A DEPENDENCE ON SOLAR CYCLE OF THE SIZE OF THE Ca^+ NETWORK

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Abstract. Calcium network diameters are shown to be smaller by 5% at solar maximum than at minimum. The average cell size at minimum is $22\,115 \pm 99$ km. The average size at solar maximum is $20\,920 \pm 112$ km, though individual maxima perform differently from each other depending probably on the dispersed remnant magnetic fields. The change in size of the network is interpreted in terms of changes in the size of the supergranular convective cell.

1. Introduction

The coarse network commonly seen on K_{232} spectroheliograms has a wide range of shapes that are frequently irregular and in many cases even incomplete. Studies of this calcium network and its association with supergranulation and other aspects e.g. magnetic field, velocity etc., by Simon and Leighton (1964) and Skumanich *et al.* (1975), among others, have greatly enhanced our information on what is apparently a normal characteristic of the solar atmosphere.

We report herein results of our study aimed at measurements of the sizes of these chromospheric network cells and a possible dependence on solar cycle. If the network is a consequence of the large scale convection phenomenon that causes supergranulation, we might hope to study an aspect of it from a study of its sizes and time dependence.

2. The Observations

We have utilized in this study the Kodaikanal collection of K_{232} spectroheliograms that date back to 1904 and hence seven sunspot maxima. These have been obtained with a 60 mm image diameter. The entire collection has been made with the same telescope and spectroheliograph combination and represents a very homogeneous set of observational material that is needed for such a study.

3. Analysis Procedures

To study the existence or otherwise of a solar cycle dependence of Ca^+ network sizes, we needed a procedure that would function with equal reliability at both solar maximum and minimum. We have, therefore, resorted to the simple expedient of drawing in the nework on positive enlargements of the spectroheliogram. Enlargements of each spectroheliogram were made to a solar diameter of 250 mm ± 1 mm on normal grade photographic paper. The marking was done along the peak emission of

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the boundary on cells that were nearly 90% complete, and was done fairly fast so as to eliminate any likely bias caused by hesitation. The chosen cells were always away from active regions. The selected plates for different epochs were all mixed together and hence the choice of a phase of sunspot cycle was random. The measurement of the areas on the enlarged prints was by use of a 1 mm grid. The values of areas have less than 3% variation caused by the measuring technique. The area of each network cell has been corrected for foreshortening. All cells measured lie within 45° of the centre of the disc.

The plates selected for any phase of the solar cycle represent a mean epoch with a spread of two to three months. The distribution of network cell sizes is evaluated by fitting a normal distribution curve; the peak of the Gaussian furnishes a value of area from which a 'size' is taken as the diameter of a circle of equivalent area. These values represent the area to the centre line of the emission boundary.

To compare our procedure with those based on auto-correlation techniques as carried out by Rogerson (1955) and Simon and Leighton (1964), we have also measured cell sizes by the auto-correlation method on seven spectroheliograms representative of the solar minima of 1923, 1933, and 1954. We use a method described by Bappu and Sivaraman (1967). In their study of the network sizes of the IQSY period, they determined the mean cell size by measuring the scattered light from an enlarged positive when it was displaced from the projected image of the plate that produced it. Each plate was projected on its own print enlarged 4 times. An aperture isolated 430 arc sec at the centre of the solar disc. The photomultiplier accepted the light from this aperture in a direction 15° from the vertical. The print was moved uniformly by a motor and scans for each plate taken over four directions close to the slit orientation of the spectroheliograph.

It must be remarked that the fine mottling on the plate proved to be a source of difficulty in effecting a measure; hence Bappu and Sivaraman used spectroheliograms obtained on high constrast plates taken in average seeing conditions. The region isolated on the spectroheliogram was free of plages on all occasions. This would not be possible at solar maximum when plages are in abundance, hence the reason for our simple graphical procedure.

4. Results

4.1. A COMPARISON OF DIFFERENT MEASUREMENTS

We have attempted to derive values of mean cell sizes by two methods. One procedure defines the cell size as the distance between the principal and first secondary maximum of the auto-correlation curve. The second defines it as that inferred from the value of the peak in a normal distribution curve of area values. The 'size' is thus the diameter of an equivalent circle of same area. In Table I we present these comparative values obtained on the seven spectroheliograms. Each of the AC values is the mean of four scans. The number of cells that have been used for deriving

TABLE I

The average size of a network cell as derived from auto-correlation measures and mean area evaluation

	Size of network cell (km)	
Date	AC curve	Mean area
January 17, 1954	31 720	22 510 (205)
January 18, 1954	34 300	23 400 (173)
May 20, 1954	32 125	22 280 (180)
December 11, 1933	30 300	22 675 (143)
January 3, 1934	31 100	23 540 (145)
March 9, 1923	33 615	23 315 (126)
January 7, 1923	30 730	23 280 (158)
Mean	31 984 ± 1489	23 000 ± 499

the diameter from the mean area curve is given in brackets below each value of the area. The ratio of columns (2) and (3) indicate a mean ratio of 1.39 with a standard deviation of 0.06. This uncertainty has the magnitude we would expect from the different measurements we have made. The AC values are similar to those of Rogerson (1955) and Simon and Leighton (1964) but are systematically larger than those derived from the graphical procedure. These latter have as boundary of the cell, the location of the peak of emission intensity. The AC curves on the other hand involve a superposition of edges; their size values inevitably contain an additional length caused by the width of the cell boundary. To evaluate the widths involved we have used microphotometer traces made across several cells on photometrically calibrated spectroheliograms of March 24, 1958 and February 2, 1964. These are typical of solar maximum and minimum conditions. The mean values of FWHM derived from such intensity tracings are in both cases 5700 ± 200 km. *There is thus no dependence of cell boundary width on solar cycle.* If this aditional width were to be added to the value of cell sizes derived from areas one would obtain a mean size of 28 700 km s^{-1} which is still short of the value derived from the AC curves. Other factors, including one of definition, may account for this difference. For example, a very significant contribution to the AC values may be from the many cells seen on a K spectroheliogram that are incompletely formed and which in a gross summation of contributions is likely to play a significant role. The area measurements on the other hand are of cells that are almost complete. Figure 1a is a typical enlargement of the central region of the solar disc as seen on a K_{232} spectroheliogram. In Figure 1b, we

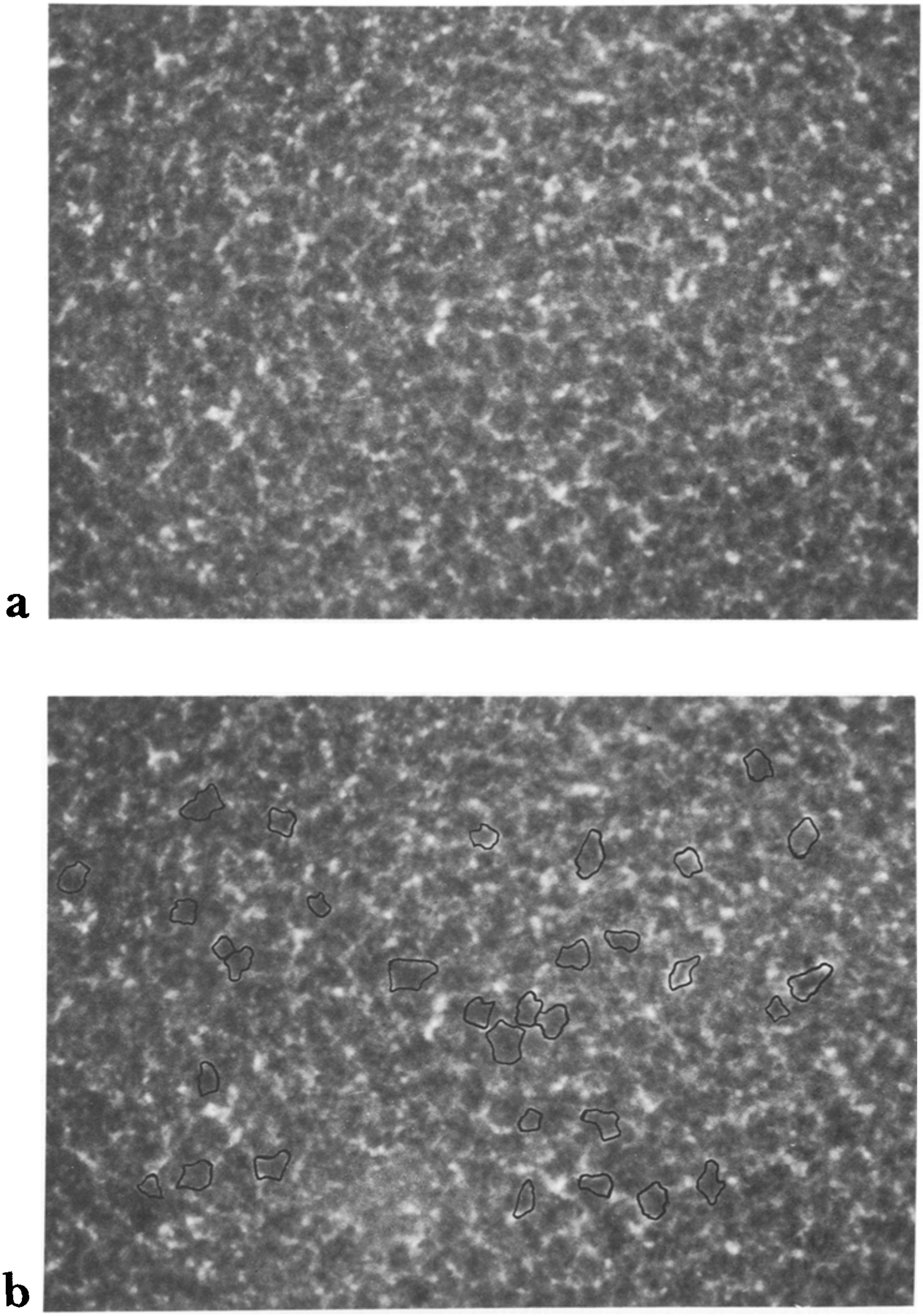

Fig. 1. Duplicate spectroheliograms of the same region with and without marking of the network boundaries.

give examples of how some of these 'cells' are drawn in for measurement. They represent a near-homogeneous kind of species which form a select category of the network seen all over the solar disc. It is this class of network cells that we examine for solar cycle dependence.

4.2. The dependence on phase of solar cycle of the network sizes

We summarize in Table II our results on mean sizes of the network cells for different epochs. Each of these covers a two to three month interval; on the average about 1800 cells per epoch have been used. The network cell sizes are evaluated by two different approaches. The standard deviation is small. Hence, any typical '*cell sizes*'

TABLE II

Mean sizes of network cells at different phases of solar cycle

				Size of network cell (km)	
	Epoch	Sunspot number	Number of cells	Peak value Gaussian	Mean[a] area
Sunspot maximum	Apr 1907–Oct 1907	62.0	2108	21 590 ± 85	22 150
	Jan 1917–Mar 1917	103.9	1518	22 110 ± 100	22 580
	Dec 1927–Mar 1928	77.8	1852	20 780 ± 160	21 300
	Jan 1937–Mar 1937	114.4	1737	20 700 ± 110	21 220
	Dec 1946–Mar 1947	151.6	1569	20 690 ± 185	21 260
	Dec 1957–Mar 1958	190.2	1631	20 200 ± 150	20 550
	Dec 1969–Mar 1970	144.6	1800	20 650 ± 165	21 190
Mean of all cells measured on plates taken at sunspot maximum			12 215	20 920 ± 112	21 474
Sunspot minimum	Jan 1912–Mar 1912	3.6	1252	22 450 ± 145	23 240
	Jan 1923–Mar 1923	5.8	2343	22 430 ± 130	23 070
	Dec 1933–Mar 1934	8.7	1852	22 140 ± 120	22 660
	Jan 1944–Mar 1944	9.6	1636	21 740 ± 100	22 290
	Oct 1953–May 1954	4.4	2160	21 980 ± 75	22 440
	Jan 1964–Feb 1964	7.2	1912	22 110 ± 130	22 200
Mean of all cells measured on plates taken at sunspot minimum			11 155	22 115 ± 99	22 636
Intermediate phase of solar cycle	Dec 1950–Feb 1951	71.7	1738	22 040 ± 90	22 380

[a] The mean area is the result of summation of all areas measured at an epoch divided by the number of cells.

as obtained by either of the two network evaluation procedures should, if used specifically, be capable of showing any subtle differences at one part of the solar cycle.

Figure 2 shows the frequency distribution of network areas together with the gaussian fit for two epochs; that of 1937 for a solar maximum, and one of 1923 for a solar minimum. These serve as a sample of the fourteen such curves used in this study. The mean '*cell size*' determined from these gaussian fits forms the basis of Table II. We also present herein the mean sunspot number for each period included in the study. The points in Figure 2 on each curve represent the numbers falling within a specified interval. The continuous curve is the gaussian that best fits the data points. The computer results also give the value of the peak of the gaussian together with the standard deviation.

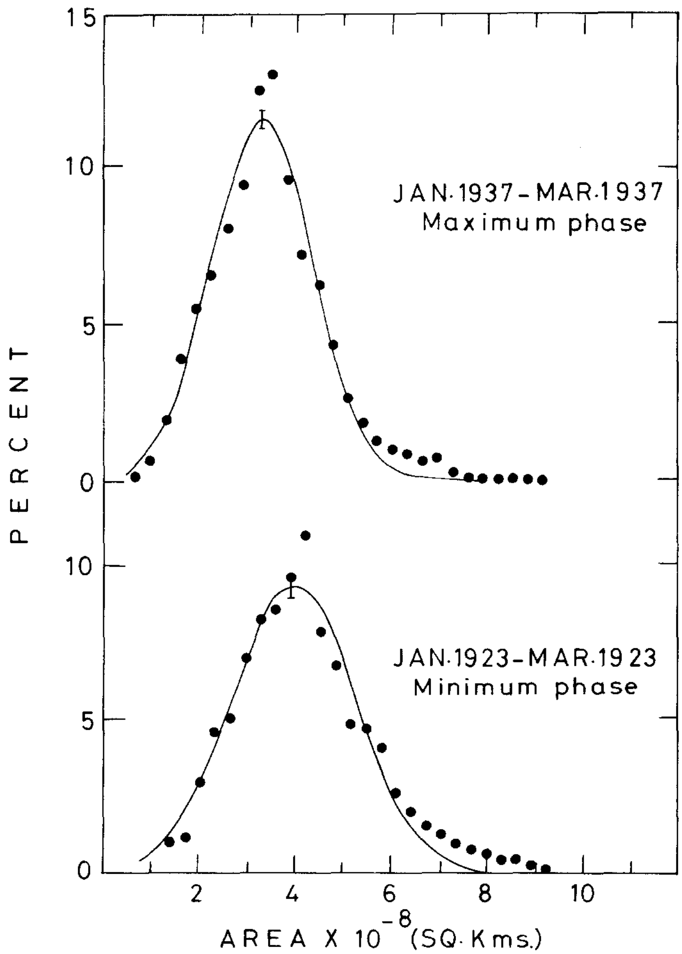

Fig. 2. Frequency distribution of network areas at solar maximum (1937) and solar minimum (1923).

The principal characteristic of Table II is the striking difference in such '*cell sizes*' between solar minimum and solar maximum. An inverse correlation between '*cell size*' and the sunspot number is apparent; the value of correlation coefficient is 0.861 when all the values in the table are taken together. Since sunspot numbers at minimum fall in a very limited range, we can increase the stability of our '*mean cell size*' at '*minimum*' by treating all the observations at this phase of solar cycle together and fitting a gaussian. The peak value of such a fit is $22\,115 \pm 99$ km. A similar treatment to the observations at the maximum phase of each sunspot cycle gives the value of '*cell size*' as $20\,920 \pm 112$ km. The difference is well over the 10σ limit of cell size determination, though an inherent statistical uncertainty of larger extent is likely. A plot of cell sizes against sunspot number as in Figure 3 demonstrates the need to recognize the contribution by noise. However, since the different solar maxima have different peak sunspot numbers, and hence differing net flux values of remnant magnetic fields, it would be reasonable to compare only the mean cell size around the maximum phase of any one solar cycle against the typical *mean cell size at minimum.* Apart from a gross demonstration of the characteristic, it is not possible at this stage to isolate one or several factors that together may contribute to such changes.

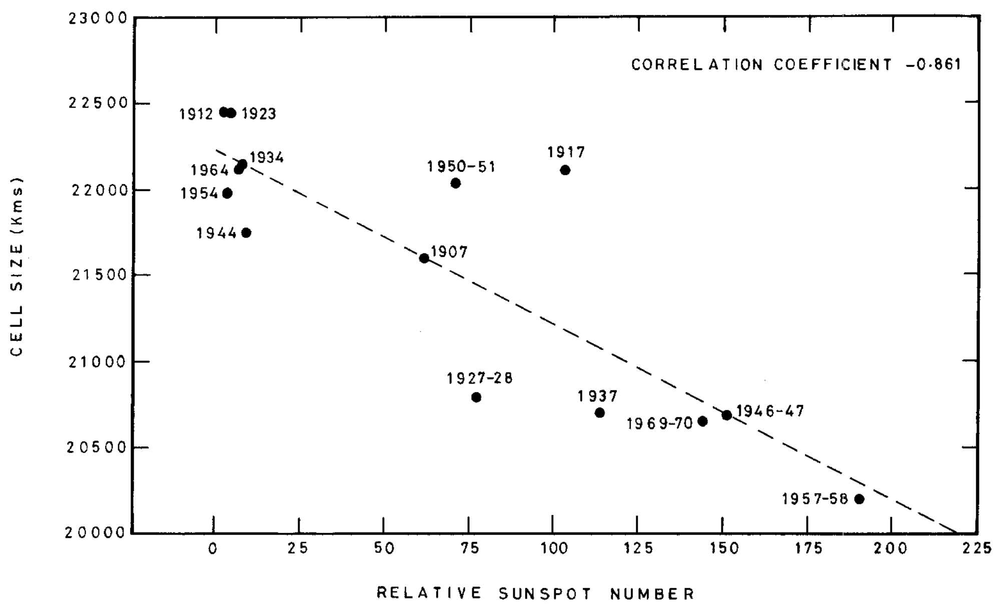

Fig. 3. Observed inverse correlation between 'cell sizes' and sunspot number. The year sampled is marked against each point.

5. Discussion

The results we have obtained depict the change of network cell size from sunspot maximum to minimum. We know the network to be a locus of accumulated magnetic fields due to the supergranular flow. Near sunspot maximum when dispersed calcium flocculi of old active regions are accumulated at the boundary of the cell, a widening in this boundary would cause the location of the mean intensity to be closer to the cell centre than it would have been when dispersed remnants are fewer. If such were to be the real situation an increase in widening of the boundary of the network would be a natural consequence at time of maximum. Our measures are clear on this point; there is little difference between the cell boundary widths at extreme phases of the cycle. There seems no alternative but to look into the mechanism of cell formation for a possible cause.

The correlation of network boundary and the boundary of supergranular flow has been the generally accepted view. The first definite efforts have been of Simon and Leighton (1964) but it has been difficult to verify that the supergranular flow does concentrate the magnetic fields at the network boundary. If so, and the correlation is high, the changes in the sizes of the chromospheric network cells reflects the changes in the structure of the supergranular network.

If supergranular flow is a convective phenomenon, a change in effective field strength of the magnetic field in the layer is capable of affecting the size of the convective cell. Following Chandrasekhar (1961) one needs only an enhancement in field by 15% to have a 5% reduction in the size of the network cell. Changes of this order of magnitude are none too rare on the solar surface especially at time of solar maximum when so many active regions are in a state of rapid evolutionary dispersal.

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