Reprinted from "The Proceedings of the Indian Academy of Sciences",
Vol. XL, No. 2, Sec. A, 1954

PROMINENCE ACTIVITY (1905-1952)

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Received June 28, 1954

1. INTRODUCTION

IN the field of prominence statistics the Kodaikanal Observatory has a large collection of uniformly worked out data commencing from 1905 till the present time. Since the Memoir published by Mr. and Mrs. Evershed (1917) in which they considered the Kodaikanal prominence data upto 1914, additional data for four more decades have been accumulated. About the time that the Jubilee commemorating fifty years of work of the observatory was celebrated in 1951, the present writer who was working as Assistant Director of the observatory till very recently felt that the time was opportune to undertake a general review and discussion of the prominence data collected since the inception of the observatory, and a detailed survey of the results of solar prominence observations made at Kodaikanal was, therefore, commenced. The material for the study was largely original data contained in a number of registers. (The half-yearly summaries of prominence observations published in the Bulletins of the Kodaikanal Observatory are based on the detailed tabulations maintained in these registers.) The scope of the study embraced both limb and disc prominences (dark markings). As the work progressed, it was felt convenient to deal with it in parts. The first part entitled *Discussion of the Results of Observations of Solar Prominences made at Kodaikanal from* 1904 *to* 1950 is under publication as Bulletin No. 137 of the Kodaikanal Observatory.* This paper which deals only with limb prominences gives an account of the methods of observation and evaluation and also incorporates detailed tables of the distribution of mean daily profile areas of prominences according to heliographic latitudes year by year for the period 1905 to 1950. Various aspects of prominence activity during the period such as comparison of the northern and southern hemispheres, life-history of the low and high latitude prominences, the east-west distribution of prominences, the distribution of "metallic" prominences, etc., are considered in the paper.

* This will be referred to as Paper I in what follows.

In connection with the work referred to in the preceding paragraph, a set of charts of prominence activity were also prepared.† Unfortunately, these diagrams could not be incorporated in Paper I. In the meanwhile, data for two more years became available so that the charts could be extended incorporating the data upto the end of 1952. It is felt that these diagrams which summarise quantitatively a vast mass of prominence data and bring out strikingly the salient features of prominence activity during the last four solar cycles might be of interest to workers in the field of solar physics and perhaps also of geophysics. They represent in three different ways the trend of prominence activity in relation to the sunspot cycle for the period 1905 to 1952. The object of this paper is to present these charts and to give a brief discussion of some of the features brought out by them.

2. Distribution of Profile Areas of Prominences according to Heliographic Latitudes

At Kodaikanal, prominence activity has been reckoned from the very beginning both in terms of the *numbers* of individual prominences observed at the limb as well as in terms of the *profile areas* of the prominences. For details of the methods of evaluation reference may be made to Paper I. For reasons discussed in that paper the Kodaikanal prominence numbers do not constitute a good index of prominence activity. The mean daily profile area of prominences, on the other hand, is a recognised representative index of prominence activity. The values of this quantity for five-degree intervals of latitude for the NE, NW, SE and SW limbs during the years 1905 to 1950 are listed in Table I of Paper I. Similar data for the years 1951 and 1952 are given in Table I of the present paper. The unit of prominence area for this table is 10^{-3} square minute of arc. (The figures in the table have to be divided by $4 \cdot 65$ in order to express the areas in terms of the international unit of prominence area which is the area of a rectangle whose height is 1 second of arc of the celestial sphere and whose base is 1 degree along the solar limb.)

To give an idea of the representative nature of the prominence statistics of Kodaikanal for the period 1905 to 1952, the number of "effective" days of observation for the individual months as well as for the individual years is listed in Table II. The *effective* days are in general somewhat less than the *total* number of days of observations since spectroheliograms for days when the sky and seeing conditions are not good, are given a weightage

† Some of these diagrams were shown at the Annual Meeting of the Indian Academy of Sciences held at Trivandrum in December, 1952.

TABLE I

Distribution of Mean Daily Prominence Areas according to Heliographic Latitudes

NORTH

Year / No. of days	Total	85–90	80–85	75–80	70–75	65–70	60–65	55–60	50–55	45–50	40–45	35–40	30–35	25–30	20–25	15–20	10–15	5–10	0–5
1951 NE	769	0	0	0	1	1	2	5	14	40	84	103	117	120	68	63	57	48	46
338 NW	724	0	0	0	1	1	1	5	13	29	64	80	105	114	74	73	56	68	40
N	**1493**	**0**	**0**	**0**	**2**	**2**	**3**	**10**	**27**	**69**	**148**	**183**	**222**	**234**	**142**	**136**	**113**	**116**	**86**
1952 NE	423	0	1	0	1	0	1	3	13	27	33	39	41	49	50	46	46	44	29
342 NW	557	0	0	0	1	1	1	1	6	26	57	74	83	70	62	43	42	46	44
N	**980**	**0**	**1**	**0**	**2**	**1**	**2**	**4**	**19**	**53**	**90**	**113**	**124**	**119**	**112**	**89**	**88**	**90**	**73**

SOUTH

0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75	75–80	80–85	85–90	Total	Year / No. of days
36	46	65	79	117	101	60	53	49	21	6	1	0	0	0	0	0	0	634	SE 1951
45	61	53	57	74	76	80	69	55	31	11	4	2	0	1	0	0	0	619	SW *338*
81	**107**	**118**	**136**	**191**	**177**	**140**	**122**	**104**	**52**	**17**	**5**	**2**	**0**	**1**	**0**	**0**	**0**	**1253**	**S**
35	28	46	33	31	42	70	102	55	15	1	1	1	1	0	0	0	0	471	SE 1952
43	54	62	47	52	62	74	81	36	8	4	1	0	0	0	0	0	1	525	SW *342*
78	**92**	**108**	**80**	**83**	**104**	**144**	**183**	**91**	**23**	**5**	**2**	**1**	**1**	**0**	**0**	**0**	**1**	**996**	**S**

TABLE II

Effective Number of Days of Prominence Observations

Month / Year		J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	I	II	Total
1905	..													159	134	284
06	..													150	103	253
07	..													165	131	296
08	..													158	140	298
09	..													159	137	296
10	..													164	141	305
1911	..													157	129	286
12	..							14	19	23	18	16	24	159	114	273
13	..	23	25	30	28	26	21	18	23	26	22	18	22	153	129	282
14	..	28	27	29	29	26	19	11	20	22	16	24	20	158	113	271
15	..	27	27	30	30	30	19	15	21	20	26	19	21	163	122	285
16	..	31	27	30	27	28	16	28	27	22	23	26	26	159	152	311
17	..	22	25	28	27	29	17	20	22	20	21	19	27	148	129	277
18	..	25	26	30	27	19	24	23	19	24	25	12	19	151	122	273
19	..	29	28	30	26	25	21	15	22	15	22	17	24	159	115	274
20	..	25	29	30	27	28	20	18	23	25	21	13	29	159	129	288
1921	..	22	26	31	29	30	23	16	24	22	21	24	25	161	132	293
22	..	28	22	31	27	23	22	15	22	22	19	16	29	153	123	276
23	..	26	28	27	28	29	23	15	19	21	17	25	17	161	114	275
24	..	27	27	29	28	27	24	27	27	27	27	27	26	162	161	323
25	..	29	28	29	27	27	23	24	23	28	27	23	27	163	152	315
26	..	31	28	31	30	29	27	29	27	27	29	25	30	176	167	343
27	..	29	27	28	29	28	24	24	23	26	27	26	30	165	156	321
28	..	24	28	29	26	30	26	26	25	28	26	18	26	163	149	312
29	..	30	25	31	27	27	21	25	29	29	28	26	28	161	165	326
30	..	29	28	27	29	29	26	24	26	27	26	26	28	168	157	325

TABLE II—(*Contd.*)

Year \ Month	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	I	II	Total
1931 .	28	28	31	28	28	29	28	29	29	29	25	20	172	160	332
32 ..	30	27	30	29	29	29	29	28	29	28	26	25	174	165	339
33 ..	28	27	30	27	27	27	28	28	27	24	25	29	166	161	327
34 ..	27	28	30	28	29	25	25	25	28	23	24	24	167	149	316
35 ..	26	27	29	26	29	27	24	24	27	25	23	24	164	147	311
36 ..	29	28	28	29	27	24	23	23	27	28	25	26	165	152	317
37 ..	26	27	30	28	30	26	25	28	28	28	24	29	167	162	329
38 ..	30	25	29	28	30	26	23	25	24	25	26	23	168	146	314
39 ..	27	27	31	24	28	22	16	22	26	23	26	28	159	141	300
40 ..	29	28	29	29	31	30	28	29	26	26	21	28	176	158	334
1941 ..	26	25	26	27	25	23	28	27	27	24	21	26	154	153	307
42 ..	29	27	28	28	28	22	27	29	28	28	28	27	162	167	329
43 ..	27	24	29	26	25	24	23	25	25	25	23	21	155	142	297
44 ..	26	22	19	26	28	26	26	29	28	28	19	22	147	152	299
45 ..	23	19	25	22	24	24	27	27	26	26	26	24	137	156	293
46 ..	30	26	30	29	26	25	25	28	25	24	19	20	166	141	307
47 ..	26	24	29	26	28	26	26	25	27	27	27	25	159	157	316
48 ..	29	24	30	27	28	30	25	28	28	27	25	25	168	158	326
49 ..	27	26	29	27	25	28	28	31	29	29	29	29	162	175	337
50 ..	27	27	29	28	29	29	28	28	26	27	28	30	169	167	336
1951 ..	29	27	30	28	31	27	27	31	29	29	22	28	172	166	338
52 ..	27	27	29	29	28	29	27	27	31	30	31	27	169	173	342
Total ..													7743	6974	14717

(For the period prior to July 1912, the number of effective days for the individual months is not available in the Kodaikanal records.)

of ¾ or ½ only depending upon the quality. In general, the observing conditions for solar work are better at Kodaikanal during the first half of the year than during the second half when the station comes under the influence of the south-west and north-east monsoons.

Upto 1923 the prominence data of Kodaikanal are based on the observations made at this observatory only. Thereafter the Kodaikanal data have been supplemented with data derived from photographs obtained from the Mt. Wilson and Meudon Observatories for the days on which Kodaikanal photographs were either of inferior quality or not available, on account of unfavourable weather conditions. This accounts for the generally greater number of effective days of observation per year since 1923. Comparison of the figures in the columns headed I and II in Table II for the years before and after 1923 shows that the number of foreign photographs required to supplement the Kodaikanal data is more during the second half of the year than during the first half.

The charts in Fig. 1 give a pictorial representation of the distribution of mean daily prominence areas round the limb of the sun year by year from 1905 to 1952. For the years 1907 to 1911 the data for the east and west limbs are not separately available in the Kodaikanal records for the north and south hemispheres. Hence, for these years the total areas for the five-degree zones have been divided by 2 and depicted symmetrically on the east and west limbs so that the diagrams for these years may have a uniform appearance with those for the remaining years. The original diagrams were drawn on a scale of 1 inch to the solar radius; also 1 inch was taken to represent 1/10 square minute of prominence area. The prominence area for each five-degree zone is represented by a radial line of appropriate length originating from the centre of the zone. As all the diagrams are drawn to the same scale and as a uniform practice has been followed at Kodaikanal for evaluation of prominence areas, the diagrams for the different years are mutually comparable quantitatively.

3. Isopleths of Mean Daily Prominence Areas

To bring out strikingly the manner in which prominence activity varies in the course of the sunspot cycle, the mean daily profile areas for five-degree latitude zones in the two hemispheres were entered on graph paper with the years as abscissae and heliographic latitudes as ordinates. The profile area corresponding to a particular five-degree interval of latitude was entered against the mean latitude of the zone. Contour lines were then drawn at intervals of 50×10^{-3} square minute of prominence area using linear interpolation between adjacent plotted values. The resulting diagram is reproduced as Fig. 2 in which the intervals corresponding to the different degrees of prominence activity are clearly demarcated. The curve of Zürich

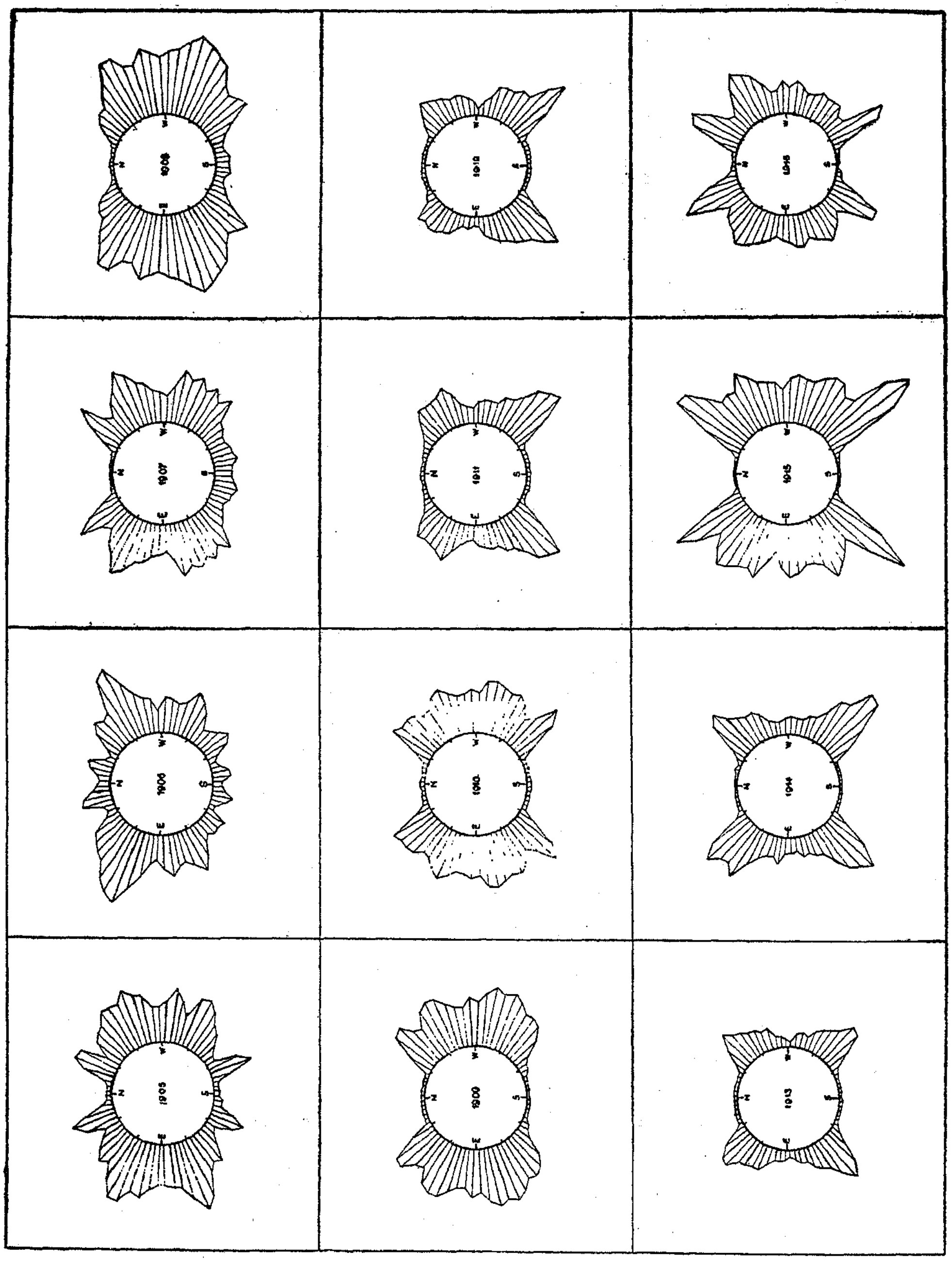

FIG. 1 (*a*).
DISTRIBUTION OF PROMINENCE AREAS ACCORDING TO HELIOGRAPHIC LATITUDES
(1905–1916)

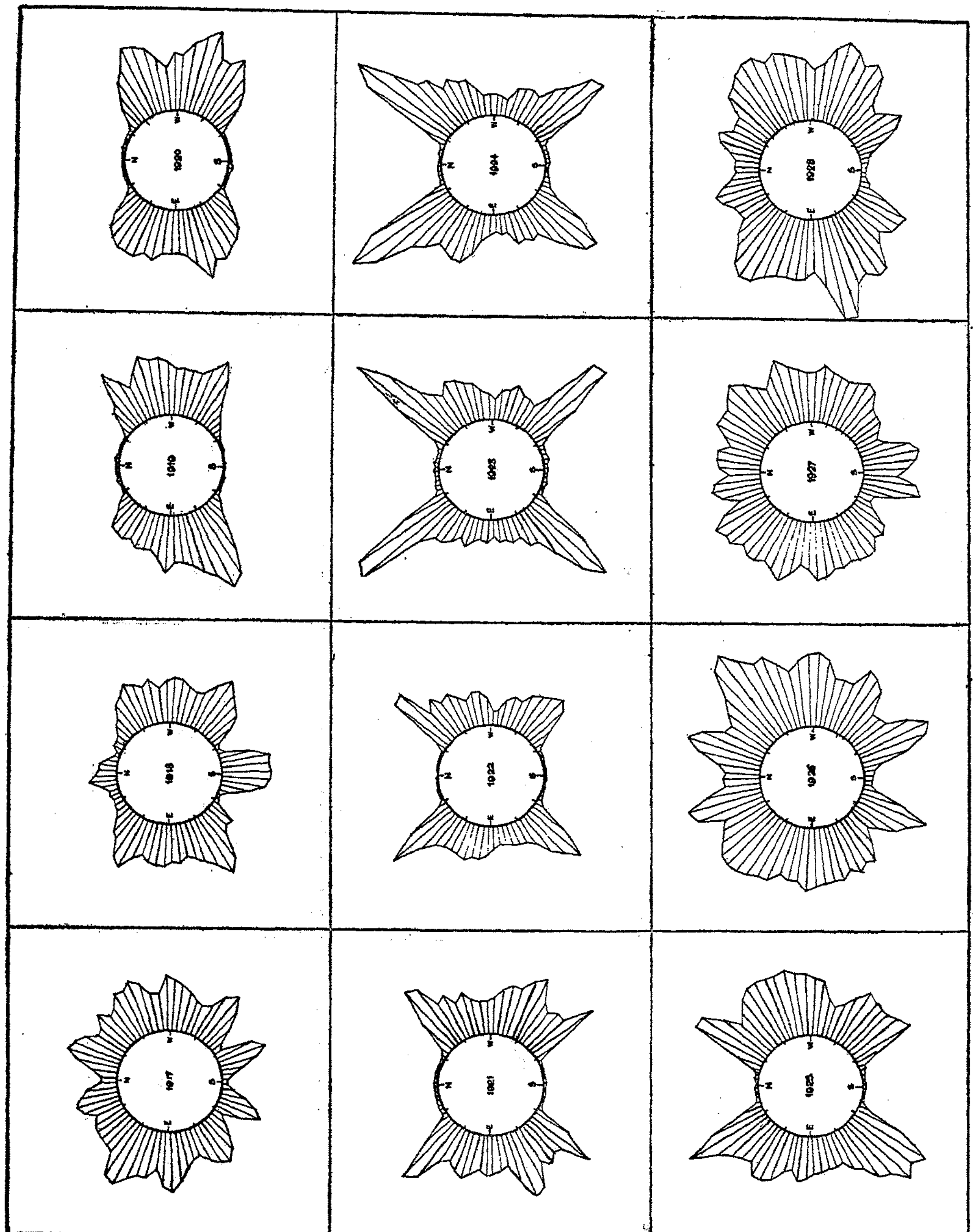

Fig. 1 (*b*)
Distribution of Prominence Areas According to Heliographic Latitudes (1917–1928)

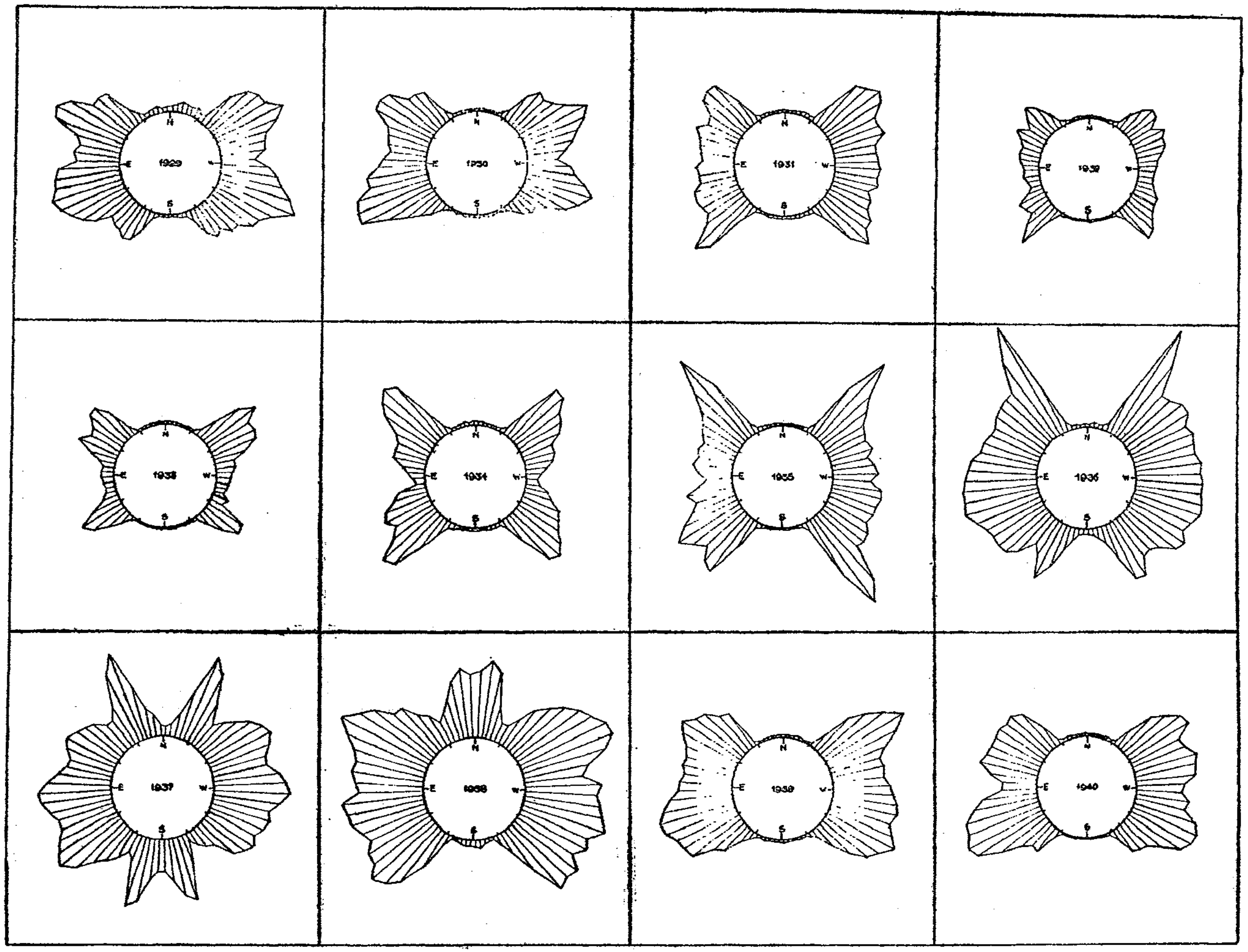

Fig. 1 (*c*)

Distribution of Prominence Areas According to Heliographic Latitudes (1929–1940)

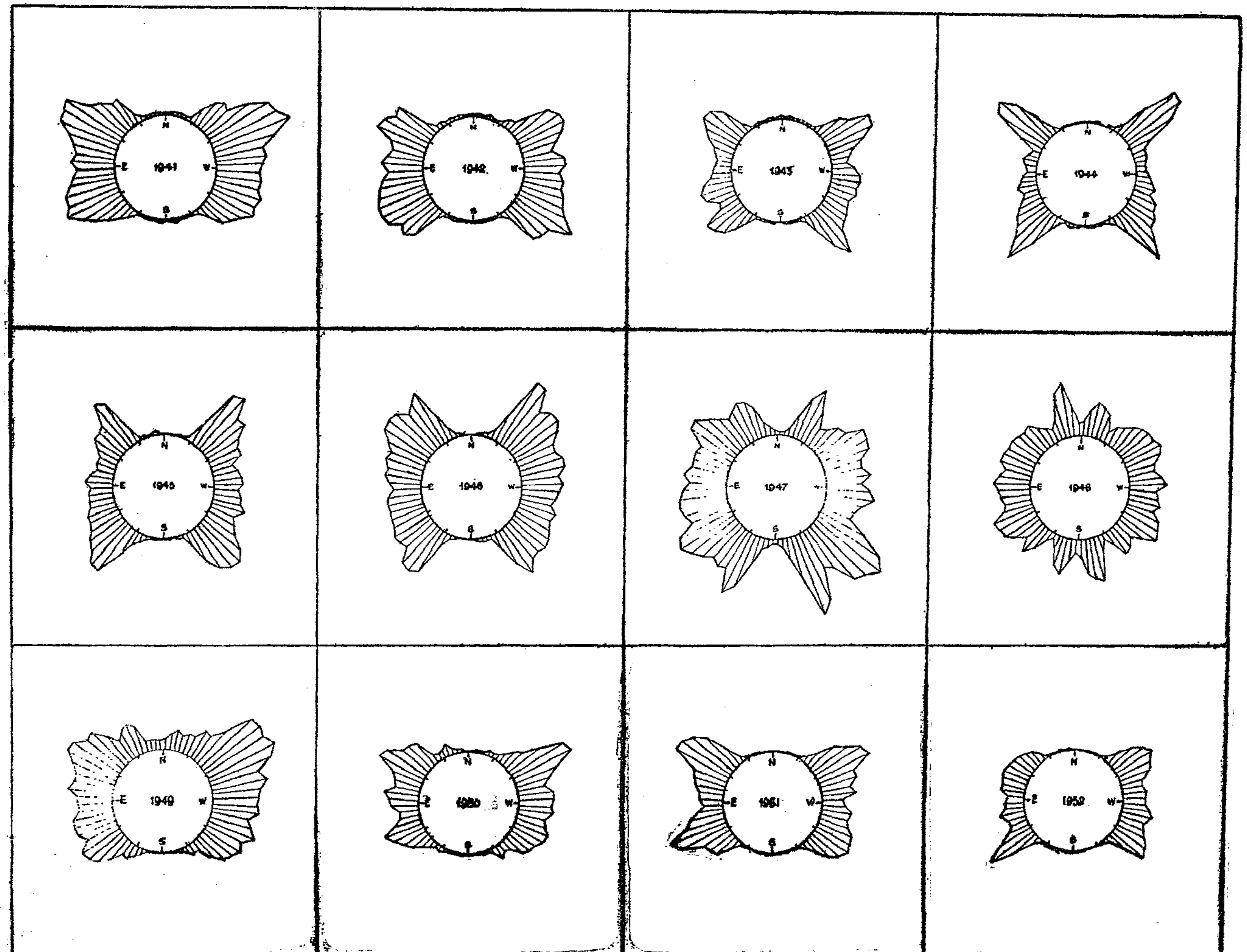

FIG. 1 (*d*)

DISTRIBUTION OF PROMINENCE AREAS ACCORDING TO HELIOGRAPHIC LATITUDES
(1941–1952)

relative sunspot numbers for the period covered by the prominence observations is given at the top of the diagram. A similar diagram was contained in a note entitled " Prominence Activity and the Sunspot Cycle " published some time back (Ananthakrishnan, 1952).

4. Zonal Variation of Prominence Activity

Figures 3 (*a*) and 3 (*b*) illustrate the variation of prominence activity in each five-degree zone for the northern and southern hemispheres during the period 1905 to 1952. The zero of the vertical scale has been appropriately displaced to avoid superposition of the curves for the different latitude zones. The horizontal line against which the designation of a particular zone is written corresponds to the zero of prominence activity for that zone. The scale of prominence areas is indicated for the zone 0–5° at the bottom of the diagram and is the same for all the other zones. As in the case of the isopleth diagram, the curve of Zürich relative sunspot numbers is given at the top of each of the diagrams. The broken curve which runs close to the sunspot curve in the two diagrams represents the mean daily sunspot areas for the two hemispheres, the values of which were obtained from the Greenwich Photoheliograph Results.

5. Prominence Activity and the Sunspot Cycle

It is well known that sunspot activity is confined to two fairly well defined zones extending from the solar equator to about 40° latitude in either hemisphere. The commencement of a new solar cycle is heralded by the appearance of spots near about latitude $\pm$ 40°. As the cycle advances the centre of spot activity shifts progressively towards lower latitudes until towards the close of the cycle the spot activity wanes off near the solar equator while spots of the new cycle begin to appear at higher latitudes.

As contrasted with sunspots, prominences occur at all latitudes on the sun. However, in respect of the manner in which prominence activity manifests itself, we can divide each solar hemisphere into two zones, *viz.*, (*i*) a low latitude zone extending from the equator to about 40° and therefore practically coinciding with the sunspot zone, and (*ii*) a high latitude zone extending from 40° to the poles.

Prominences always occur in the low latitude zones although the activity is a minimum at the minimum epoch of the sunspot cycle. Prominence activity in the high latitude zones above latitude 60° is conspicuous only at and near the time of sunspot maximum. The activity dies down very rapidly thereafter. These broad features of prominence activity first established through the pioneering researches of Secchi and Respighi and sub-

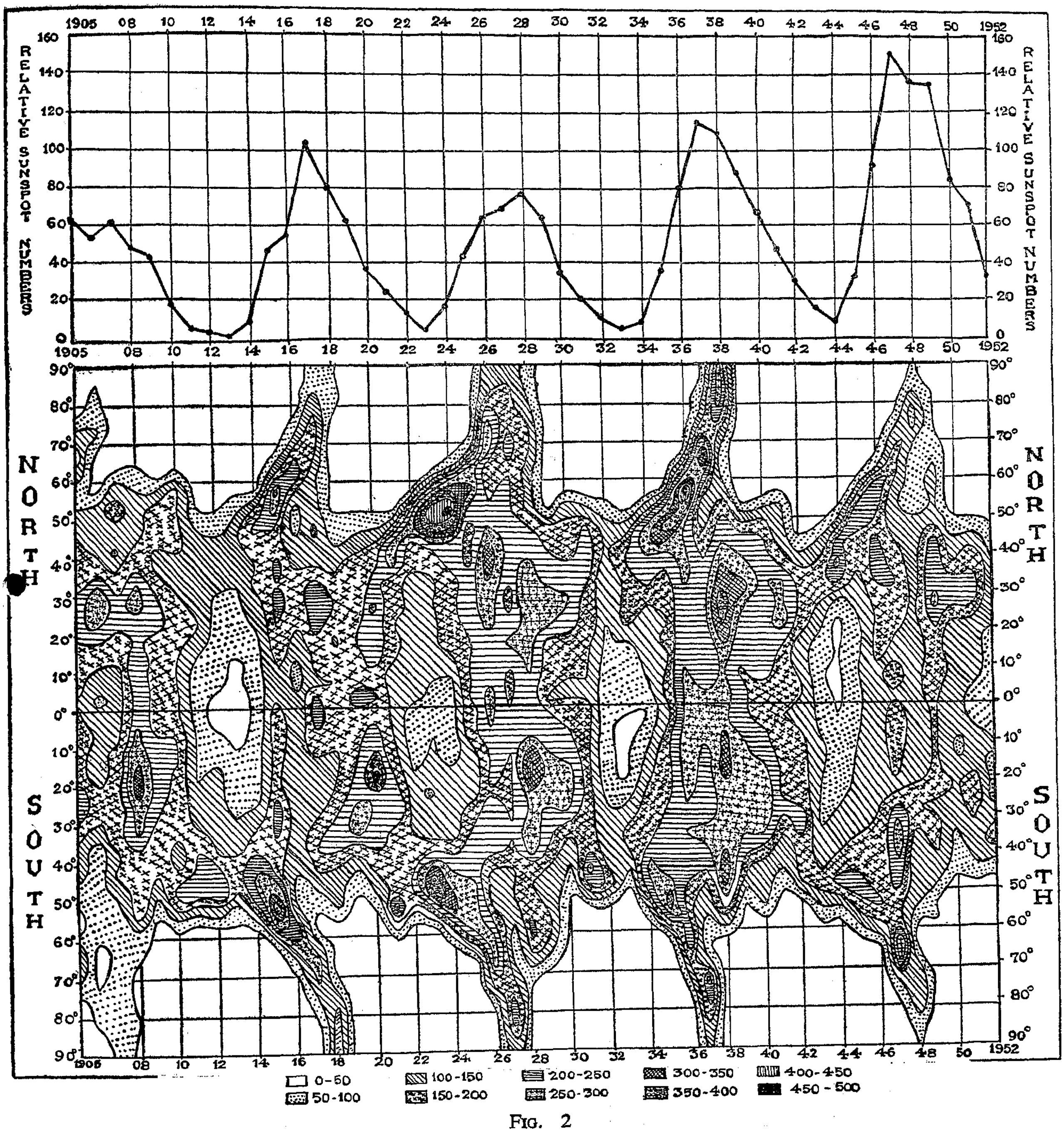

FIG. 2

Isopleths of mean Daily Prominence Areas (Unit: 10^{-3} sq. min.)

PROMINENCE ACTIVITY AND THE SUNSPOT CYCLE

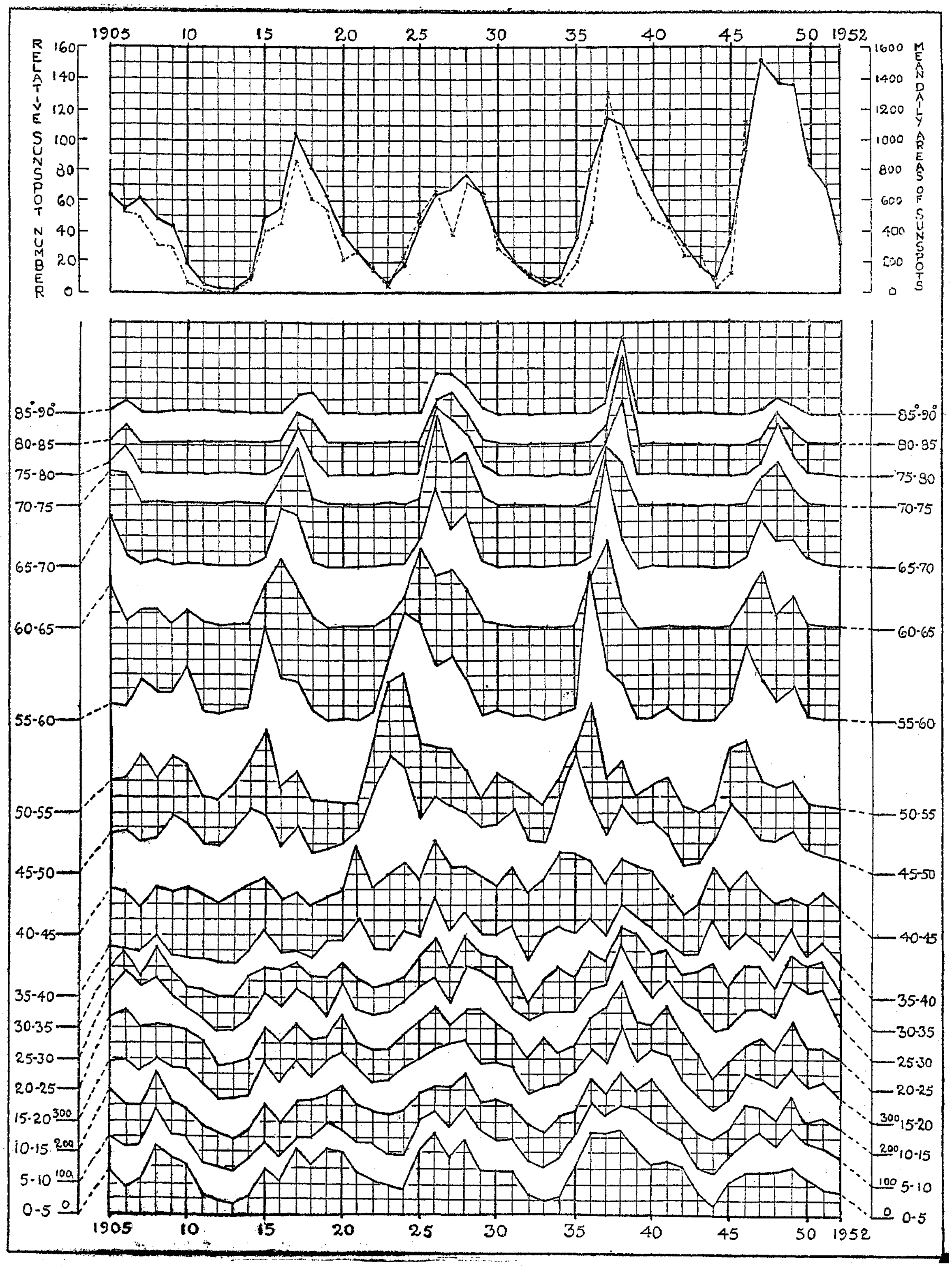

FIG. 3 (*a*)

VARIATION OF PROMINENCE ACTIVITY IN FIVE-DEGREE LATITUDE ZONES
(Northern Hemisphere)

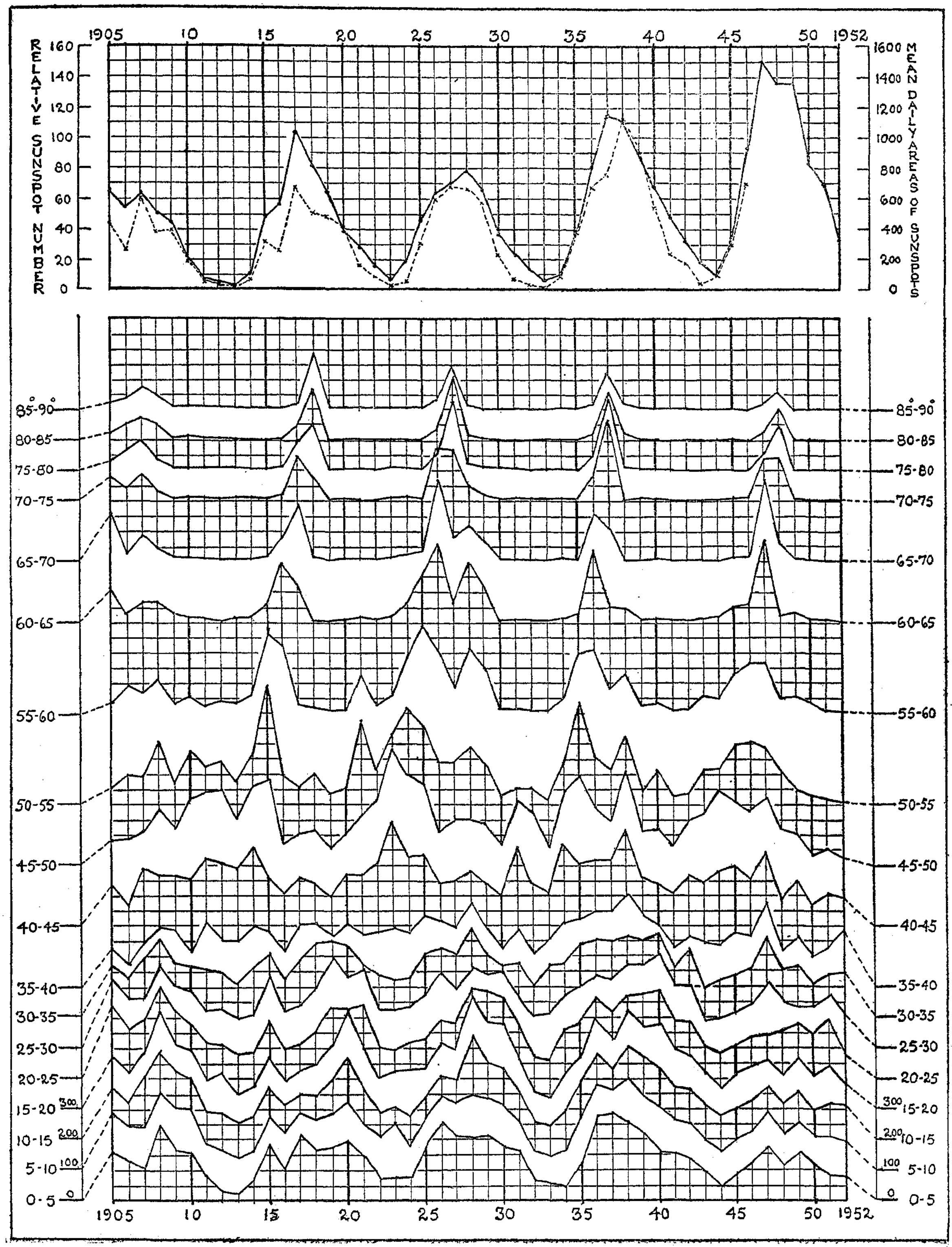

FIG. 3 (*b*)

VARIATION OF PROMINENCE ACTIVITY IN FIVE-DEGREE LATITUDE ZONES
(Southern Hemisphere)

sequently corroborated by the investigations of Ricco (1891, 1914), Lockyer (1903), Evershed (1917), Bocchino (1933), Baroccas (1939), Moss (1946) and D'Azambuja (1948), are clearly brought out by the diagrams which illustrate the present paper for each of the four cycles of solar activity covered by the period under study.

The manner in which prominence activity develops and progresses in the low and high latitude zones has been discussed by several workers. Although there is general agreement as regards the high latitude zones there is not such a consensus of opinion about the trend of activity in the low latitude or sunspot zones. According to Evershed, prominence activity begins to develop in the high latitude zones between 40° and 50° soon after sunspot minimum. With increasing sunspot activity the centres of high latitude prominence activity gradually move polewards until near the epoch of sunspot maximum there is a rapid rush towards the poles. The high latitude prominence activity suddenly disappears soon after sunspot maximum. These features are clearly illustrated by the figures which accompany the present paper.

The trend of activity in the low latitude zone is not so clearly defined because of irregularities caused by the co-existence of several active centres. From his observations Evershed concluded that in the sunspot zones prominence activity drifts more or less in phase with the sunspots from higher latitudes towards the equator and dies out near the lowest latitude reached by sunspots at the time of sunspot minimum. Lockyer and Lockyer (1903) concluded from their study of the Italian prominence data for the period 1872 to 1901 that the low latitude prominence activity is centred round latitude $\pm 24°$ where the activity begins to manifest itself shortly after sunspot minimum. With the ascending phase of the sunspot cycle there is a corresponding rise in prominence activity in the sunspot zone without appreciable shift of the centre of activity. Finally the centres of prominence activity recede and merge with the high latitude zones at about $\pm 40°$ before sunspot minimum. Thus it will be seen that the conclusions of Evershed and those of Locyker and Lockyer are rather divergent in respect of the growth and progress of prominence activity in the sunspot zones.

To get a better insight into the nature of latitudinal migration of prominences M and M^{me} D'Azambuja made a large number of measurements on long-lived H-alpha dark markings (prominences seen in projection on the disc) over the elven-year period 1919 to 1930 which covered both the ascending and descending phases of the sunspot cycle. Their measurements led them to conclude that *on the average* all prominences have a slow pole-ward drift in both the hemispheres. The rate of pole-ward drift was found to be about 2° per solar rotation near the equator and decreased progressively to about 1° per solar rotation near latitude 50°. It was also found that the rate of pole-ward drift was at least twice as rapid in the ascending phase of the sunspot cycle than in the descending phase particularly in the high latitude zones. Based on these findings, M and Mme D'Azambuja have advanced the view that all prominences originate in the sunspot zones and migrate towards higher latitudes, thus indicating the existence of a meridional circulation on the sun which is postulated by certain solar theories.

While the meridional movement of high latitude prominences at the rate of about 1° per solar rotation is clearly brought out by the diagrams reproduced here, the statistical study of prominences fails to give direct evidence about the pole-ward migration of prominences in the low latitude zones. From an examination of Figs. 3 (*a*) and 3 (*b*) it will, however, be seen that the amplitude of variation of prominence activity in the five-degree intervals of the sunspot zones decreases with increasing latitude and is least at the outer boundaries of the zones. It will also be seen that in the high latitude zones the progress of prominence activity from 70° to the poles is more rapid than the progress from 45° to 70°. For a fuller discussion of the significance of these features reference may be made to Paper I.

6. Prominence Activity and the Solar Corona

In a series of papers Dr. Lockyer (1903, 1922, 1931) has shown that there is an intimate connection between the distribution of prominences round the solar limb and the forms of the corona. He has classified the different forms of the corona into three main types, *viz.*, (i) "polar" or maximum type; (ii) "equatorial" or minimum type; and (iii) the "intermediate" type. In the ploar type, the coronal streamers are found all round the solar disc and the polar rifts are absent. It is usually known as the maximum sunspot type. In the equatorial type of corona the streamers are restricted to low solar latitudes and the polar rifts are conspicuous. This type which occurs at the time of minimum sunspot activity is also called the "wind-vane" or "fish-tail" form of corona. As its name suggests, the intermediate corona forms a transition between the polar and the equatorial types. In it the streamers occur at mid-solar latitudes and the rifts though present are less extensive and the equatorial extensions less pronounced as compared with the minimum type.

From his study of the coronal drawings and photographs obtained during the total solar eclipses for the period 1870 to 1930, Dr. Lockyer found that the polar type corona occurs only when prominence activity is pronounced at high latitudes in one or both the hemisphers of the sun. As we have already seen this occurs only at or near the epoch of sunspot maximum. The equatorial forms of the corona occur when the prominence activity is confined to the lowest latitudes which occurs near the epoch of minimum sunspot activity. Lockyer distinguishes between two types of intermediate coronal forms, " intermediate up " and " intermediate down " corresponding to the waxing and waning phases of the sunspot cycle.

An examination of the charts showing the distribution of prominences according to heliographic latitudes reproduced in Fig. 1 bears out the rather striking similarity between the prominence distribution round the solar limb and the coronal forms considered above. A question which naturally arises is, whether the coronal forms are to be correlated more directly with sunspot activity or with prominence activity. There is some difference of opinion on this point. Ludendorff (1928) and Mitchell (1929) have suggested that the coronal form is governed by sunspot action while Lockyer (1931) and Bergstrand (1930) incline to the view that there is more direct connection between prominence distribution on the sun and the forms of the corona. In this connection an observation of Evershed which has been quoted by Lockyer is of interest. In the Memoir on " Results of Prominence Observations ", Evershed examined the connection between the distribution of prominences with the types of corona and found that Lockyer's theory generally agreed with observations except in the case of the corona of 1908 January 3. As we see from Fig. 1, prominence activity in the southern hemisphere enveloped the pole during 1907 and 1908, but in the northern hemisphere the activity practically stopped beyond 65°. According to Lockyer's theory the coronal streamers should be more pronounced over the south polar region than over the north. However, from the illustration of the corona given in McClean's Report it appeared that streamers were developed almost all round the disc except at the south pole. Evershed remarked that " if Mr. McClean's corona is correctly oriented, therefore, the distribution of streamers in the polar regions does not agree with the distribution of prominences at that time". At a later date Evershed discovered that the north and south poles had been interchanged in the picture of the corona; the apparent contradiction with Lockyer's theory, therefore, disappeared.

Although various forms of solar activity closely follow the sunspot cycle the exact nature of the causal relationships between them are at present only very imperfectly known. Nevertheless, it would appear that the coronal forms are more directly related to the distribution of prominences than of sunspots.

7. Solar Activity during the Latest Cycle

Judged by sunspot activity the latest solar cycle which attained a maximum in 1947 is one of the most active. This cycle has also the unique distinction of having been characterised by some of the biggest spot groups on record. But examination of Figs. 1, 2 and 3 reveals that prominence activity has been less pronounced during this cycle as compared with the two previous ones in which spot activity reached the peak in 1937 and 1928. In this connection it is significant that Behr and Siedentoff (1952) and Kleczek (1953) found that solar flare activity has also been less during the latest cycle as compared with the previous one. The trend of geomagnetic activity during the maximum epochs of the last four solar cycles indicates that the latest cycle has been geomagnetically the least active (Ananthakrishnan, 1953). In fact a preliminary examination suggests that during the maximum phase of the sunspot cycle geomagnetic activity shows a better correlation with prominences than with sunspots.

8. Acknowledgements

The author's thanks are due to all members of the Kodaikanal Observatory staff, past and present, who have participated in the collection of the large mass of prominence data. Mr. P. Madhavan Nayar, Professional Assistant of the Kodaikanal Observatory who collaborated in the present work and is co-author of Paper I, assisted in preparing the charts reproduced in Fig. 1. The help of Mr. D. K. Das of the Meteorological Office, Nagpur, in tracing and inking Fig. 2 from the original prepared by the author is also acknowledged with thanks.

Summary

The paper illustrates with a series of diagrams the variation of prominence activity during the period 1905 to 1952 based on the prominence statistics collected at the Kodaikanal Observatory. The main features of prominence activity brought out by these diagrams are briefly discussed.

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