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AN APPROACH TO 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. One can observe 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 much diverse approach gives an added insight into this finding.
Keywords: Sun: Granulation - Sun: Activity - Sun : Photosphere

INTRODUCTION:

Observation of the solar photosphere through high resolution instruments have long indicated that the surface of the Sun is not a tranquil, featureless surface but is beset with a granular appearance. These cellular velocity patterns are a visible manifestation of sub- photospheric convection currents which contribute substantially to the outward transport of energy from the deeper layers, thus maintaining the energy balance of the Sun as a whole.

Convection is the chief mode of transport in the outer layers of all cool stars such as the Sun (Noyes,1982). Convection zone of thickness 30% of the solar radius lies in the sub-photospheric layers of the Sun. Here the opacity is so large that heat flux transport is mainly by convection rather than by photon diffusion.

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Convection is revealed on four scales. On the scale of 1000 km, it is granulation and on the scale of 8-10 arcsec, it is mesogranulation. The next hierarchial scale of convection, supergranules are in the range of 30-40 arcsec. The largest reported manifestation of convection in the Sun are giant Cells or giant granules, on a typical length scale of about 10^8 m.

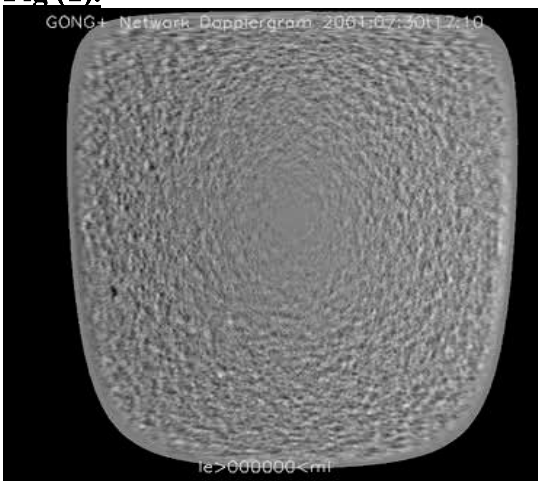
About 2 million granules are found at any point of time on the solar surface. They are columns of hot gases rising from below the photosphere with a velocity of about 1-2 km/s. Each granule persists for about 8 min. In addition to vertical currents of gases, the gases rhythmically pulse up and down with speeds of about 1/3 km/s, taking about 5 min for a complete cycle, the five minute oscillation. Granules appear to have critical scale of 1.37 arcsec at which point drastic changes in the properties of granules occur; in particular the fractal dimension changes at the critical scale. The granules smaller than this could be of turbulent origin. Non-linear interactions between small fluid elements in an energetically open system facilitate the formation of large coherent stable structures (Krishan, 1991). This self-organization occurs on all scales of solar granulation occurring in the turbulent medium of the solar atmosphere. The mechanism provides explanations for the intrinsic weakness of mesogranulation and rare appearance of giant cells in addition to the sizes and lifetimes of these structures. The entire energy spectrum from smallest granules to the largest giant cells brings out the prevalence of Kolmogorov's $K^{-5/3}$ law. Based on the inverse cascade of energy in a turbulent medium, a model of the solar convection encompassing all spatial scales, has been proposed (Krishan 1996).

A much larger convection pattern called 'Supergranules' is caused by the turbulence that extends deep into the convection zone. They have a lifetime of about 24 hr with spicules marking their boundaries. Gas rises in the centre of the supergranules and then spreads out towards the boundary and descends.

The extent of significance of horizontal motion was fully realized by Leighton and his collaborators (Leighton, Noyes and Simon, 1962). There is an evidence of vertical velocities at the centre and at the boundaries of the individual cells. The horizontal flow is typically in the range 0.3-0.4 km/s, fed by central upwelling and vertical downward motions concentrated towards the cell boundaries are typically in the range 0.1-0.2 km/s. By virtue of geometric projection, such outflowing regions always show velocity of approach to the observer along the line-of-sight on the side of the cell closer to the centre of the disc and velocity of recession on the side closer to the limb. Near the centre of the disc, where the horizontal outflows are transverse to the line-of–sight, there is less Doppler shift and hence the image is almost uniformly grey as can be understood in Fig (1).

Broadly speaking supergranules are characterized by the parameters namely the length ‘L’, the lifetime ‘T’ horizontal flow velocity ‘v_h’„ Area ‘A’ and Perimeter ‘P’. The interrelationships amongst these parameters can shed light on the underlying dynamics (Paniveni et al., 2004,2005,2010).

Fig (1).



In this paper I report interrelationship between area and perimeter, interrelationship between latitude and area, interrelationship between latitude and circularity and interrelationship between area and fractal dimension.

Source of data

Ca II K intensity data obtained from Kodaikanal Solar Observatory in 1999 (Ascending phase) has been used. The Kodaikanal Intensitygram is obtained with a resolution of 2" which is twice the granular scale. Further, the data is time averaged over an interval of 10 m which is twice the 5m period of oscillation. Thus the signal due to granular velocity is averaged out.
Similarly, the contributions due to p-mode vibrations are reduced after time averaging. Accentuation of the supergranular cell is borne out by visual inspection. Corrections due to solar rotation are applied to the dopplershifts. Well defined cells lying in between 15^0 and 60^0 angular distance limits are selected in order to discount weak granular flow signature and foreshortening effects.

Data Processing

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

A fiducial y- direction was chosen on the cell 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 the two juxtaposed 'crests' separated by a 'trough' expected in the intensitygram or the dopplergram. 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. The area-perimeter relation is used to evaluate the fractal dimension (Paniveni et al., 2005). The area and perimeter analysis was carried out for different cells at different latitudes. he latitudinal position of each one of the cells was noted. Circularity of the cells was also measured at various latitudes. All these parameters are evaluated using IDL codes.

RESULTS 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 (Fig (2)).

The size variation is more or less anticorrelated with latitude. There is an unsymmetrical variation of cell sizes with latitudes.

The logA vs logP relation is linear as shown in the lower frame of (Fig(3)).

A correlation coefficient of 0.8444 indicates a strong correlation. Fractal dimension D, calculated as 2/slope is found to be $D = 1.57 \pm 0.1921$. 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 $D = 1.11736 \pm 0.0841$.

The difference in D values could be due to the fact that the error bars are not symmetrical and the sample is small.

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).

The plot shows approximately N-S symmetry with two minima at about 25^0 N and 25^0 S. For this data, there is an unsymmetrical variation of cell sizes with latitudes (Fig (4)). It was conjectured that this could possibly be due to the network field enhancements which closely follow the sunspot field (Harvey et al.,1994). Variation is not consistent per different data sets. For this data, the average area a = 209.5 Mm^2 with variance = 12188.4 (σ = 110.401).

Similar work is done by Raju K.P. et. al. (1998). They have used CaK line spectroheliograms obtained during the solar minimum phases at Kodaikanal between 1913 and 1974 to study the network cell sizes. They have calculated the AC for 2D strips for 5 deg interval upto $\pm 50^0$ latitude. But their symmetrical pattern shows minima at 20^0 N and 20^0 S. They have adopted the autocorrelation technique and the curves are obtained by sliding the image in a direction parallel to the solar equator.

The small variation could be due to the change in the phase of the solar cycle. So it appears that while most authors agree that the supergranular sizes decrease from the equator to poles, the question of the dependence of cell length scales on the solar activity is yet to be ascertained. The decrease of supergranular sizes towards higher latitudes is in tune with the latitudinal variation of convective flux, predicted from models (Gilman, 1981). The minima are thought to be due to network field enhancements because there is a theoretical calculation which indicates that the enhanced fields will reduce the supergranular cell sizes (Chandrasekhar, 1961).

Another argument 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, Meunier, 2004) and hence the fractal dimension.

Fractal dimension varies strongly with size (Fig (5)).

For the ascending phase of the 23rd cycle solar data, variation of fractal dimension with latitude is minimal with the variation being in the range 1.15-1.2 in the latitudinal limits of 30^0 N and 30^0 S (Fig (6)).

On the sidelines of the data processing, circularity of the cells is also measured (Srikanth,1999) at various latitudes (Fig (7)).

CONCLUSION:

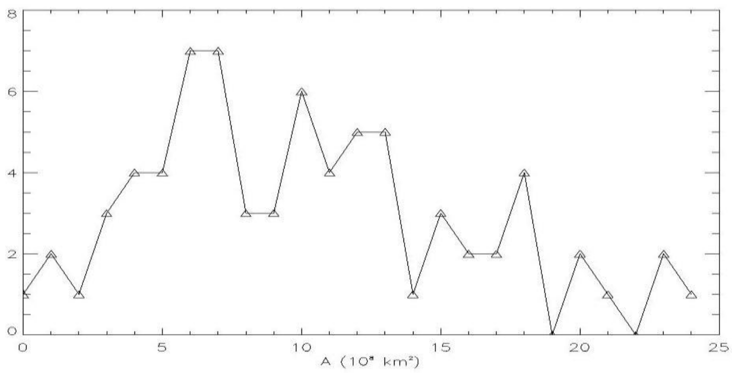
The spectral distribution of the temperature, a passive scalar, is related to the spectral distribution of kinetic energy. It can be easily shown that the Kolmogorov energy spectrum, $K^{-5/3}$, both in two and three dimensional turbulence leads to a temperature spectrum of $K^{-5/3}$. Thus the temperature variance $<\theta^2>$ varies as $r^{2/3}$ as a function of the distance r (Tennekes and Lumley, 1970). According to Mandelbrot (1975), an isosurface has a fractal dimension given by D_I = (Euclidean dimension) – ½ (exponent of the variance). Thus $D_T = 2 - (1/2\times2/3) = 5/3 = 1.66$ for an isotherm.

It is interesting that Roudier and Muller (1986) obtained a similar dimension for smaller granules. Unlike in granules, our plots show that a single linear fit is suitable for the entire observed range of supergranules. The self-similarity exhibited by a large range of scales of convection lends support to the turbulent convection based on horizontal flow velocity, lifetime and length scale data for supergranulation.

The pressure variance $\langle p^2 \rangle$ on the other hand, is proportional to the square of the velocity variance i.e. $\langle p^2 \rangle \propto r^{4/3}$ (Batchelor 1953). The fractal dimension of an isobar is therefore found to be $D_p = 2 - (1/2\times4/3) = 1.33$. Our data furnishes evidence for the fractal nature and that the supergranular network is close to being isobaric than isothermal.

There is an unsymmetrical variation of cell sizes with latitudes. Again, fractal dimension varies with size. Also there is a non-monotonous variation of the fractal dimension with area. Variation of fractal dimension with solar cycle is one of the most important results and models should be able to reproduce this type of results to be realistic.

Fig (2)



Fig(3)

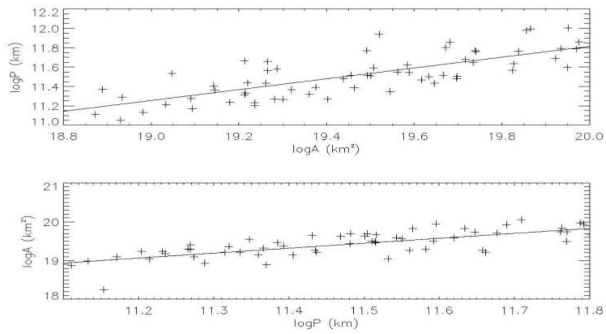


Fig (4)

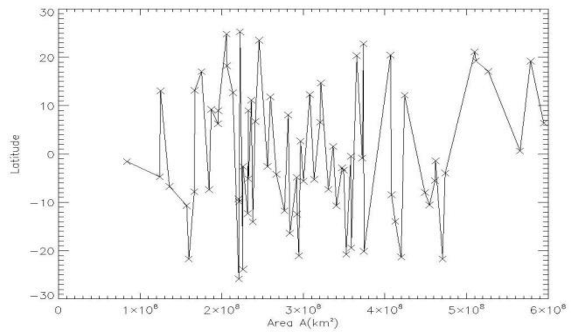


Fig (5)

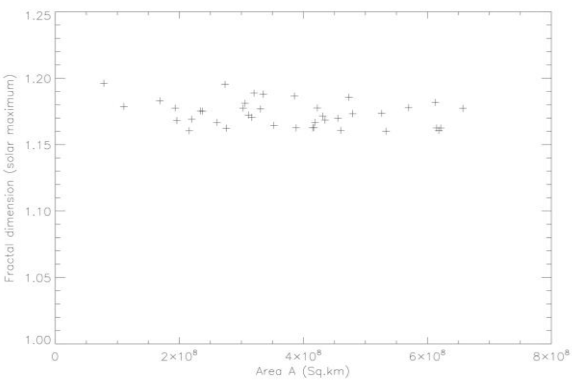


Fig (6)

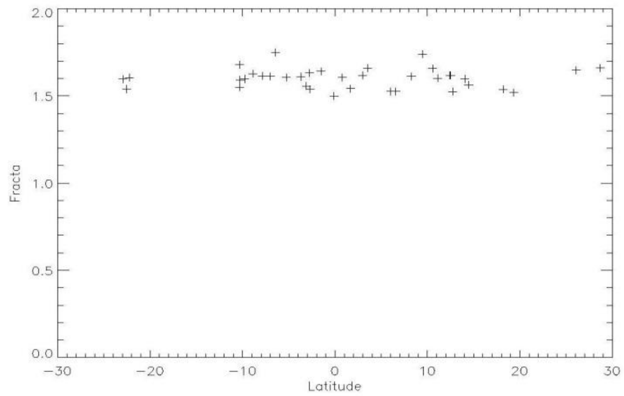
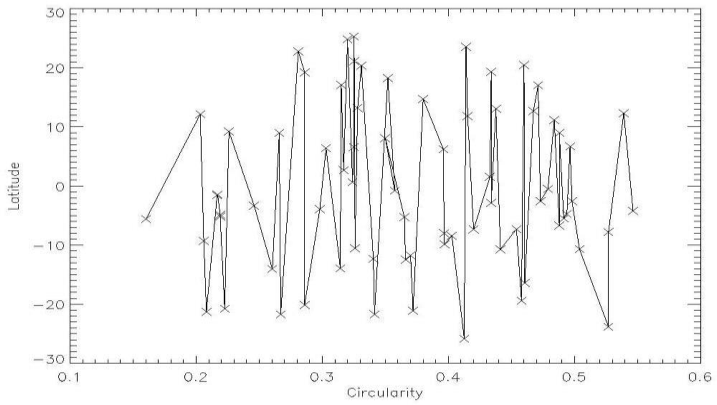

2.0
1.5
1.0
0.5
0.0
Fracta
−30
−20
−10
0
10
20
30
Latitude

Fig (7)


30
20
10
0
−10
−20
−30
Latitude
0.1
0.2
0.3
0.4
0.5
0.6
Circularity

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