RESEARCH ARTICLE

A Study of Supergranulation through Its Parameters

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Abstract: Supergranulation is examined through its various parameters such as Area, perimeter, circularity and fractal dimension. A connection amongst these parameters throws light on the turbulent aspect of this convective feature. Area and perimeter at various latitudes are also studied in detail. The spread shows an asymmetric dispersion with a minimum dimension at around ±25º because there is a theoretical calculation which indicates that the enhanced fields will reduce the supergranular cell sizes (Chandrasekhar, 1961) around these latitudes. A different technique of analysis on a larger sample could consolidate these findings.
Keywords: Sun; Granulation-Sun; Activity-Sun; Photosphere

1. Introduction

In the outer layers of all cool stars such as the sun, convection takes the lead. About 30% of the solar radius below the photosphere is the convection zone (Noyes, 1982). Photon diffusion is suppressed and convection takes over in this zone because of large opacity.

Revelation of convection is most predominantly by granulation and supergranulation. Granulation is marked by a length scale of 1" - 2" and lifetime 10 min whereas supergranulation is marked by length scale of 30" - 40" and a lifetime of 24 hours.

These larger convective features sweep up any shreds of flux tubes in their path towards the boundaries resulting in excessive heat and hence chromosphere network formation along the boundary. One finds a temperature increase of 2.5 K at the cell boundary instead of a decrease suggesting that they are convective overshoot phenomena.

Supergranules manifest regions of horizontal flow diverging from the cell centre with a typical speed in the range 0.3-0.4 km/s and vertical downward motions are in the range 0.1-0.2 km/s at the boundaries. By virtue of geometric projection these outflow regions show velocity of approach on the side of the cell close to the centre and velocity of recession close to the limb. Near the centre of the disc where the horizontal flow is transverse to the line of sight, there is minimum dopplershift and hence the image is almost uniformly grey. Non-linear interactions between small fluid elements in an energetically open system result in the formation of large coherent stable structures (Krishan, 1991). Supported by the theory of the inverse cascade of energy in a turbulent medium, a model of the solar convection encompassing all spatial scales has been proposed (Krishan,1996).

From the time of the discovery of supergranulation using photospheric Doppler images and chromospheric network patterns, a lot of work has been done to understand the origin and nature of these features. Several tools and parameters were developed to measure the size, lifetime, flow speed and so on.

Its evolution over several days was studied (De Rosa and Toomre, 2004) using the space based data. Recent helioseismic analysis puts a question on the origin of the supergranulation (Hanasoge and Sreenivasan, 2013).

Broadly speaking supergranules are characterized by the parameters namely the length scale L, lifetime T, horizontal flow velocity vh, Area A and Perimeter P. The interrelationships amongst these parameters can throw light on the underlying convective processes (Paniveni *et al*, 2004, 2005, 2010)

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A relationship between the horizontal flow velocity and cell size has been established and the two are correlated with a relation vh $\propto$ L1/3 and this can be identified with the Kolmogorov spectrum with eddy size L (Krishan *et al*., 2002).

A relationship between the horizontal flow velocity and cell lifetime has been found and the two are correlated with a relation vh $\propto$ T 0.5 and this is in agreement with turbulent convective model of the Solar atmosphere (Paniveni *et al*., 2004).

The area A and perimeter P are well correlated with a relation P $\propto$ AD/2 from which a fractal dimension D for supergranulation of about 1.25 is obtained. By relating this to the variances of kinetic energy, temperature and pressure, it is concluded that the supergranular network is close to being isobaric and that it has a possible turbulent origin (Paniveni *et al*., 2005).

The distribution of cell lifetime and cell size is fairly well represented by skewness and kurtosis. It is found that the cell lifetimes are distributed in a more asymmetric and more lumped fashion than the cell sizes (Paniveni *et al*., 2005).

Fractal dimension is a valuable mathematical tool to quantify the turbulent aspect of the supergranular eddies. A dependence of the fractal dimension of active region magnetic structures on activity level (spots, flares) and solar cycle phase (Meunier ,2004) as well as on the active region area (Meunier, 1999) has been observed. Berrilli, Florio and Ermolli (1998) have employed fractal analysis to characterize the complexity of the supergranular flows using Ca-K images of the chromospheric network.

Sykora (1970) finds cell size dependence on solar latitude as also confirmed by Raju, Srikanth and Singh (1998). Berrilli *et al*. (1999) report a 2% anisotropy for the chromospheric network cell orientation and a 30% size reduction towards poles. Srikanth,Singh and Raju (2000) used a method of tessellation to automatically identify supergranular network pattern and measure the degree of circularity of cell shapes.

In this work, I study the supergranular network geometry using the method of visual inspection on Kodaikanal intensity patterns. Cell size distribution, its latitudinal dependence, circularity and fractal dimension are all studied using a small sample but in a fool proof way of analyzing by visual inspection.

2. Data analysis

2.1 Source of data

About a month long data obtained from the Kodaikanal solar Observatory in the year 2001 during the solar maximum phase of the solar cycle has been used. The Kodaikanal solar tower telescope houses a K-line spectroheliograph, a 2-prism instrument with spectral dispersion of 7 A^o/mm near 3930 A^o. It functions with a 60 mm image formed from a 30 cm Cooke photovisual triplet. A foucalt siderostat with 46 cm diameter reflects sunlight onto the 30 cm lens. Exit slits centered at K_{232} admits 0.5A^o

The images are digitized in strips running parallel to the equator using the Photo digitizing system.

2.2 Data processing

The intensity patterns are obtained with a resolution of 2" which is twice the granular scale. Further, the data is time averaged over an interval of 10 min which is twice the 5 min period of oscillation. Accentuation of the supergranular cell is borne out by visual inspection. Well defined cells lying between 15^0 and 60^0 angular distance limits are selected in order to avoid weak granular flow signatures near the disk centre and foreshortening effects near the limb. Errors due to projection effects are also minimised.

2.3 Supergranular area and perimeter

The profile of a visually identified cell was scanned as follows:

A fiducial y-direction on the cell was chosen and velocity profile scans were performed along the x-direction for all the pixel positions on the y-axis. In each scan, the cell extent is taken to be marked by two juxtaposed crests separated by a trough expected in the dopplergrams. This set of data points was used to determine the area and perimeter of a given cell and of the spectrum of all selected supergranules using a programme compatible with IDL software. Latitudinal positions and the circularity of the cells are determined using the IDL software programme. The area perimeter relation is used to evaluate the fractal dimension. The area and perimeter analysis was carried out for different cells at different Latitudes.

3. Result and discussion

The area distribution shows an asymmetry with a steeper rise on the lower scale and gentler fall on the larger scale. It peaks at around 6.5×10^8 km^2 or a diameter of 25.5 Mm, assuming circularity (**Figure 1**).

The size variation is more or less anticorrelated with Latitude. For the solar maximum data, there is an unsymmetrical variation of cell sizes with latitudes (**Figure 2**). The plot shows approximately N-S symmetry with two minima at about 25° N and 25° S (**Figure 1**). It is conjectured that this could possibly be due to the network field enhancements which closely follows the sunspot field (Harvey *et al*., 1994). Another justification is that supergranular cells show a dependence on the solar cycle with a reduction of sizes at the solar maximum phase (Singh and Bappu,1981; Ermolli *et al*.1998) and hence the fractal dimension.

2) Similar work is done by Raju K.P. *et al*., 1998. They have used CaK spectroheliograms obtained during the solar minimum phases at Kodaikanal between 1913 and 1974 to study the network cell sizes. They have adopted the autocorrelation technique and the curves are obtained by sliding the image in a direction parallel to the solar equator. They have calculated the autocorrelation for 2D strips for 5 deg interval up to ±50° Latitude. But their pattern shows minima at 20° N and 20° S. The small variation could be due to the change in the phase of the solar cycle.

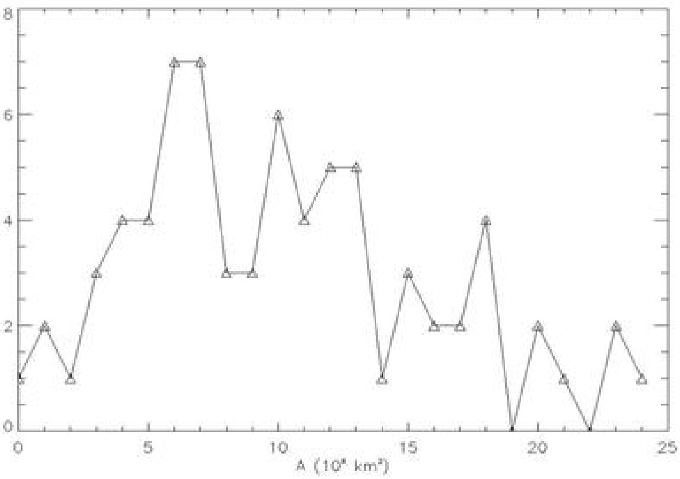

Figure 1; Histogram showing Area distribution**.**

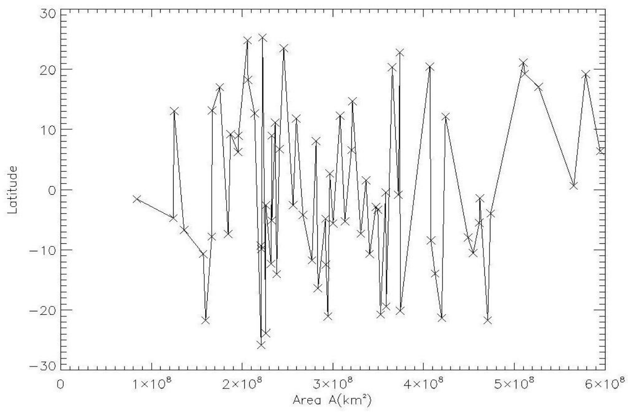

Figure 2; Area versus Latitude variation**.**

Based on Fourier analysis of supergranular velocity fields, Rimmele and Schroter (1989), find evidence of decreasing cell diameter towards higher latitudes. The minimum cell size has been seen at about 45° latitude. Berrilli *et al*. (1999) find a 30% decrease in the network cell area towards the poles, and an anti-correlation of cell dimensions with the solar cycle phase. The decrease of supergranular sizes towards higher latitudes is in tune with the latitudinal variation of convective flux, predicted from models (Gilman, 1981).

Circularity shows dependence on the latitude and shows a symmetrical maximum around ± 25°. This is in tune with the Area reaching a minimum value at these latitudinal points. Smaller cells tend to be more circular than the larger ones. This could be because of the fact that supergranular outflow pressure decreases with the radial distance (Srikanth, 1999). The log A vs log P relation is linear as shown in the lower frame of (**Figure 4**).

A correlation coefficient of 0.8444 indicates a strong correlation. Fractal dimension D, calculated as 2/slope is found to be D = 1.57 ± 0.1921. If we interchange the log A and log P axes , as in the upper frame, fractal dimension D is 2× slope and is found to be D = 1.11736 ± 0.0841. The difference in D values could be due to the fact that the error bars are not symmetrical and the sample is small.

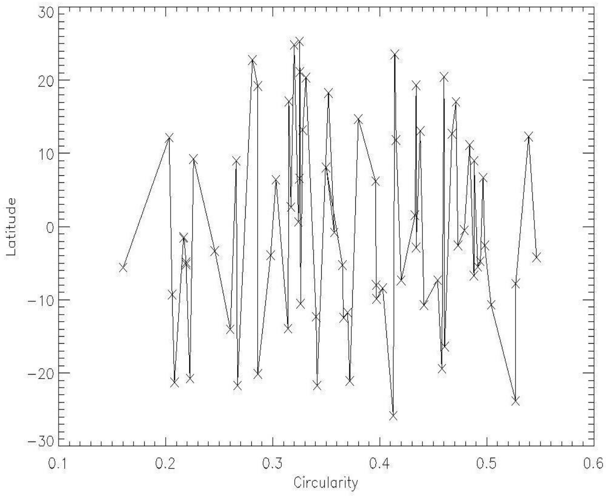

Figure 3. Circularity versus Latitude variation

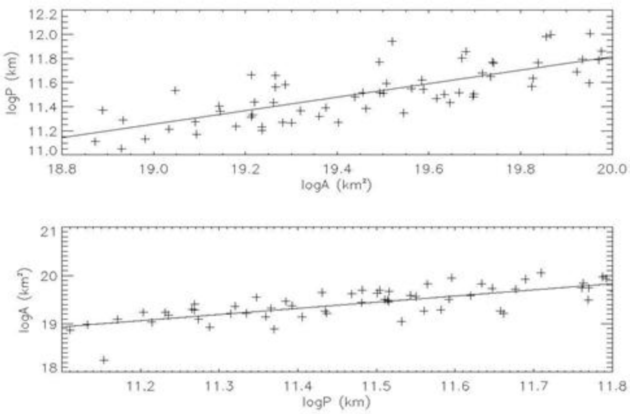

Figure 4; Plot of the natural logarithm of the supergranular area log A against the natural logarithm of perimeter log P in the lower frame; the ordinate and the co-ordinate axes are interchanged in the upper frame**.**

Since the error bar in the lower frame plot is more, the upper frame plot is taken into consideration. Fractal dimension value of supergranulation of approximately 1.12 in the Solar Active Phase is in tune with the value reported by our team earlier (Paniveni *et al*. 2010).

4. Conclusion

The cells are spread over symmetrically about ±25° latitude.

The minimum cell area at these latitudinal belts is interesting. One explanation is the enhanced magnetic field around these belts.

The results reported in this paper slightly differ from those of other authors who have done similar work. This is because of the kind of data chosen as well as the data processing method, say, the visual inspection method that is adopted for the analysis. It would be more interesting and useful if the solar cycle variation of the cell size along various latitudinal belts would be presented.

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