activity for the recurrence of 14 July 1952. A 12-monthly periodicity is shown conclusively by the smoothed curve in Fig. 2.

Fig. 3 for the *B*-sequence also shows a 12-monthly periodicity. But the time of maxima and minima are different. High activity occurs around March and low activity around September. In spite of the lack of smoothness of the actual curves, the periodicity is evidently twelve monthly. It, therefore, seems rather likely that the two maxima found in the mean monthly geomagnetic activity may be made up of a number of variations of 12-monthly periodicity, some having maxima in March and others in September.

4. Cause of the Annual Variation

Bartels' (1932) suggestion that the recurrent type of geomagnetic activity is due to corpuscular emission from the hypothetical *M*-regions on the sun is generally accepted in spite of the fact that the nature and location of the *M*-regions still remains unknown. Whatever be the nature of these regions and of the particles emitted from them it is reasonable to assume that the particles are emitted in a circular (or elliptical) cone with axis along the solar radius through the M-region. It seems most likely that the position of the earth in its orbit would be responsible for the annual variation of geomagnetic activity. Two explanations have been put forward to account for this variation. According to one of them (the equinoctial hypothesis) maxima occur depending upon the sun's geocentric position (relative to the earth's equator). On 21 March and 23 September (the vernal and the autumnal equinoxes) the sun lies on the plane of the earth's equator (the declination of the sun is then zero). According to this hypothesis the geomagnetic activity would exhibit two maxima, one about the time of each equinox.

According to the second hypothesis (the axial hypothesis) the cause lies in the earth's heliocentric position (relative to the sun's equator). The tilt of the solar axis of rotation to the ecliptic is $7^{\circ}.2$. The earth is situated on the plane of the solar equator on 6 June and 6 December. In between these dates on 7 September and 5 March respectively, it attains its maximum northerly and maximum southerly heliographic latitudes of $7^{\circ}.2$. This explanation was first put forward by Cortie (1912) according to whom the reason for the equinoctial maxima of the mean monthly geomagnetic activity is that the line joining the sun's centre to the earth is nearest to one or the other of the two zones of sunspot activity in these months ; the sunspots are considered to be associated with the emission of corpuscular radiation. Bartels did not agree with this explanation, but recently Gnevishev and Ol (1946) have supported it on the basis of their work on the increase of geomagnetic activity associated with sunspots.

If we postulate that the intrinsic activity of an M-region remains nearly constant over a period of the order of an year, and that the magnitude of the disturbance will be largest when the line joining the sun's centre to the earth passes closest to an M-region we can draw the following conclusions from the geometry of the situation :

(*i*) If an M-region is located at any heliographic latitude equal to or greater than $7^{\circ}\cdot 2$, north or south, there will be a single yearly maximum of activity around 7 September or 5 March depending upon whether the M-region is in the northern or the southern hemisphere, with the minimum occurring around the other date.

(*ii*) If the heliographic latitude of the M-region is less than $7^{\circ}\cdot 2$, north or south, there will be two maxima of activity equally displaced from 7 September or 5 March, depending upon the hemisphere whether north or south. The amount of displacement depends upon the latitude of the M-region, increasing as the latitude decreases. One of these maxima will be primary and the other secondary.

(*iii*) If the M-region is located on the solar equator, there will be two equal maxima of activity about 6 December and 6 June.

Thus according to the equinoctial hypothesis there will be two maxima in a year, one about 21 March and the other about 23 September, whereas according to the axial hypothesis (provided the latitude of the M-region is greater than $7^{\circ}.2$) there will be one maximum in a year either about 5 March or about 7 September and one minimum about the other date. In the dates of the maxima there is a difference of only 16 days according to the two hypotheses, and the analysis is not refined enough to make a distinction possible on this basis. The crucial factor is therefore the period of variation. Since the period of variation for our long sequences is twelve months, we conclude that, at least in so far as the long sequences of recurrent type of geomagnetic activity are concerned, the axial hypothesis is in good accord with the results of our analysis. Probably this hypothesis also applies to variations in all other types of geomagnetic activity.

5. Location of the *M*-Regions

So far it has not been possible to determine even approximately the location on the sun of an *M*-region supposed to be responsible for a particular sequence of geomagnetic activity. This indeed has been the greatest difficulty in identifying the *M*-region with features on the sun. All investigations on this identification have been attempts to correlate the magnetic storms with the central meridian passage or appearance or disappearance at a solar limb etc of a certain visible feature on the sun. It is obvious that if we know, howsoever crudely the location of an *M*-region on the sun, the task of identification will become simpler. Thus, for example, if we could ascertain that a particular *M*-region lies in the northern hemisphere, we would not attempt to correlate it with features which lie in the southern hemisphere.

Fortunately as a result of the study of the annual variation of activity for our long sequences some information on the heliographic location of the *M*-regions can be obtained although the exact latitude and longitude cannot be described. Since the period of annual variation is twelve months we conclude that the *M*-regions responsible for the long sequence [henceforth called *M*-region (A) and *M*-region (B)] lie at heliographic latitudes higher than $7^\circ \cdot 2$. Further, since the *A*-sequence has maxima about September and minima about March, the *M*-region (A) lies in the northern solar hemisphere, and similarly the *M*-region (B) lies in the southern solar hemisphere. It is not possible to determine the longitude of the *M*-regions. But, since the two sequences are separated by approximately 10 days, it follows that the longitudes of the two *M*-regions are separated by about 130°.

We mentioned earlier that the first eight disturbances of the *A*-sequence are discussed by Maxwell (1952) who associated the *M*-region responsible for the disturbances with an active coronal region overlying a sunspot group of unusual radio characteristics. The latitude of this sunspot group was 18° south. Since the *M*-region (A) is found to be located in the northern hemisphere, Maxwell's suggestion is not in accord with the results of our investigation.

6. Acknowledgement

The authors are grateful to Dr. A. K. Das, Director, Kodaikanal Observatory for his assistance and useful suggestions in the course of this investigation.

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SOLAR INFLUENCE ON BAROMETRIC PRESSURE

During recent years, positive evidence has accumulated to suggest a correlation between upper atmospheric phenomena and weather. Martyn and Pulley (1936) found a significant correlation between ionisation of the E region and barometric pressure at the ground. Gherzi (1950) has reported that the character of ionospheric echoes at a fixed frequency of 6 Mcs sec^{-1} is closely related to the movement of air masses in the China Seas. Abbot (1948) has found that the temperature at Washington is lowered on days of severe magnetic storms. Wulf and Hodge (1950) have observed a relationship between anomalies in the large scale air circulation of the troposphere and those in the upper atmospheric current system that produces the geomagnetic variations. The mechanism by which changes in the upper atmosphere are communicated to the troposphere is far from understood even in a qualitative way.

It is well known that the upper atmosphere is subjected to a marked solar control through changes in the ultraviolet radiation as well as in the corpuscular radiation from the sun. Hence it would be logical to examine whether solar variability could influence the troposphere also through the intermediary of the upper atmosphere.

Duell and Duell (1948) have shown that during the winter season in years of low sunspot activity, sea level barometric pressures at European stations fall to a minimum value 3 to 4 days following magnetically disturbed days, and rise to a maximum 3 to 4 days following magnetically quiet days. They have attempted to explain these relationships as due to the bombardment of the upper atmosphere by the corpuscular radiation emanating from the solar M-regions, and to a resulting chain of complex interactions in the upper atmosphere and the stratosphere.

It is well known, that the solar M-regions have fairly long periods of existence, and as a result of the sun's rotation, geophysical phenomena caused by corpuscular radiation exhibit a tendency for recurrence with a 27-day period. Geomagnetic activity, auroral phenomena and variations in the earth currents may be listed among these. If barometric pressure at the earth's surface were also to be influenced by radiation from the solar M-regions, we should expect it also to exhibit the 27-day recurrence tendency. Such a relation was sought for by the author and has been found. The results of a preliminary investigation in this direction are given below.

The barometric pressure data of many stations in South India for the years 1952 and 1953 (years of low sunspot activity) were examined. The interdiurnal changes of both morning (0300 GMT) and evening (1200 GMT) pressures at several stations showed a tendency for recurrence with a period of about 27 days. In some cases this tendency persisted for a long period covering three consecutive solar rotations. Two such cases are shown in Figs. 1 and 2 in which the 0300 GMT pressures of Madras for the period 13 July to 1 October 1952 and of Tiruchirapalli for the period 1 June to 20 August 1953 ar plotted in rows of 27 days. It will be seen that for the greater part of the 27-day period, the features of the curves undergo well-marked repetitions and these appear, in all probability, to be of solar origin. During these periods chosen, the sunspot activity was low and even this did not exhibit the 27-day recurrence; on the other hand the geomagnetic activity did so thus suggesting that the pressure variations and the magnetic activity were caused by the same solar features, *viz.*, the M-regions. The barometric pressure at Delhi during the winter of 1913-14 (a period of low sunspot activity) was also found to exhibit the recurrence tendency

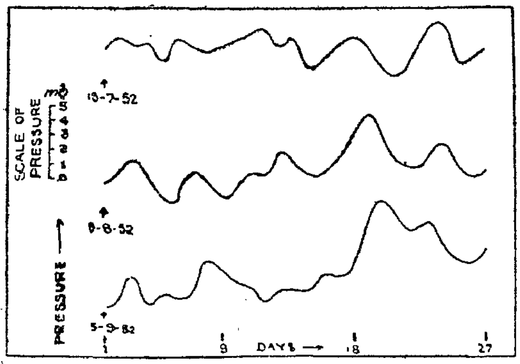

Fig. 1. Variation of 0300 GMT barometric pressure at Madras during the period 13 July to 1 October 1952

This observed solar control of the barometric pressure is in agreement with the statistically deduced findings of Duell and Duell.

Duell and Duell did not find any relationship between solar corpuscular radiation and barometric pressure at European stations during summer. In the present investigation however, using the data of tropical stations, the effect is observed during the summer season as well. This difference in the behaviour of pressure between the high latitudes and the tropics will have to be given due consideration in all attempts at explaining the mechanism by which changes in solar radiation (both corpuscular and ultraviolet) could affect the surface pressure. The possibility of solar M-regions being sources of ultraviolet radiation also, has been suggested by Wulf and Nicholson (1948) and by Das and Bhargava (1953).

During the years 1948 and 1949 when sunspot activity was high, the 27-day recurrence tendency in barometric pressure could not be found. This is what one would probably expect, considering the fact that during such periods the effects caused by the M-regions on the upper atmosphere would be completely masked by those caused by the more active solar phenomena like sunspots, chromospheric eruptions, faculae etc.

The recurrence tendency in barometric pressure seems to hold out some promise

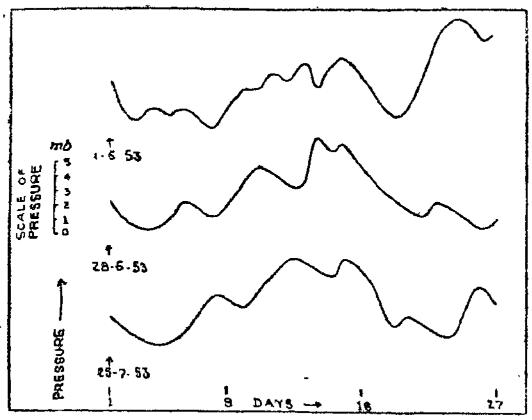

Fig.2. Variation of 0300 GMT barometric pressure at Tiruchirapalli during the period 1 June to 20 August 1953

in long range weather forecasting during years of low sunspot activity. However before any such attempt is made, an examination of extensive weather data will be necessary with the view of studying the solar control of large scale weather systems.

Further investigation of this type is in progress.

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M/L32DGOB—250—8-12-54—GIPS

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ALTITUDE AND AZIMUTH OF THE SUN

The position of the sun in the sky at different hours of the day at any place and its variation in different parts of the year are of considerable interest to architects and building engineers. To meet the requirements of designers of buildings in India diagrams (Figs. 1—6) have been prepared which give the altitude and azimuth of the sun for five particular hours of the day, namely, 0600, 0900, 1200, 1500 and 1800 hrs local apparent time throughout the year at 5° latitude intervals from 5°N to 35°N (excepting Fig. 5, where curves are drawn only at 10° latitude intervals to avoid congestion). The values of altitude and azimuth for any intermediate latitude can be obtained with sufficient approximation by interpolation. A knowledge of the position of the sun at these five specified hours is also sufficient to give a good idea of the diurnal movement of the sun across the sky and to locate approximately the position of the sun at any intermediate hour.

The values of altitude have been calculated with the help of the cosine formula of spherical astronomy :

$$\text{Cos } z = \text{Sin } \phi \text{ Sin } \delta + \text{Cos } \phi \text{ Cos } \delta \text{ Cos } h$$

where z = zenith distance of the sun
=90°—altitude,
ϕ=latitude of the place,
δ=declination of the sun,
h=hour angle of the sun.

The azimuth can also be calculated from a similar cosine formula, but it has been found more convenient for computational purposes to use the four-parts formula :

$$\text{Sin } \phi \text{ Cos } h = \text{Cos } \phi \tan \delta - \text{Sin } h \text{ Cot } a$$

$$\text{or Cot } a = \frac{\text{Cos } \phi \tan \delta - \text{Sin } \phi \text{ Cos } h}{\text{Sin } h}$$

where a = azimuth of the sun. Figs. 2, 3 and 4 give the altitude of the sun at 0600 and 1800, 0900 and 1500, and 1200 hrs local apparent time respectively. Figs. 5 and 6 give the azimuth of the sun at 0600 and 1800, and 0900 and 1500 hrs local apparent time respectively. At 1200 hrs local apparent time the sun will always be on the meridian, its azimuth being either zero or 180° ; at any latitude the azimuth will be zero, *i.e.*, the sun will be north of the zenith for the periods indicated by the dotted portion of the curve for that latitude in Fig. 4, and for the rest of the year the azimuth will be 180°, *i.e.*, the sun will be to the south of zenith.

To determine the position of the sun in the sky at a given place on any day at any of the specified hours, one has to find out from the two relevant figures, which give the altitude and azimuth respectively for that particular hour, the values of altitude and azimuth for that day given by that particular curve which corresponds to the latitude of the place. For example, at 1500 hrs local apparent time on 15 August at a place at 10°N latitude, the altitude (obtained from Fig. 3) is 45° 53′ and the azimuth (obtained from Fig. 6) is 79° 50′ west of north. Again, at 1200 hrs local apparent time on the same day at the same place, the sun will be (as obtained from Fig. 4) at an altitude of 85° 47′ (measured from the south point) on the meridian.

Fig. 1 gives the equation of time. To obtain the local mean time corresponding to any local apparent time, the equation of time for that particular day should be algebraically subtracted from the apparent time. For instance, in the above example the local mean times corresponding to 1500 and 1200 hrs apparent times on 15 August at 10°N latitude, are 15 h 04 m 30 s and 12h 04 m 30 s respectively (the equation of time from Fig. 1 being —4 m 30 s). To convert local mean time to Indian Standard Time, the appropriate longitude correction will have to be applied.

S. R. GANGULY

Kodaikanal Observatory,
Kodaikanal
June 3, 1953.

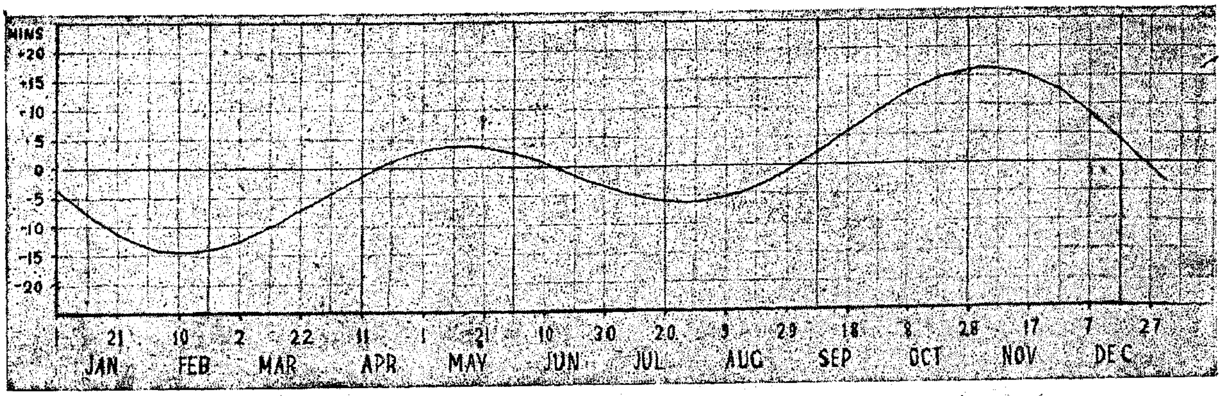

Fig. 1. Equation of time (Apparent—Mean)

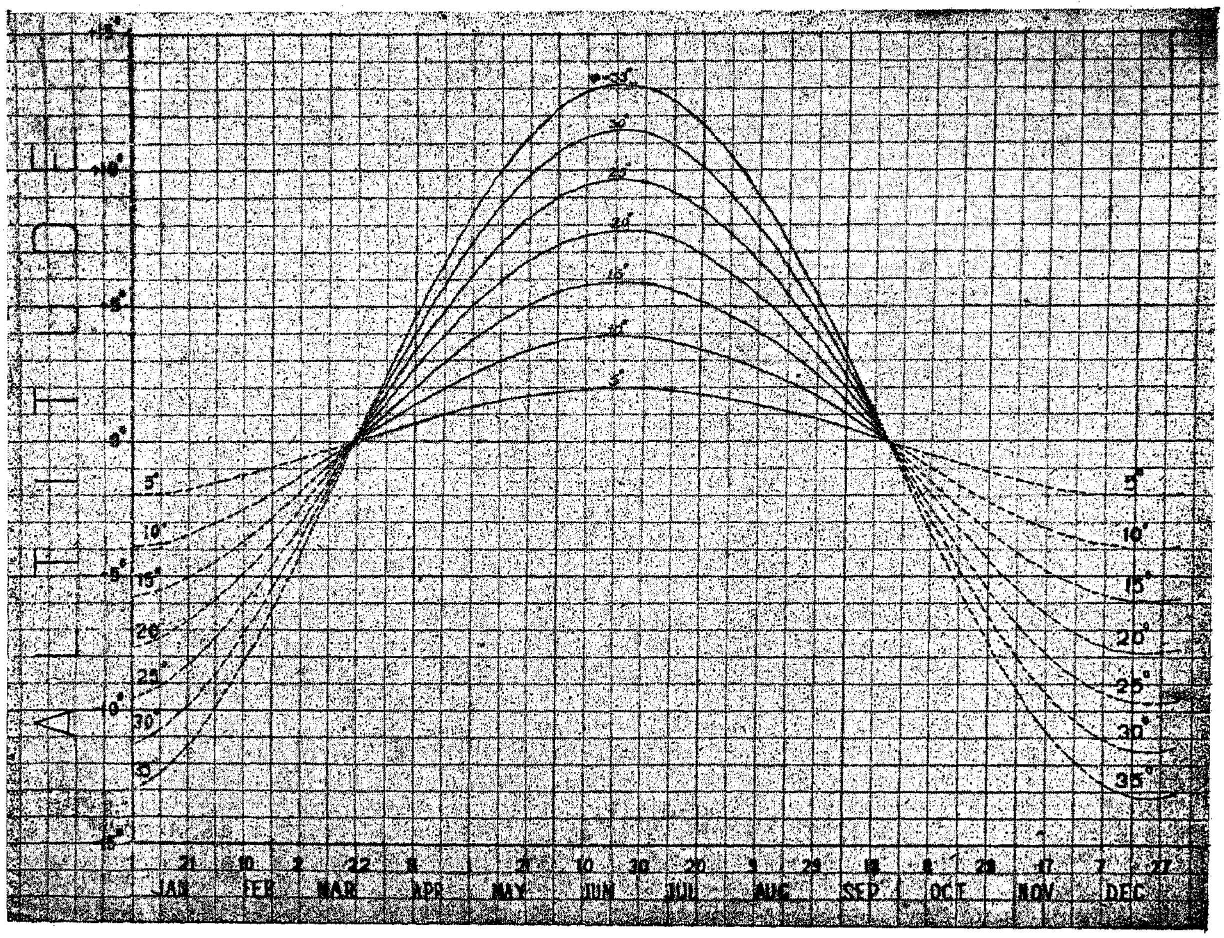

Fig. 2. The altitude of the Sun at 0600 and 1800 hrs Local Apparent Time
(The dotted portion of the curves giving negative altitude indicates that the Sun is below the horizon)

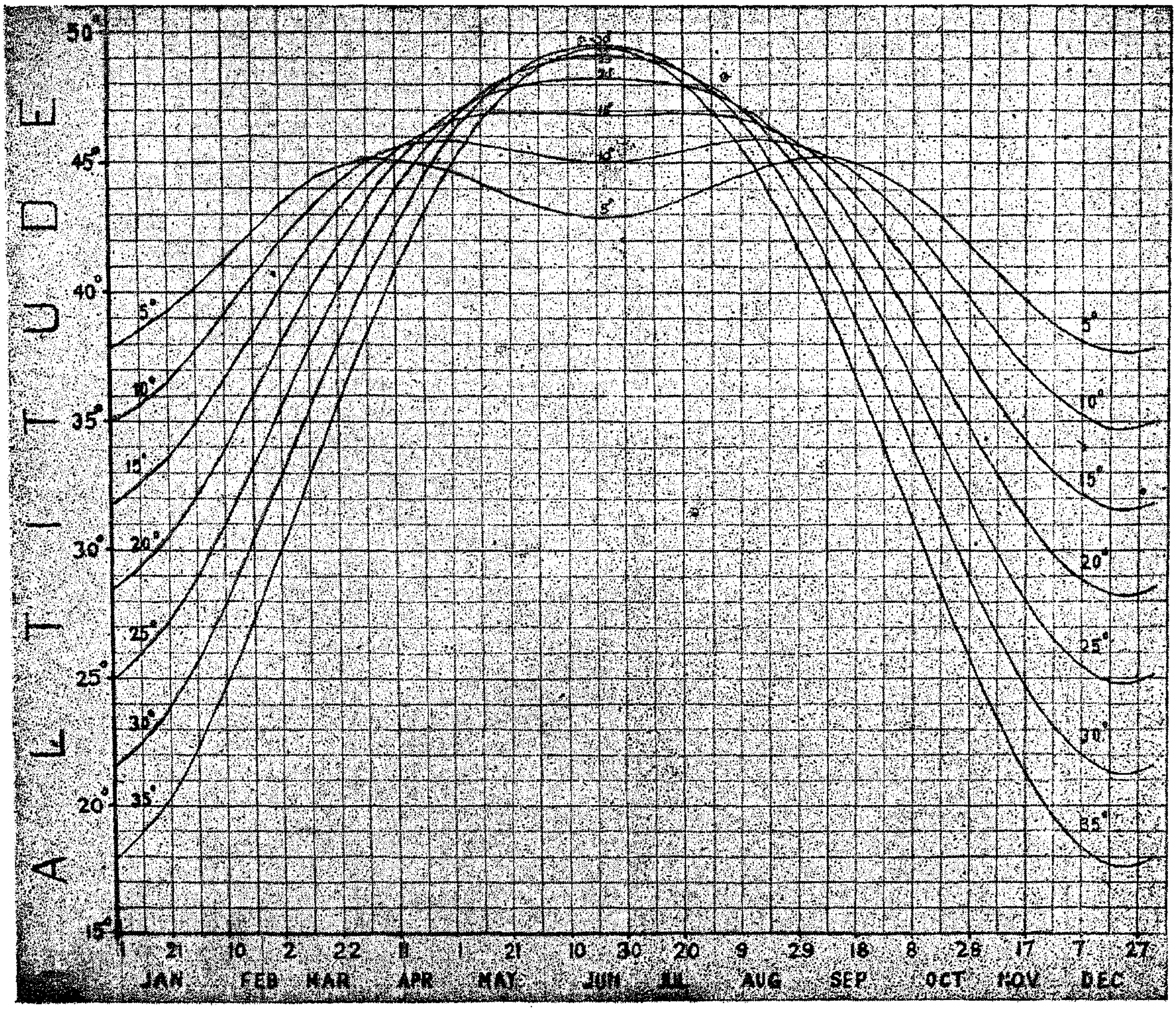

Fig. 3. The altitude of the Sun at 0900 and 1500 hrs Local Apparent Time

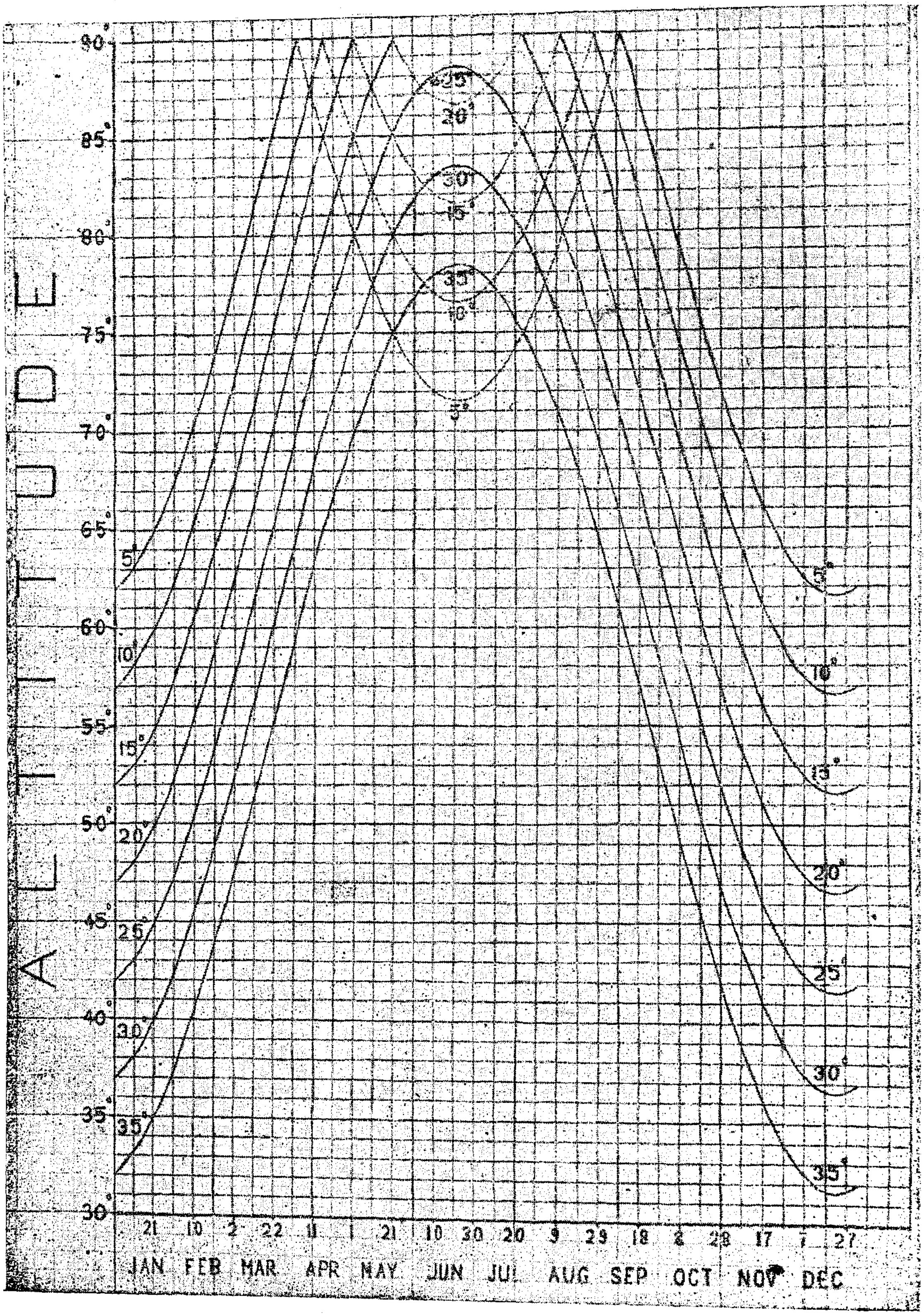

Fig. 4. The altitude of the Sun at 1200 hrs Local Apparent Time
(The altitudes indicated by the dotted portions should be reckoned from the north point of the horizon and those given by the continuous lines from the south point)

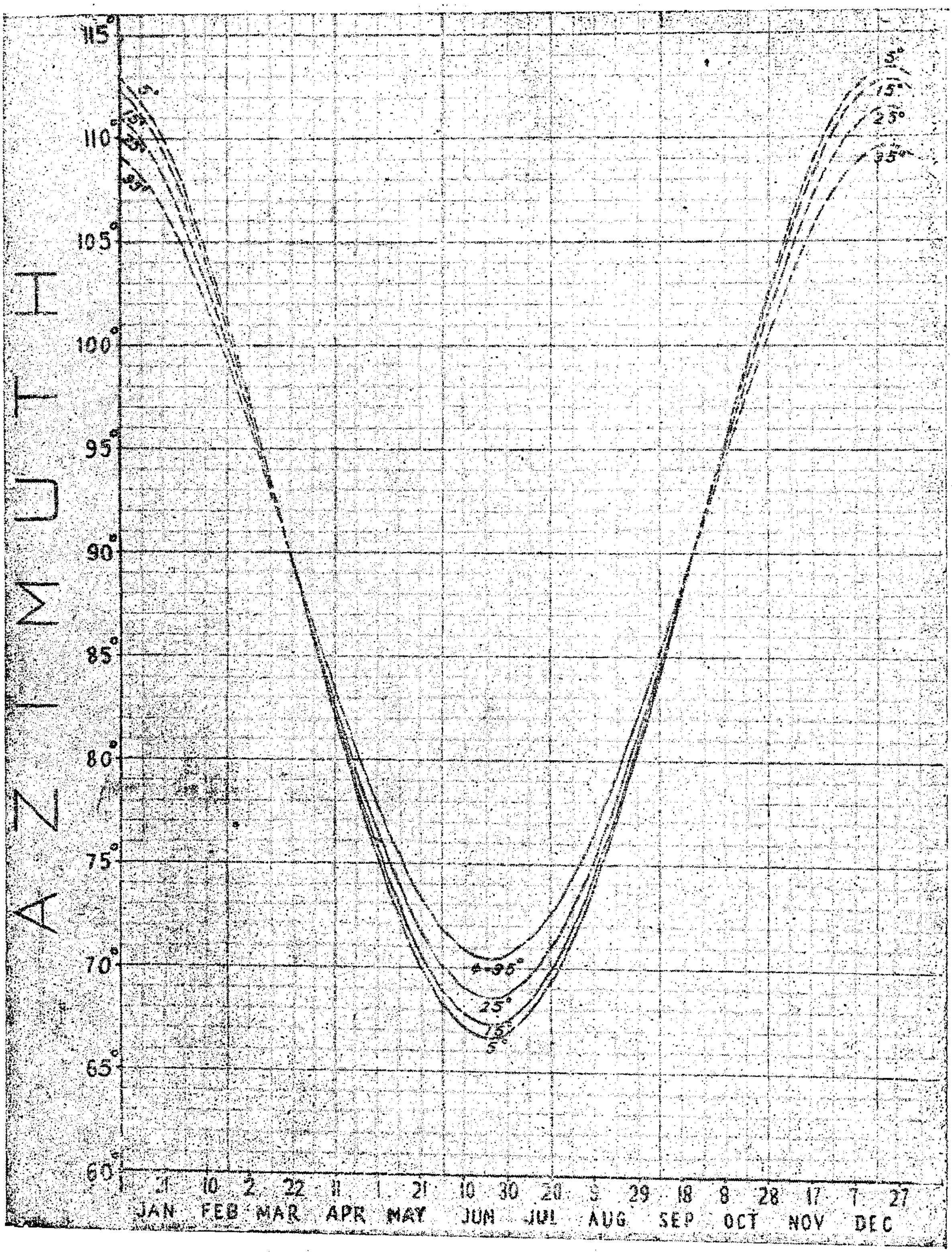

Fig. 5. The azimuth of the Sun at 0600 and 1800 hrs Local Apparent Time

(For 0600 hrs, the azimuth should be reckoned east of north and for 1800 hrs, west of north. The dotted portions indicate that the Sun is below the horizon)

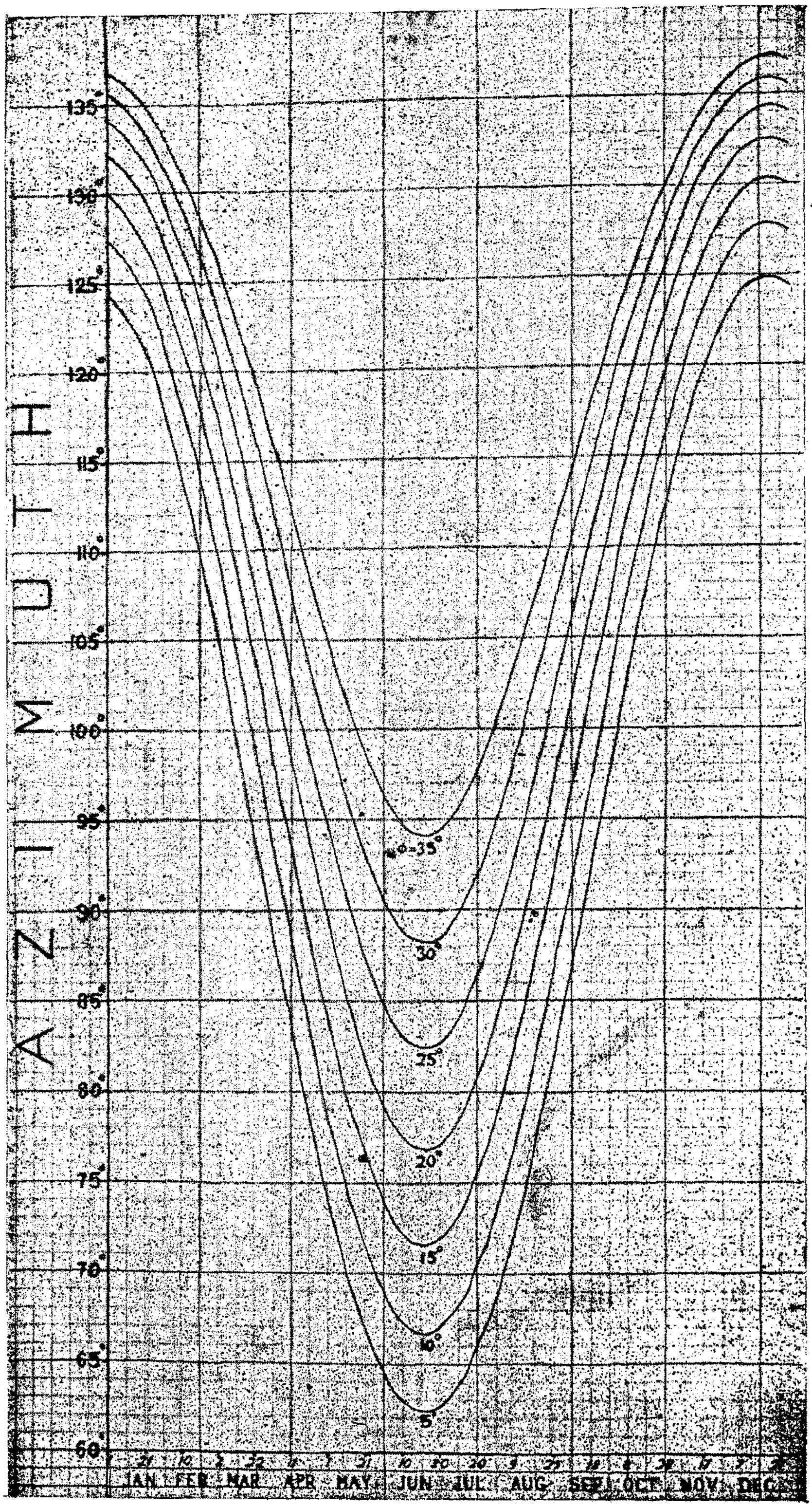

Fig. 6. The azimuth of the Sun at 0900 and 1500 hrs Local Apparent Time

(For 0900 hrs, the azimuth should be reckoned east of north
and for 1500 hrs, west of north)