KODAIKANAL OBSERVATORY

BULLETIN No CXXXVII

DISCUSSION OF THE RESULTS OF OBSERVATIONS OF SOLAR PROMINENCES MADE AT KODAIKANAL FROM 1904 TO 1950

BY

R ANANTHAKRISHNAN AND P MADHAVAN NAYAR

1 Introduction

In Volume I Part 2 of the Memoirs of the Kodaikanal Observatory Mr and Mrs Evershed (1917) have discussed the results of solar prominence observations made at Kodaikanal during the years from 1904 to 1914 supplemented with Mr Evershed s own observations at Kenley in Surrey (England) during the period 1890 1904 Since then a large volume of observational data relating to solar prominences has been accumulated at this observatory and several contributions relating to various aspects of the subject have appeared from time to time The object of the present paper is to give a general review and discussion of the prominence data collected at Kodaikanal during the first half of this century The period covered comprises four sunspot cycles The scope of the paper is restricted to prominences observed at the limb A parallel study of the absorption markings on the disc observed in the H alpha line is in progress

At Kodaikanal systematic visual observations of prominences in the C line were commenced in 1903 with a six inch Cooke Equatorial and a grating spectroscope mounted in the South Dome of the observatory The grating spectroscope was replaced by a three prism Evershed spectroscope towards the end of 1904 In October 1912 the Cooke equatorial and Evershed spectroscope were removed from the south dome and a six inch Cooke photo visual telescope with equatorial mounting received from the Takhta inghji Observatory at Poona was installed in this dome A good grating spectroscope also from the Poona Observatory was adapted for use with the telescope for visual study of solar limb and disc features

Upto 1904 February 21 the solar limb was scanned only with eight settings of the position circle after that date the entire limb was scanned for prominences The daily observations were entered on charts and the data comprising the heliographic coordinates extents heights and descriptions of the prominences were published half yearly in the Bulletins of the Observatory Abstracts giving mean heights mean frequency and mean heliographic latitudes of the prominences in each hemisphere for every month as well as quarterly and half yearly frequencies of prominences in ten degree latitude zones for every year were also included in the Bulletins

In August 1904 a two prism spectroheliograph manufactured by the Cambridge Scientific Instruments Co Ltd was installed at the observatory and daily photographing of the limb and the disc in the H line of Ca^+ was commenced from the end of that year The limb spectroheliograms were compared with the sketchings of prominences in H alpha at the prominence spectroscope and a complete list of all prominences recorded visually and/or photographically was included in the Bulletins In about two years the H line was discarded in favour of the K line and since then the calcium spectroheliograms of the disc and the limb have always been taken in the K line

Beginning from 1908 the half yearly prominence data published in the Bulletins included a diagram giving the zonal distribution of the mean daily profile area of prominences in the two hemispheres The publication of the detailed list of prominences was discontinued from 1912 since that time only a summary of the prominence observations has been published for every half year

18 DGO/53

Price Rs 5 12 or 9 sh

In 1934 a Hale spectrohelioscope was installed and from that time visual examination of the limb and the disc in the C line at specified times with this instrument has also formed part of the routine observational programme of this observatory

Weather permitting the routine daily solar observations with the prominence spectroscope and the spectroheliograph are made between 0730 and 1000 hrs I S T (0200 to 0430 hrs U T) when the sky and seeing conditions are generally the best at Kodaikanal The results discussed in the present paper are therefore largely based on daily prominence observations made during this interval Upto 1922 the available data relate to Kodaikanal observations only In accordance with the resolution of the International Astronomical Union at its first meeting in Rome in 1922 the Kodaikanal Observatory undertook the work of compilation and discussion of the statistics derived from photographs of prominences and H alpha absorption markings Since then the Mt Wilson and Meudon Observatories have been cooperating with this observatory by supplying copies of their photographs for those days when Kodaikanal records are imperfect or wanting Consequently the number of days for which prominence data are available is somewhat greater for the years subsequent to 1922 than for the previous years

2 Data for Analysis

The half yearly summaries of prominence observations published in the Bulletins of the Observatory are based on detailed tabulations maintained in the registers These registers constitute the source of the data discussed in the present paper They contain a vast mass of prominence data derived from observations with the prominence spectroscope the spectroheliograph and the spectrohelioscope An account of the data available in the registers is given below –

(*a*) *Extent of Base Heliographic Coordinates and Heights of Prominences* —

Tabulations giving extent of base mean latitude and maximum height of all prominences observed at the limb are available continuously from April 1904 onwards except for interruptions caused by unfavourable weather conditions Up to the end of 1911 these detailed data have also been published in the Bulletins of the observatory

(*b*) *Mean Daily Profile Areas of Prominences* —

Tabulations of the mean daily area of prominences for every month for each five degree latitude interval in the NE NW SE and SW quadrants based on limb spectroheliograms are available from 1905 onwards

At Kodaikanal the prominence areas are estimated visually by superposing on the spectroheliograms a glass grid (Fig 1) The inner circle of this grid has the same diameter as the solar disc in the spectroheliograms ($\simeq$60 mm) The diameter of the circle is equal to 100 grid divisions Assuming the mean geocentric semi angular diameter of the sun as 16 minutes of arc (this varies from about 16 m 18 s to 15 m 45 s) each small square on the measuring grid represents an area of 1/10 square minute of arc of the celestial sphere with a sufficient degree of accuracy This is the unit of prominence area employed in the measurements Areas are estimated correct to one half of a small square on the grid The grid also contains a set of concentric circles so spaced that the interval between adjacent circles represents 30 seconds of arc on the scale employed for the sun s diameter The heights of the prominences above the chromosphere are estimated with reference to these circles

The international unit of prominence area employed by Arcetri Zurich and some other observatories is different from the Kodaikanal unit It is equal to the area of a rectangle whose height is one second of arc of the celestial sphere and whose base is one degree along the solar limb From the old records of the Kodaikanal Observatory it is seen that this unit was tried here in 1907 but was subsequently given up in favour of the unit equal to one tenth square minute of the celestial sphere The prominence areas for 1907 available in the registers are in terms of the area of a unit rectangle whose sides correspond to one degree along the solar limb and 10 seconds of arc of the celestial sphere that is 10 international units The areas for 1907 as tabulated in the registers have therefore to be appropriately reduced in order to make them comparable with the data for the preceding and succeeding years

Assuming the mean geocentric semi angular diameter of the sun as 16 minutes of arc we see that 1 along the solar limb corresponds to $\frac{2\pi \times 16}{360}$ minutes as seen from the earth Hence the area represented by a rectangle whose sides are 1 along the solar limb and 10 seconds of arc of the celestial sphere is 0 46 x 10^{-1} sq min As this is a smaller unit than one tenth square minute the areas for 1907 given in the registers have to be multiplied by 0 465 to make them comparable with those for the remaining years It is readily seen that the Kodaikanal unit of prominence area (one tenth square minute) is equal to 21 5 international units

In the registers the separate tabulations of prominence areas in 5 latitude intervals for all the four quadrants are available only for 1905 1906 and for the period subsequent to August 1911 For the period January 1907 to July 1911 prominences on the east and west limbs have been combined and the data are available separately only for the north and south hemispheres

(c) *Mean Daily Prominence Numbers* —

For the period 1904 to 1911 the numbers of prominences observed in each ten degree latitude zone in the two hemispheres have been published in the Observatory Bulletins for every month every quarter half year and full year From July 1912 onwards the prominence numbers for each five degree zone have been separately tabulated in the registers month by month for all the four quadrants of the sun s disc It has been the practice at Kodaikanal to group equatorial prominences (prominences whose mean bases lie within one degree of the solar equator) separately

The convention which has been adopted for prominence numbers from the beginning of this observatory is as follows The apparent mean latitude of each prominence is taken as the average of the apparent latitudes of its two extremities From the apparent mean latitude the true latitude is found by applying a correction which varies with the heliographic latitude of the centre of the disc (correction for the tilt of the plane of the solar equator to the plane of the ecliptic) If the corrected latitude thus obtained falls within a particular five degree interval it is reckoned as one prominence number for that interval irrespective of the size of the prominence or its total extent

The practice followed at the Zurich Observatory for reckoning prominence numbers is somewhat different When a large prominence extends over several degrees along the solar limb each five degree zone in which any part of the prominence lies gets a weightage of one for prominence number (This is the practice followed at Kodaikanal for reckoning numbers of H alpha dark markings in five degree latitude zones) On the other hand if there are two or three tiny prominences within the same five degree interval on the same day then it is the Zurich practice to reckon these as only one number for that zone (W Brunner Hagger 1940)

The diagrams illustrating the latitudinal distribution of prominence areas and prominence numbers for the years 1936 to 1939 in the Zurich *Astronomische Mitteilungen* reveal a close parallelism On the other hand Mr and Mrs Evershed found that the Kodaikanal prominence number curve for the period 1905 to 1914 showed little variation of activity from year to year unlike the curve of prominence areas for the same period which showed a close resemblance to the curve of sunspot activity They remarked that the flatness of the prominence number curve was due to the fact that at Kodaikanal all prominences down to the smallest visible are recorded not only those of 30 and over as at Catania and other observatories and small prominences are numerous at all times

It is well known that the Greenwich sunspot areas and the Zurich relative sunspot numbers have a high degree of correlation and either of these can be employed as a representative index of sunspot activity But prominence numbers reckoned according to the Kodaikanal practice cannot obviously constitute a good index of prominence activity since the same weightage is given to large and small prominences It is often not possible to judge uniquely from the appearance of a prominence at the limb whether it is single or is a superposition of more than one prominence In some cases adjacent prominences which are apparently separated may be parts of one and the same prominence For these reasons prominence numbers cannot be regarded as indicating unequivocally the number of individual prominences Despite these limitations the original practice has been continued at Kodaikanal for the sake of continuity

Any procedure which assigns less weightage to small prominences and more weightage to larger ones would result in better correlation betwen prominence areas and prominence numbers The conventions followed by Zurich and Catania are steps in this direction

It appeared to be of interest to examine the degree of correlation between prominence areas (A) and prominence numbers reckoned in two different ways (*a*) according to the existing Kodaikanal practice explained above (N) (*b*) by giving a weightage of one to each five degree zone on all days when prominences are observed in that zone (N′) The years 1949 and 1950 were chosen for this study Table I(*a*) (Appendix) gives the mean daily areas and the mean daily numbers of prominences in the five degree zones for the north and south hemispheres Table I(*b*) (Appendix) gives the corresponding percentage frequencies We see from this table that the latitudinal distribution of prominences as represented by mean daily areas shows more pronounced maxima than when the activity is represented by numbers reckoned in the two different ways It is also seen that the distribution given by the numbers N obtained by method (*b*) corresponds more nearly to the distribution given by prominence areas than that given by the numbers N obtained by method (*a*)

In Figs 2*a* and 2*b* the mean daily areas A for five degree zones for the years 1949 and 1950 are plotted against the mean daily numbers N and N respectively These diagrams at once reveal that N′ is better correlated with A than N For comparatively small areas the relation between A and N is practically linear For larger areas the trend of the points indicates that $\frac{dA}{dN}$ is no longer constant but increases the correlation between A and N also decreases at the same time as is evident from the greater scatter of the points

The decrease of prominence activity from 1949 to 1950 as estimated by A N and N is given below —

		North rn hemisph re	South rn hemisph re
$\frac{1950}{1949}$	A	57 /	64 5 /
	N	69 3	82 1
	N	63 2	75

Again we see that N is a better index of prominence activity than N

The numbers N as defined above are practically identical with the Zürich prominence numbers On account of the fairly good correlation between A and N it is possible to derive an equation connecting these two quantities from a statistical analysis of the corresponding data for one solar cycle It would then be possible to derive the area distribution curve from the corresponding curve for N

On account of the unrepresentative nature of the Kodaikanal prominence numbers as a measure of prominence activity we have made little use of this data in the present study

(*d*) *Metallic Prominences* —

In the visual observations with the prominence spectroscope a special record is kept of prominences which can be seen in the emission lines of sodium magnesium iron etc Such prominences which are comparatively rare are designated as metallic in the Kodaikanal records

3 Mean Daily Profile Areas of Prominences

It is well known that the profile area of prominences is by far the best index of prominence activity The Kodaikanal data in this respect constitute an unbroken sequence commencing from 1905 Unfortunately the data in the form available in the registers could not be directly made use of for the purpose of the present investigation The data for the entire period 1905 1950 were therefore retabulated month by month and year by year for each of the four quadrants or five degree intervals of latitude The mean daily area for each interval was found by dividing the total area by the effective number of days of observation in the year

Table II (Appendix) gives the mean daily profile areas of prominences year by year separately for each of the four quadrants for five degree intervals of latitude from the equator to the poles The data for the two hemispheres north and south obtained by adding the corresponding areas for the eastern and western limbs are also given in the table In order to avoid decimals the unit of prominence area for this and other tables has been chosen as 10 square minute of arc that is $\frac{1}{}$ of the Kodaikanal prominence unit (The figures in the table have to be divided by 4 65 in order to express the areas in terms of the international prominence unit) For the years 1907 to 1911 during which areas are not separately available for the four quadrants the corresponding entries are absent in the table The effective number of days of observation for each year is given in brackets under the year

Figs 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 under study 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 each figure and is the same for all other zones The curve of Zurich relative sunspot numbers is given at the top of each of the diagrams

4 Four Zones of Prominence Activity

Systematic collection of prominence statistics by visual observations was organised by the Italian school of astronomers under the leadership of Respighi Secchi and others from about the seventies of the last century and the results have been discussed in a series of papers by Ricco (1891 1914) Lockyer and Lockyer (1903) Bocchino (1933) and Barocas (1939) Since the invention of the spectroheliograph it became possible to make more exact measurements of prominence areas on limb spectroheliograms and collection of such data was started at Kodaikanal by Evershed who had already commenced visual study of prominences at his private observatory at Kenley in Surrey as early as 1890—seventeen years before he joined the Kodaikanal Observatory The combined observational data for the period 1890 1914 have been discussed by him and Mrs Evershed in the Memoir already cited

The main features of solar prominence activity brought out by these researches are as follows There are four zones of prominence activity two in the northern and two in the southern hemisphere The low latitude zones extend from the solar equator to about 40 on either side while the high latitude zones extend from 40 to the poles The manner in which prominence activity manifests itself in the course of the sunspot cycle in the low and high latitude zones is different Prominences always occur in the low latitude zones although the activity is a minimum at the minimum epoch of sunspot activity 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 are clearly brought out by the diagram reproduced in a note entitled Prominence Activity and the Sunspot Cycle by one of us (Ananthakrishnan 1952) Figs 3(*a*) and (*b*) also illustrate these features We now proceed to a discussion of the prominence data covered by the present study

5 Comparison of the Northern and the Southern Hemispheres

For a comparative study of prominence and sunspot activities in the northern and southern hemispheres the mean daily profile areas of prominences for the two hemispheres and the mean daily areas of sunspots extracted from the Greenwich *Photo Heliographic Results* are represented graphically in Fig 4 Despite the general similarity of the two sets of curves we see also some striking differences

1905 1913—In the northern hemisphere sunspot activity reached its maximum in 1905 after which there was a progressive decrease till the minimum in 1912 For the southern hemisphere spot maximum was reached only in 1907 although there was a temporary decrease in actıvıty from 1905 to 1906 The southern mınımum was reached ın 1913 The maxımum of promınence actıvıty for both the hemıspheres was reached only ın 1908 by whıch tıme a declıne ın spot actıvıty had already set ın The promınence mınıma for the two hemıspheres occurred ın the same years as the correspondıng sunspot mınıma

1913 1923 —Sunspot actıvıty ın both the hemıspheres attaıned a maxımum ın 1917 In conformıty wıth the usual trend the fall was less steep than the rıse and the mınımum for both the hemıspheres was reached ın 1923 Durıng thıs cycle the behavıour of promınence actıvıty was somewhat abnormal After a steep rıse from 1913 to 1915 there was an apprecıable declıne ın actıvıty ın both the hemıspheres durıng 1916 probably assocıated wıth the temporary declıne ın sunspot actıvıty ın the southern hemısphere and the temporary slowıng down of actıvıty ın the northern hemısphere The promınence maxımum for the northern hemısphere was reached ın 1917 the same year as the sunspot maxımum whıle the southern maxımum whıch was attaıned ın 1918 was less marked than the southern peak ın 1915 There occurred two mınıma of pro mınence actıvıty ın both the hemıspheres the first ın 1919 and the second ın 1922 a year before the spot mınımum

1923 1934 —There was a rapıd rıse ın spot actıvıty ın the northern hemısphere whıch reached a peak ın 1926 There was then an apprecıable declıne durıng 1927 followed by a revıval next year when the maxımum of the cycle was reached The southern maxımum whıch was rather flat occurred ın 1927 The spot mınımum came sıx years after the maxımum for both the hemıs pheres ın 1933 for the south and ın 1934 for the north The southern mınımum was the feebler of the two The ınterestıng feature of promınence actıvıty for thıs cycle ıs the two peaked maxı mum for both the hemıspheres These two peaks occur ın the same years as the two peaks ın the sunspot curve for the northern hemısphere However the maxımum promınence actıvıty for the north was ın 1926 and for the south ın 1928 The promınence mınımum for the northern hemısphere occurred two years before the correspondıng sunspot mınımum whıle for the southern hemısphere the epochs of sunspot and promınence mınıma coıncıded

1934 1944 —In thıs cycle the northern maxımum for sunspots was reached ın 1937 (three years after the prevıous mınımum) whıle the southern maxımum whıch was separated from the prevıous mınımum by five years occurred ın 1938 The fall of actıvıty was steeper ın the southern hemısphere than ın the north the mınıma beıng reached ın 1943 and 1944 respectıvely The peak of promınence actıvıty for the northern hemısphere occurred a year after the sunspot maxı mum whıle for the southern hemısphere ıt occurred two years before sunspot maxımum The promınence actıvıty however showed very lıttle decrease ın the southern hemısphere durıng the next two years The northern mınımum for promınences came a year before and the southern mınımum a year after the correspondıng sunspot mınıma

1944 1950 —The publıshed Greenwıch sunspot areas are avaılable only up to 1946 and hence the sunspot curves do not extend beyond that year However accordıng to Zurıch relatıve sun spot numbers the peak of spot actıvıty takıng both hemıspheres together occurred ın 1947 The steep rıse of actıvıty from 1944 to 1947 surpassed the rate ın the three prevıous cycles Wıth a slıght fall the spot actıvıty persısted at a hıgh level durıng 1948 and 1949 after whıch a rapıd declıne set ın For the southern hemısphere promınence maxımum was reached ın 1947 In the northern hemısphere the actıvıty remaıned at a steady level durıng 1946 and 1947 after whıch there was a fall followed by a rıse to the maxımum ın 1949

Table III gıves the mean daıly areas of promınences and of sunspots for the northern and southern hemıspheres and also the excess north mınus south ın each case From thıs table we see that a northern excess or defect of sunspot actıvıty ıs not always accompanıed by a corres pondıng change of promınence actıvıty Such a correspondence exısts only ın 27 years out of 46 or ın about 60 per cent cases The ıntegrated actıvıty for the entıre perıod has been slıghtly more ın the northern hemısphere than ın the southern ın respect of promınences as well as of sun spots The percentage northern excess ıs about 4 per cent for promınences and 12 per cent for sunspots

TABLE—III

Mean Daily Areas of Prominences and Sunspots in the Northern and Southern Hemispheres

Y	P min (M da ly A as)			S nsp ts (M da ly A as)		
	N	S	N—S	N	S	N—S
1905	2463	2149	+ 314	750	440	+ 310
06	2328	1657	+ 671	539	39	+ 300
07	1945	2238	— 293	488	593	— 105
08	2496	3083	— 587	316	381	— 65
09	119	2058	+ 61	299	393	— 94
10	05	2069	— 14	66	198	— 132
1911	1273	1636	— 363	17	47	— 30
12	946	1507	— 561	1	37	— 36
13	1075	1098	— 23	5	3	+ 2
14	1503	1597	— 94	99	53	+ 46
15	2610	681	— 71	399	318	+ 81
16	2058	1702	+ 356	470	254	+ 216
17	2893	2273	+ 620	860	677	+ 183
18	1824	2385	561	609	509	+ 100
19	17 7	1928	— 201	559	493	+ 66
20	2045	2262	— 217	08	410	— 202
1921	1853	2282	— 429	261	1r9	+ 102
22	1771	1461	+ 310	161	91	+ 70
23	2354	2009	+ 345	33	22	+ 11
24	2793	2051	+ 742	232	45	+ 187
25	3012	2600	+ 412	517	313	+ 204
26	4314	3234	+1080	663	599	+ 64
27	3507	2998	+ 509	379	679	— 300
28	3675	3444	+ 231	727	663	+ 64
29	2269	2682	— 413	656	586	+ 70
30	2112	1945	+ 67	286	230	+ 56
1931	017	1922	+ 95	200	75	+ 125
32	1130	1020	+ 110	123	40	+ 83
33	1317	864	+ 453	86	2	+ 84
34	1832	1808	+ 24	44	74	— 30
35	2288	2569	— 281	205	419	— 214
36	3573	3463	+ 110	463	678	— 215
37	3437	3452	— 15	1317	757	+ 560
38	4384	3395	+ 989	899	1120	— 221
39	2409	2421	— 12	649	931	— 282
40	2296	2363	— 67	499	540	— 41
1941	2198	1591	+ 607	437	232	+ 205
42	1425	1782	— 357	252	171	+ 81
43	1089	1341	— 252	249	46	+ 03
44	1154	1285	— 131	42	83	— 41
45	1562	1739	— 177	121	309	— 188
46	2363	1905	+ 458	1127	690	+ 437
47	2363	3159	— 796			
48	2034	1900	+ 134			
49	2633	1643	+ 990			
1950	1506	1071	+ 435			
Total (1905 1950)	**102030**	**97722**	**+4308**			
Total (1905 1946)	**93494**	**89949**	**+3545**	**16313**	**14599**	**+1714**

6 Life History of the Low and High Latitude Prominences

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 some difference of opinion about the trend of activity in the low latitude or sunspot zones According to Evershed the high latitude prominence zones begin to be active between 40 and 50 soon after sunspot minimum With increasing sun spot activity the centres of high latitude prominence activity gradually move polewards until at the epoch of sunspot maximum there is a rapid rush towards the poles The high latitude prominence activity suddenly disappears soon after sunspot maximum The trend of activity in the low latitude zones is not so clear because of greater 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 the higher towards lower latitudes and dies out near the equator 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 zones are centred round ± 24 where they appear shortly after sunspot minimum wax in intensity with rising sunspot activity and finally recede and merge with the high latitude zones at about ± 40 before sunspot minimum

The latitude of separation between the low and high latitude prominence zones is not quite clear cut Bocchino and Barocas have taken this limit as ± 40 —the boundaries of the sunspot zone M and Mm D Azambuja (1948) have remarked that while this limit is nearly correct on the mean it varies with the phase of the sunspot cycle From their study of individual H alpha dark markings they found that at the beginning of the sunspot cycle the majority of the important prominences of the equatorial zones whose low latitude extremities were at 30 extended without discontinuity upto 55 At the end of the sunspot cycle the extreme latitudes of such prominences lay between 10 and 35 They have therefore ascribed a varying limit of demarcation ranging from 35 to 55 between the low and high latitude prominence zones depending upon the phase of the sunspot cycle For the discussion in the present paper we have taken a fixed limit of ± 40 between the two zones

An important finding of M and Mm D Azambuja from measurements made on long lived H alpha dark markings over the period 1919 to 1930 is that on the average all prominences have a slow pole ward drift in both the hemispheres The mean values for the pole ward drift ($\Delta\varphi$) per solar rotation derived by them are —

Lat zone	0 10	11 20	21 30	31 40	41 50	51 69
$\Delta\varphi$	2 3	1 6	1 3	1 2	0 9	0 8

The rate of pole ward drift was found to be at least twice as rapid in the ascending phase of the sunspot cycle than in the descending phase particularly in the high latitude zone

Based on the above findings M and Mm D Azambuja have advanced the view that all prominences originate in the sunspot zone and migrate towards higher latitudes During the ascending phase of the sunspot cycle the centres of activity at which prominences originate are assumed to be round about ± 30 and the rate of pole ward drift is high For both these reasons prominences are able to reach high latitudes right up to the poles During the declining phase of the cycle the centres of formation are assumed to be round about ± 15 and the velocity of pole ward migration is less Hence prominence activity does not reach much beyond ± 50 (Attention has however been drawn by the French astronomers to the fact that in the majority of cases there is no direct correspondence between the manifestations of prominence activity in the low and high latitude zones) M and Mm D Azambuja have emphasised that the observed general movement of prominences towards the poles at all latitudes indicates the probable existence of a meridional circulation on the sun which is postulated by certain solar theories

While the results and conclusions of the French astronomers briefly outlined above are largely based on the study of long lived hydrogen absorption markings (which are prominences seen in projection against the back ground of the solar disc) it is interesting to see how far these are confirmed by the statistical study of limb prominences which is the scope of the present investigation For this purpose the mean latitudes of the prominences of the low and high latitude zones were worked out in the following manner If A_1 A_3 A_5 are the mean daily areas of the prominences for the five degree zones 0 5 5 10 10 15 then the mean latitudes of prominence activity for the two zones are —

(*a*) Sunspot zone (0 40)

$$\varphi_S = \left(\frac{A + 3\ A + 5\ A + \qquad + 15\ A}{A + A + A + \qquad + A} \right) \times 2\ 5$$

(*b*) High latitude zone (40 90)

$$\varphi_H = \left(\frac{17\ A + 19\ A + \qquad + 35\ A}{A + A + \qquad + A} \right) \times 2\ 5$$

The values of φ_S and φ_H thus obtained are given in Table IV which also contains the mean daily prominence areas for the two zones The mean daily sunspot areas and the mean heliographic latitudes of the spots extracted from the Greenwich Photoheliographic Results are also given in this table

TABLE IV

Mean Latitudes and Areas of Low and High Latitude Prominences and of Sunspots

	NORTH						SOUTH					
Y	S pt		P m (0 40)		P m (40 90)		S nsp ts		P m (0 40)		P m en (40 90)	
	M A	M an L t	M Ar	M L t	M A	M L t	Mea A	M L t	Mean A	M L t	Me Are	M an L t
1905	750	11 66	1518	20 6	945	59 0	440	15 5	1434	19 9	715	60 6
06	539	13 98	1521	22 5	807	60 8	239	14 01	1042	19 3	615	61 8
07	488	10 12	1319	21 3	626	53 2	593	13 77	1328	20 8	910	61 7
08	316	10 42	1878	18 6	618	52 9	381	10 34	2136	19 5	947	56 6
09	299	9 45	1432	0	687	51 6	393	9 92	1607	19 9	451	51 0
10	66	8 55	1267	19 6	788	53 6	198	11 18	1395	19 1	674	51 3
1911	17	7 80	879	22 6	394	52 2	47	5 99	963	23 4	673	49 5
12	1	20 53	625	23 2	321	51 6	37	7 78	830	24 2	677	49 8
13	5	24 81	573	24 4	50	51 7	3	20 08	597	25 6	501	49 7
14	90	1 11	847	23 7	656	50 4	53	23 06	816	24 8	781	49 2
15	379	17 95	1466	21 6	1144	53 4	318	19 75	1502	20 5	1179	50 3
16	470	15 14	1070	4	988	60 1	254	17 05	904	20 4	798	57 1
17	860	13 82	1520	0	1364	63 7	677	15 66	1315	19 7	958	62 2
18	609	11 97	1291	19 9	533	64 5	509	13 69	1411	21 5	974	68 0
19	559	9 85	1446	19 1	281	40 0	493	11 79	1711	20 8	217	48 0
20	208	11 31	1711	20 3	334	49 2	410	9 98	1898	19 9	364	48 5
1921	261	7 27	1349	21 8	504	46 7	159	8 92	1503	21 0	779	51 4
22	161	8 82	1065	20 9	706	49 0	91	6 62	875	23 6	586	47 8
23	33	13 88	1037	21 8	1317	51 3	22	17 32	940	22 6	1069	49 0
24	23	2 19	1242	23 0	1551	52 3	45	25 54	915	23 1	1136	51 5
25	517	20 70	1700	20 3	1312	55 4	313	19 37	1365	21 1	1235	52 6
26	663	19 27	2118	1 1	2136	62 9	590	17 08	1808	21 0	1426	61 5
27	379	17 75	1670	20 2	1837	62 7	679	13 54	1601	19 6	1397	67 0
28	727	11 93	2156	20 7	1519	62 0	663	15 23	2298	20 5	1146	56 8
29	656	10 73	1684	21 8	585	54 0	586	10 27	1907	19 6	775	54 8
30	286	10 60	1582	21 8	530	49 7	230	8 96	1706	19 1	39	50 6
1931	200	7 91	1417	21 8	600	48 5	75	9 39	1342	20 6	580	48 1
32	123	8 22	770	21 9	360	48 4	40	8 62	626	22 6	394	47 6
33	86	10 60	983	24 7	334	47 0	2	8 35	672	26 4	192	48 2
34	44	16 45	1114	24 4	718	42 0	74	28 09	1056	24 6	752	49 4
35	205	22 42	1309	21 0	979	48 6	419	23 72	1501	21 8	1068	50 8
36	463	19 36	2002	19 9	1571	53 6	678	21 02	2134	19 4	1329	57 4
37	1317	17 63	1777	19 7	1660	62 5	757	15 96	1953	19 4	1499	65 8
38	899	15 55	2478	21 0	1906	66 1	1120	14 17	2304	19 9	1091	51
39	649	14 64	1891	21 6	518	48 1	931	12 57	2037	20 1	384	49 4
40	499	11 65	17 7	20 8	539	48 7	540	10 72	1941	21 1	422	49 1

TABLE IV—*contd*

Mean Latitudes and Areas of Low and High Latitude Prominences and of Sunspots—*contd*

Y ar	NORTH Sunsp ts		Prom nence (0 -40)		P mm (40 90)		SOUTH S nsp t		P mm n es (0 40)		P om es (40 90)	
	Mea Ar	M L t	M an Ar	Mea L t	M n Are	M L t	Mean A	M an L t	M an Are	Mean L t	M an Ar	M n L t
1941	437	11 13	1730	21 2	468	50 5	232	8 67	1375	19 9	216	47 9
42	252	9 32	1267	20 6	158	50 2	171	8 45	1397	21 2	385	47 3
43	249	9 01	909	24 0	180	47 6	46	15 87	838	20 6	503	49 2
44	42	19 00	758	28 0	396	46 1	83	22 81	688	23 6	597	48 6
45	121	20 13	867	21 9	695	49 5	309	20 26	934	22 1	805	51 0
46	1127	20 74	1332	21 6	1031	52 6	690	18 79	1120	21 0	785	52 3
47			1330	20 9	1033	59 2			1577	21 1	1582	58 6
48			1033	19 7	1001	64 1			1038	20 9	862	65 5
49			1655	21 5	978	57 6			1268	20 1	375	49 5
1950			1198	21 8	308	51 7			893	20 2	178	50 0
Total (1905 1950)			**63552**		**38478**				**62501**		**35221**	
Total (1905 1946)	**16313**		**58336**		**35158**		**14599**		**57725**		**32224**	

The mean latitudes of high and low latitude prominences and of the sunspots for the two hemispheres are graphically represented in Fig 5 Fig 6 represents the mean daily prominence areas for the low and high latitude zones and also the mean daily sunspot areas for the two hemispheres In Fig 7 the peaks of prominence activity in the various five degree zones have been plotted against the years The primary peaks are indicated by black dots and the secondary peaks by open circles The history of prominence activity in the low and high latitude zones is clearly brought out by Figs 3 5 6 and 7

Prominence activity is comparatively short lived above latitude 60 In the polar zones from 75 to 90 its maximum phase is practically coincident with the epoch of sunspot maximum The corresponding years of prominence and sunspot maxima are —

P m maxim m (75 90)	N	1906	1917 18	1926 27	1938	1948
	S	1907	1918	1927	1937	1948
Sun p t maximum	N	1905	1917	1928	1937	1947
	S	1907	1917	1927	1938	

The high latitude prominence activity can be traced back to latitude 40 45 (*vide* Figs 3 and 7) where it begins to manifest itself about two years before sunspot minimum and becomes quite conspicuous immediately after the minimum of spot activity is reached Fig 7 indicates a progressive march of the peak of high latitude prominence activity from 40 45 latitude belt to the poles during the ascending phase of the sunspot cycle From the trend of these peaks we may calculate the mean rate of pole ward drift of the prominences of the high latitude zone A period of 3 to 4 years elapses between the first appearance of high latitude prominence activity near latitude 45 and the appearance of prominence activity at the poles Assuming a uniform rate of poleward drift we get a mean latitudinal movement of 11 to 15 per year or about 0 8 to 1 1 per solar rotation —a value in fair agreement with that found by M and M[me] D Azambuja

A pole ward drift of about 1 in 30 days was also found by Moss (1946) for high latitude prominences from a study of the Kodaikanal prominence data for the period 1905 to 1928

A more critical examination of Figs 3 and 7 indicates that the march of prominence activity from 70 to the poles is somewhat more rapid than the progress from 45 to 70 There is hardly an interval of 1 year between the prominence maximum in the zone 65 70 and the maximum activity in all the higher five degree zones up to the poles The progress of activity from 45 70 takes about 2 to 3 years We therefore get a mean pole ward drift of 8 12 per year (or 0 6 to 0 9 per solar rotation) from 45 70 and 20 per year (or 1 5 per solar rotation) from 70 90 This indicates an accelerated pole ward drift on approaching the poles The sudden appearance of prominence activity at the poles practically simultaneous with the epoch of sunspot maximum was designated by Evershed as dash to the poles of prominences

In the low latitude or sunspot zone (0 40) no direct evidence for the pole ward drift of the prominences can be adduced from the present study based on annual means Some interesting features are however brought out by Fig 5 which depicts the variation in the mean latitudes of low and high latitude prominences and of sunspots As is well known the mean latitude of sunspots is lowest just before the minimum of the cycle At the minimum epoch spots of the new cycle already begin to appear at the higher latitudes between 30 and 40 so that there is a steep increase in the mean latitude of the spots the maximum being reached shortly after the epoch of sunspot minimum The mean latitude of sunspots ranges from about 7 to 28 The interval from minimum to maximum is seen to vary from 1 to 3 years while the corresponding interval from maximum to minimum varies from 8 to 9 years during the sunspot cycles covered by the present study

When we consider the manner in which the mean latitude of the prominences of the sunspot zone varies we find that the range of variation is much less than that of sunspots The mean latitude of low latitude prominences varies from 19 to 26 which is only about a third of the range for sunspots For most of the time the mean prominence activity is centred round about 20 which is the mean latitude of the sunspot zone The maximum mean latitude for low latitude prominences is reached generally about a year ahead of that for sunspots that is almost simultaneous with sunspot minimum The mean latitude of low latitude prominences attains a minimum at or near the epoch of sunspot maximum In this connection it is interesting to see how the prominence activity in the five degree belts of the low latitude zone varies in the course of the sunspot cycles Examination of Figs 3a and 3b shows that the variations are generally in phase with the sunspot cycle but the *amplitude of variation becomes less as we approach the limits of the sunspot zone* This accounts for the highest mean latitude of low latitude prominence activity at the time of sunspot minimum

M and Mme D Azambuja explain the lack of prominence activity beyond latitude ±50 at the declining phase of the sunspot cycle by assuming the centre of origin of prominences at about latitude ±15 and showing by rough calculation that the pole ward drift in about 2½ years will not take such prominences beyond ±50 We should however consider the fact that the origin of the prominences in the sunspot zone and their pole ward migration take place continuously throughout the sunspot cycle in such a way that *prominence activity is always present at the boundaries of the sunspot zone where it undergoes the least variation in the course of the sunspot cycle* Why then should there be no activity beyond 55 at the declining phase of the sunspot cycle a fact so clearly brought out by Figs 3a and 3b If we assume with M and Mme D Azambuja that the high latitude prominences are transported from the sunspot zone by a meridional circulation then the velocity of this circulation probably decreases rapidly beyond the sunspot zone and becomes vanishingly small at latitude ±55 That is the meridional circulation undergoes a cyclic variation in phase with the sunspot cycle The work of the French astronomers has already furnished some evidence in this direction but as they have remarked it is necessary to undertake new measurements on the pole ward drift of prominences in the sunspot and high latitude zones to confirm their results and establish them more precisely

The mean latitude of high latitude prominences varies from about 42 to 68 It reaches the lowest value approximately when the low latitude prominences have their highest mean latitude that is at the epoch of sunspot minimum The highest mean latitude of high latitude prominences is reached almost simultaneous with the epoch of sunspot maximum The maximum mean latitude of sunspots and the corresponding latitude of high latitude prominences are separated by about 40 and a time interval of 3 to 4 years from which again we may calculate a mean pole ward drift of 10 to 13 per year or about 1 per solar rotation for prominences of the high latitude zone if they have their origin in the sunspot zone

The comparison of the prominence areas for the low and high latitude zones with the sun spot areas (Fig 6) brings out some interesting features For the sunspot zones the minimum of prominence activity occurs in the same year or a year before the minimum of spot activity The prominence maxima are characterised by multiple peaks in both the hemispheres the peaks being generally double and at times triple indicating two or three outbursts of prominence activity The low latitude prominence activity corresponding to the sunspot cycle of 1913 23 presents some extraordinary features The northern hemisphere shows three peaks and the southern two The highest prominence activity in both the hemispheres occurred in 1920 three years after the sunspot maximum—by which time the high latitude prominences had already attained a minimum For the next three cycles the low latitude prominence maxima occurred either simultaneously with or a year after the sunspot maxima A retardation of prominences over sun spots is thus indicated If we now consider the high latitude prominences we find that the minimum is reached 1 to 4 years before the minimum of sunspot activity while the maximum is reached in the same year as the sunspot maximum or one to two years before it Thus generally speaking the indications are that in the sunspot zone prominence activity slightly lags behind spot activity while in the high latitude zone prominence activity leads over the spot activity

M and M^{m} D Azambuja (1948) have investigated the correlation between prominences and sunspots Their researches have revealed that an impulse of spot activity is generally followed by an impulse of prominence activity in the sunspot zone after 3 or 4 solar rotations A correlation of this nature should be brought out by a comparative study of the monthly means of prominence and sunspot areas It is hoped to go into this question at a future date

7 Mean Daily Heights Extents and Numbers of Prominences

At Kodaikanal the height of a prominence is reckoned as the elevation above the chromosphere of the highest point of the prominence The extent of a prominence is reckoned as the number of degrees along the solar limb for which the prominence appears continuous All prominences observed daily are tabulated in this manner and the mean heights and extents are worked out for each month each quarter and each half year The mean height (in seconds of arc) and the mean extent (in degrees along the solar limb) of the prominences for the period 1915 to 1950* are listed in Table V and represented diagrammatically in Fig 8 In this figure the mean extent of base is represented along the abscissa and the height along the ordinate The interval between the marks corresponding to adjacent years represents an extent of base of 10 Thus the horizontal extent or thickness of each rectangular block is proportional to the extent of base while its vertical extent is proportional to the mean height of the prominences for the corresponding year Both these parameters undergo variations generally in unison with the sun spot cycle The mean extent of base varies from 3 to 7 while the mean height varies between 30 and 50 seconds It will be seen from Fig 8 that the mean height is a maximum for the latest sunspot cycle while the mean extent of base is a maximum for the cycle just previous to it The reason for the lower prominence activity during the latest cycle (*vide* Section 10) is to be attributed to the smaller number of prominences during this cycle as compared with the two previous cycles The mean daily prominence numbers from the Kodaikanal records which are also given in Table V indicate that this was actually the case For reasons explained in Section 2 these numbers do not however constitute a reliable index of prominence activity

---

I th K daik al d mean h ights f p min ilabl f m 1904 d m t ts f m 1912 wa d
A rutiny f th dat h w er h ws th t th d t p t 1915 ar n t q t mp bl w th th sub q t dat
Hon th se ha t b t ken int ns d rat th present dis uss n

TABLE—V
Mean Daily Heights Extents and Numbers of Prominences

Y	H ght (S l f A	Ext t (D gr)	N mb	Y	H ight (S d f A)	Ext t (D gr)	N mb
1915	36 8	3 50	18 68	1933	39 3	4 47	8 72
16	3 3	2 94	18 97	34	34 4	4 43	12 96
17	38 1	3 66	19 3	35	37	5 61	13 58
18	33 2	3 52	17 05	36	4 4	7 41	15 0
19	31 7	3 14	1 48	37	42 9	7 02	15 37
20	31 3	3 19	14 55	38	43 7	7 60	14 84
				39	38 9	6 34	13 06
1921	31 8	3 52	14 09	40	37	5 77	13 52
22	33 9	3 02	10 70				
23	33 7	3 71	1r 25	1941	33 7	4 71	1 64
24	35 5	4 24	14 74	42	34 4	4 15	10 88
25	37 7	4 65	16 44	43	3r 4	3 00	8 98
26	40 6	5 69	17 84	44	41 5	5 54	7 40
27	37 1	r 39	19 19	45	46 5	6 6	9 61
28	4 6	6 85	18 35	46	51 7	6 78	10 74
29	36 9	6 30	13 75	47	48 0	5 49	12 40
30	3 8	5 77	11 67	48	43 4	4 55	12 09
				49	4 3	4 74	10 23
1931	31 8	[illegible]	12 91				
32	32 2	3 76	0 58	1950	40 3	3 98	7 64

8 Metallic Prominences

Hydrogen helium and singly ionised calcium are the main constituents of the majority of solar prominences and prominence spectra invariably exhibit the emission lines belonging to the Balmer series of hydrogen the D line of helium and the H and K lines of Ca^+ In fact hydrogen and Ca^+ are so closely interlinked in prominences that spectroheliograms taken in the H alpha and K lines indicate that quiescent prominences have no essential differences in form in these two elements as has been shown by Dr Royds (1932) and others Dr Royds also found that even in the case of eruptive prominences the similarity of form persists and both the elements partake equally in the motion

It is well known from observations of flash spectra that the three elements which are most abundant in prominences are also those which rise to greater heights in the chromosphere compared with other elements According to Mitchell (1935) the H and K lines of Ca^+ can be traced upto a height of 14 000 km in the chromosphere the H alpha line upto 12 000 kms H beta upto 8 500 kms and H gamma and H delta upto 8 000 kms Next in order of height come helium (7 500 kms) Mg (7 000 kms) Ti^+ Sc^+ Sr^+ (6 000 kms) neutral Ca (5 000 kms) Al (2 000 kms) and Fe Ti V Cr Sr Ni Co Mn (1 500 to 3 000 kms) Several lines belonging to the low lying elements neutral or ionised are found in the spectra of prominences during total eclipses but are ordinarily not observed Occasionally prominences do appear in which emission lines of one or more of the elements Mg Na Fe Fe^+ Cr etc appear conspicuously even outside an eclipse Such prominences are generally small intense very active and short lived and hence they form a class by themselves In the Kodaikanal records they are classified and tabulated under the heading Metallic Prominences The emission lines which are generally observed in such prominences in visual observations with the prominence spectroscope are given in the following table —

λ	Elem t	λ	Elem t
4923 92	F^+	5275 99	F^+ Cr
5015 68	H	5316 61	F^+
5018 43	F^+	5362 86	F^+
b b b b	Mg F F^+	D D	N
5234 62	F^+	6678 10	H F
5275 25	C	7065 20	H

In the great majority of them the D lines of sodium the b lines of magnesium and the enhanced lines of iron appear prominently

Table VI (Appendix) gives the frequency distribution in five degree zones of all metallic prominences observed at Kodaikanal during the period 1904 to 1950 It is based on visual observations of the solar limb made with the prominence spectroscope generally between 8 A M and 10 A M on all clear days A casual examination of the frequency table reveals the close connection between metallic prominences and sunspots They are most abundant in the sun spot zone and the frequency pattern resembles the well known butterfly diagram of Maunder The maximum frequency of metallic prominences in both the hemispheres occurs in the latitude belt 10 20 Such prominences are often observed in the vicinity of active sunspots when they are just appearing at the east limb or disappearing at the west limb Some of them at least may be manifestations of flares occurring at the limb

Are metallic prominences exclusively confined to the sunspot zone ? We see from Table VI that this is not the case although their frequency of occurrence falls off very rapidly outside the confines of the sunspot zone In this respect we find that the observations of the earlier years from 1904 to 1920 indicate a somewhat greater frequency in the higher latitudes as compared with the subsequent period Hardly any metallic prominences have been recorded above latitude 60 since 1920 while we find that prior to this year such prominences have been observed upto latitude 85 Evershed analysed the metallic prominences observed at Kodaikanal during the period 1904 to 1914 and found that about 15 per cent of them occurred above latitude 40 From the percentage frequencies for different five degree zones given at the end of Table VI we see that about 95 per cent of metallic prominences were observed within the sunspot zone during the period 1904 to 1950

9 Comparison of Prominence Activity on the East and West Limbs

Since the publication of Mrs Maunder s well known paper (1907) in which she showed that there is a well marked and steady preponderance of the eastern half of the sun s disc over the western half both as regards the areas of the spots and as to the numbers of the separate groups several investigators have sought to find if there is a similar asymmetry in the case of other solar phenomena Towards the end of her paper Mrs Maunder showed that the unexpected asymmetry revealed by her analysis of sunspots for the period 1889 1901 existed also in the case of prominences She found that the Italian prominence observations for the period 1882 to 1904 showed a steady eastern excess of prominences for all the years The eastern excess of sunspots and prominences was interpreted as an apparent extinguishing effect of the earth on these two forms of solar phenomena

At Kodaikanal Evershed (1912) examined the distribution of prominences on the east and west limbs for the period 1894 to 1912 and found that there was a systematic eastern preponderance of prominence numbers In the case of prominence areas the excess was less marked than for numbers and was often in favour of the west limb Following a different method of analysis Evershed and Chidambara Iyer (1921) were led to a conclusion apparently opposed to the suggestion that the earth tends to extinguish a prominence in its passage across the visible disc

Royds and Sitarama Ayyar (1913) applied the periodogram method of Schuster for interpreting the eastern excess of prominences for the years 1904 1912 discussed by Evershed They were led to the conclusion that the excess cannot be interpreted as due to planetary influences and that an effect due to the earth is improbable Das and Narayan (1940) made a statistical study of solar prominences observed at Kodaikanal during the period 1913 37 They found that the maximum mean daily area of prominences occurred in January and the minimum in July This was interpreted as evidence of the existence of a tide raising influence of the earth on the sun Recently a number of papers on Solar Asymmetry and ' Planetary Influences on the Sun have appeared in the *Bulletin of the Central Astronomical Institute of Czechoslovakia* by Link and his co workers (1951 1952 and 1953) In view of the long standing nature of this problem we have felt ıt worthwhıle to consıder ın some detaıl the East West dıstrıbutıon of promı nences durıng the perıod covered by the present study

Table VII gıves the mean daıly promınence areas for the east and west lımbs year by year from 1905 to 1950 The last column of thıs table gıves the eastern excess E mınus W We see that there has been an eastern excess of promınences only ın 11 years out of 41 Out of the 20 years from 1931 to 1950 promınence actıvıty has been more pronounced on the west lımb durıng 18 years For the entıre perıod of 41 years promınence actıvıty on the west lımb has been 3 5 per cent greater than that on the east lımb For the perıod 1931 to 1950 the correspondıng value ıs 5 5 per cent The largest western excess of 17 2 per cent occurred ın 1950 For the years 1920 1926 1931 1942 1945 and 1949 the western excess amounted to over 14 per cent We thus see that promınence actıvıty ȷudged by profile area of promınences has been more at the west lımb of the sun The western excess ıs more pronounced sınce 1920 than ın prevıous years

TABLE—VII
East West Dıstrıbutıon of Promınence Areas

Y	East	W t	E—W
1905	2390	222	+ 168
06	026	1959	+ 67
07			
08			
09			
10			
1911			
12	1187	1266	— 79
13	1116	1057	+ 59
14	1594	1506	+ 88
15	2598	2603	— 95
16	1889	1871	+ 18
17	565	2601	— 36
18	2081	2128	— 47
19	1851	1804	+ 47
20	2005	2302	—297
1921	2054	2081	— 27
22	1609	16 3	— 14
23	095	2268	—173
24	490	2354	+136
25	2727	885	—158
26	3514	4034	—520
27	3178	3327	—149
28	3598	3521	+ 77
29	2440	2511	— 71
30	2111	1946	+165
1931	1837	2102	—265
32	1018	1132	—114
33	1032	1149	—117
34	1919	1721	+198
35	2318	2539	—221
36	3500	3536	— 36
37	3502	3387	+115
38	3871	3908	— 37
39	2371	2459	— 88
40	2322	2337	— 15
1941	1858	1931	— 73
42	1563	1644	— 81
43	1130	1300	—170
44	1175	1264	— 89
45	1542	1759	—217
46	2047	2221	—174
47	2658	2864	—206
48	1918	2016	— 98
49	1975	2301	—326
1950	1184	1393	—209
Total	87858	90922	—3064

For a closer study of the east west asymmetry of promınence areas we consıder the northern and southern hemıspheres separately Tables VIII (*a*) and (*b*) gıve the east-west dıstrıbutıon of mean

TABLE—VIII(*a*)
East West Dıstrıbutıon of Prominence Areas (North Hemısphere)

Y ar	NE			NW			NE—NW		
		b	= +b		b	= +b		b b	
	0 40	40 90	0 90	0 40	40 90	0 90			
1905	794	462	1256	724	483	1207	+ 70	—21	+ 49
06	787	433	1220	734	374	1108	+ 53	+59	+112
1912	283	155	438	34	166	508	— 59	—11	— 70
13	293	257	550	280	245	525	+ 13	+12	+ 25
14	487	336	823	360	320	680	+127	+16	+143
15	767	540	1307	699	604	1303	+ 68	—64	+ 4
16	483	519	1002	587	469	1056	—104	+50	— 54
17	796	646	1442	733	718	1451	+ 6	—72	— 9

TABLE—VIII(*a*)—*contd*

East West Distribution of prominence Areas (North Hemisphere)—*contd*

Y	NE			NW			NE—NW		
		b	= +b		b	= +b			
	0 -40	40 90	0 90	0 40	40 90	0 90	a—	b—b	c—c
1918	650	298	948	641	35	876	+ 9	+ 63	+ 72
19	619	143	762	827	138	965	—208	+ 5	—203
20	791	181	972	920	153	1073	—129	+ 28	—101
1921	680	250	930	669	251	923	+ 11	— 4	+ 7
22	524	354	878	541	352	893	— 17	+ 2	— 15
23	437	669	1106	600	648	1248	—163	+ 21	—142
24	669	789	1458	573	762	1335	+ 96	+ 27	+123
25	715	671	1386	985	641	16 6	—270	+ 30	—.40
26	932	1082	2014	1186	1114	2300	—254	— 32	—286
27	824	899	1723	846	938	1784	— 22	— 39	— 61
28	1061	745	1806	1095	774	1869	— 34	— 29	— 63
29	840	278	1118	844	307	1151	— 4	— 29	— 33
30	779	266	1045	803	264	1067	— 24	+ 2	— 22
1931	600	298	898	817	302	1119	—217	— 4	—221
32	347	183	530	423	177	600	— 76	+ 6	— 70
33	429	179	608	554	155	709	—125	+ 24	—101
34	583	371	954	531	347	878	+ 52	+ 24	+ 76
35	622	499	1121	687	480	1167	— 65	+ 19	— 46
36	961	791	1752	1041	780	1821	— 80	+ 11	— 69
37	798	844	1642	979	816	1795	—181	+ 28	—153
38	1227	933	2160	1251	973	2224	— 24	— 40	— 64
39	880	254	1134	1011	264	1275	—131	— 10	—141
40	808	276	1084	949	263	1212	—141	+ 13	—128
1941	800	227	1027	930	241	1171	—130	— 14	—144
42	622	61	683	645	97	742	— 23	— 36	— 59
43	418	94	512	491	86	577	— 73	+ 8	— 65
44	375	162	537	383	234	617	— 8	— 72	— 80
45	377	308	685	490	387	877	—113	— 79	—19
46	639	471	1110	693	560	1253	— 54	— 89	—143
47	649	555	1204	681	478	1159	— 32	+ 77	+ 45
48	494	522	1016	539	479	1018	— 45	+ 43	— 2
49	717	437	1154	938	541	1479	—221	—104	—325
1950	536	186	722	662	122	784	—126	+ 64	— 62
Total	27093	17624	44717	29684	17741	47425	—2591	—117	—2708

TABLE VIII(*b*)

East West Distribution of Prominence Areas (South Hemisphere)

Y	SE			SW			SE—SW		
		b	=a+b	a	b	= +b			
	0 40	40 90	0 90	0 40	40 90	0 90	—a	b—b	c—c
1905	760	374	1134	674	341	1015	+ 86	+ 33	+119
06	527	279	806	515	336	851	+ 12	— 57	— 45
1912	421	328	749	409	349	758	+ 12	— 21	— 9
13	307	259	566	290	242	532	+ 17	+ 17	+ 34
14	388	383	771	428	398	8 6	— 40	— 15	— 55
15	756	535	1291	746	644	1390	+ 10	—109	— 99
16	481	406	887	423	392	815	+ 58	+ 14	+ 72
17	649	474	1123	666	484	1150	— 17	— 10	— 27
18	713	420	1133	698	554	1252	+ 15	—134	—119
19	963	126	1089	748	91	839	+215	+ 35	+250
20	856	177	1033	1042	187	1229	—186	— 10	—196

TABLE VIII(*b*)—*contd*

East West Distribution of Prominence Areas (South Hemisphere)—*contd*

	SE			SW			SE—SW		
		b	= +b		b	= +b		b —l	
	0 40	40 90	0 90	0 90	40 90	0 90			
1921	7 9	305	1124	774	384	1158	— 4	+ 11	— 34
22	397	334	731	478	52	730	— 81	+ 8	+ 1
23	454	535	989	486	534	10 0	— 3	+ 1	— 31
24	456	576	103	459	560	1019	— 3	+ 16	+ 13
25	6 0	721	1341	745	514	1259	—1 5	+ 06	+ 82
26	849	651	1500	959	775	1734	—110	—1 4	— 34
27	795	660	1455	806	737	1543	— 11	— 77	— 88
28	1198	594	1792	1100	55	165	+ 98	+ 4	+140
29	944	378	132[illegible]	963	397	1360	— 19	— 19	— 38
30	95	114	1066	754	125	879	+198	— 11	+187
1931	634	305	939	708	275	953	— 74	+ 30	— 44
32	84	04	488	342	190	53	— 58	+ 14	— 44
33	333	91	424	339	101	440	— 6	— 10	— 16
34	543	42	965	513	330	843	+ 30	+ 9	+12
35	751	446	1197	750	622	137	+ 1	—176	—175
36	1084	664	1748	1050	665	1715	+ 34	— 1	+ 33
37	1022	838	1860	931	661	1592	+ 91	+177	+ 68
38	11 1	590	1711	1183	501	1684	— 62	+ 89	+ 7
39	10 3	14	1237	1014	170	1184	+ 9	+ 44	+ 53
40	1036	20	1238	905	220	11 5	+131	— 18	+113
1941	713	118	831	66	98	760	+ 51	+ 0	+ 71
42	604	186	880	703	109	902	— 9	— 13	— 22
43	41	206	618	426	297	723	— 14	— 91	—105
44	3 0	318	638	368	279	647	— 48	+ 39	— 9
45	448	409	857	486	396	882	— 38	+ 13	— 5
46	537	400	937	583	385	968	— 46	+ 15	— 31
47	783	671	1454	794	911	1705	— 11	— 40	251
48	516	386	90	5	476	998	— 6	— 90	— 96
49	608	213	8 1	660	16	822	— 5	+ 51	— 1
1950	405	57	462	488	1 1	609	— 83	— 64	—147
Total	**27482**	**15659**	**43141**	**27590**	**15907**	**43497**	**—108**	**—248**	**—356**

daily prominence areas for the two hemishperes The data are given separately for the sunspot zones and for the high latitude zones An examination of these tables reveals the following facts —

(*a*) *Sunspot zone* (0 —40)

(i) For the entire period of 41 years prominence activity at the east limb has been slightly more in the southern hemisphere than in the north the magnitude of the excess $\frac{S-N}{N}$ being 1 44 per cent At the west limb however prominence activity has been appreciably less in the southern hemisphere compared with the north the deficit $\frac{S-N}{N}$ being 7 05 per cent

(ii) There has been western excess of prominences in both the hemispheres the magnitude of the excess $\frac{W-E}{F}$ being 9 56 per cent for the north hemisphere and 0 39 per cent for the south Thus the hemisphere with smaller total prominence area at the east limb shows larger western excess

(iii) There has been western excess of prominence activity for 31 years in the northern hemisphere and for 24 years in the southern hemisphere during the total period of 41 years

(*b*) *High Latitude Zone* (40 —90)

(i) On the whole prominence activity at the east and west limbs has been less in the southern hemishpere the deficit $\frac{S-N}{N}$ being 11 14 per cent and 10 33 per cent respectively for the two limbs

(ii) There has been western excess of prominence activity in both the hemispheres the magnitude of $\frac{W-E}{E}$ being 0 66 per cent for the north and 1 58 per cent for the south Again we find that the hemisphere with smaller total prominence area at the east limb shows larger western excess

(iii) There has been western excess of prominence activity for 18 years in the northern hemisphere and for 20 years in the southern hemisphere during the total period of 41 years

Judged by profile areas the aggregate prominence activity for the high latitude zones has been 60 per cent of that for the sunspot zones

The main feature brought out by the above analysis is that during the period covered by the present study the east west asymmetry has been more conspicuous for the sunspot zone than for the high latitude zone The asymmetry has been most pronounced for the sunspot zone of the northern hemisphere despite the fact that the total prominence area at the east limb of this zone has been less compared with the southern hemisphere

Indeed over 85 per cent of the total observed western excess for the sun as a whole arises from the sunspot zone of the northern hemisphere Since neither the observational technique nor the method of evaluation of prominence areas from the photographs gives a preferential bias to either hemisphere the observed asymmetry between the two hemisphere as brought out by the east west distribution of prominence areas appears to be an intrinsic feature of prominence activity during the period under consideration It does not seem possible to explain the observed facts on the basis of terrestrial or planetary influences on the sun

In this connection a recent study of the eastern excess of sunspots by Romana and Torroja (1948) appears to be of interest From one of the tables presented in their paper it is seen that the eastern excess of sunspots has been much less conspicuous since 1930 than during the half century prior to this year As a matter of fact the integrated spot activity for the period 1930 to 194 shows a western excess It is also seen that the eastern excess of sunspots was particularly well marked in the solar cycle investigated by Mrs Maunder This change in trend has been interpreted by them as a slow periodic variation of the inclination of the axes of sunspots with an amplitude of 3 around a mean position of 1 15 towards the west From a short note by M Hotinli (1952) in the *Publications of the Istanbul University Observatory* it is seen that during each of the years 1948 1949 and 1950 more spots were observed on the western half of the sun s disc than on its eastern half the western excess being about 6 to 7 per cent

10 Solar Activity during the Latest Sunspot Cycle

It is well known that judged by spot activity the latest solar cycle which attained its maximum in 1947 is one of the most active on record This cycle has also the unique distinction of having been characterised by some of the biggest spot groups ever observed But even a casual examination of Figs 3 and 4 which illustrate this paper shows that prominence activity has been less pronounced during the latest solar cycle as compared with the two previous ones with maxima during 1937 and 1928 In this connection it is worth recalling that Behr and Sidentopf (1952) and Kleczek (1953) have found from their analyses of solar flare data that flare activity has also been less during the latest cycle as compared with the previous one These facts tend to confirm the result which is repeatedly brought home by solar researches that the broad correlation between sunspots and other solar phenomena does not mean that there is one to one correspondence among them and that no single factor can furnish an adequate measure of solar activity

11 Acknowledgement

The survey and discussion presented in the preceding pages are based on prominence observations and computations made by many members of staff of the Kodaikanal Observatory under the directions of its successive directors Prof C Michie Smith Mr J Evershed Dr T Royds Dr A L Narayan and Dr A K Das To all of them our thanks are due

SUMMARY

The paper contains a discussion of the results of solar prominence observations made at Kodaikanal during the first half of this century The first two sections give an account of the observational procedure and the nature of the available data on which the rest of the paper is based The distribution of mean daily profile areas of prominences according to heliographic latitude for the period 1905 1950 is given in Table II (Appendix) The variation of prominence activity in the course of the sunspot cycle for the northern and southern hemispheres is illustrated by Figs 3(*a*) and 3(*b*) Comparison of prominence and sunspot activities in the two hemispheres shows that a northern excess of spot activity is not always accompanied by a corresponding excess of prominence activity The life history of the low and high latitude prominence zones is considered A mean poleward drift of about 1 per solar rotation has been found for the prominences of the high latitude zone in fair agreement with the value found by M and M D Azambuja by measurements made on long lived H alpha dark markings There is some evidence of an accelerated poleward drift as the prominences approach the poles The mean heliographic latitudes and the mean daily areas have been worked out for the prominences of the sunspot and high latitude zones and compared with the mean latitudes and mean daily areas of sunspots Generally speaking prominence activity in the sunspot zone attains its highest mean latitude (about 26) at the time of sunspot minimum and the lowest mean latitude (about 19) at the time of spot maximum High latitude prominences on the other hand attain their lowest mean latitude (about 42) at sunspot minimum and highest mean latitude (about 68) near spot maximum Prominence activity undergoes the least variation at the boundaries of the sunspot zone (±40) during the course of the solar cycle The highest prominence activity occurs near ±50 during the ascending phase of the sunspot cycle

The mean daily heights extents and numbers of prominences undergo variations more or less in unison with the sunspot cycle The frequency of metallic prominences during 1904 to 1950 indicates their close association with sunspots 9 per cent of such prominences were observed within the sunspot zone Comparison of prominence activity on the east and west limbs indicates a western preponderance the western excess being most pronounced in the sunspot zone of the northern hemisphere It is found that the aggregate prominence activity has been less during the latest solar cycle as compared with the previous two cycles despite the fact that judged by spot activity the latest cycle is one of the highest on record

KODAIKANAL OBSERVATORY
NOVEMBER 19 3

R Ananthakrishnan
P Madhavan Nayar

References

1 Ananthakrishnan R *Nature* Vol 170 p 156 (19 2)
2 Barocas V *Ap J* Vol 89 p 486 (1939)
3 Behr A and Siedentopf H *Z f Ap* Vol 30 p 177 (195)
4 Bocchino G *M S A Ital* V l 6 p 479 (1933)
5 Brunner Hagger W *Astro Mitt Zurich* No 140 p 522 31 (1940)
6 Das A K and Narayan B G *Ind J Phys* Vol 14 p 311 (1940)
7 D Azambuja L M and M *Ann d Ol Paris* Vol 6 Fas 7 (1948)
8 Evershed J *Bull Kod Obs* Vol 2 p 09 (1912)
9 Evershed J and Evershed M A *Mem Kod Obs* Vol I Part p 5 (1917)
10 Evershed J and Chidambara Iyar P R *Bull Kod Obs* Vol 4 p 1 (1921)
11 Hotinli M *Pub Ist Uni Obs* Vol 17 Series A No 4 p 384 (19 2)
12 Kleczek N *Bull Ast Inst Cza* Vol 4 p 9 (1953)
13 Lockyer N and Lockyer W J S *M N R A S* Vol 63 p 446 (1903)
14 Maunder A S D *M N R A S* Vol 67 p 451 (1907)
1 Mitchell S A *Eclipse of the Sun* 4th Edn p 342 (1935)
16 Moss W *Ann Sol Phy Obs Cambridge* Vol 3 p 119 (1946)
17 Ricco A *M S Sp Ital* Vol 20 p 135 (1891)
18 Ricco A *M S Sp Ital* (2nd Series) Vol 3 p 17 (1914)
19 Romana A and Torroja J M *Urania* Vol 32 No 218 p 1 (1948)
20 Royds T *Bull Kod Obs* Vol 4 p 37 (1932)
21 Royds T and Sitarama Ayyar S *Bull Kod Obs* Vol 3 p 37 (1913)