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SUPERGRANULATION-A CONVECTIVE PHENOMENON

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Abstract: I study the complexity of supergranular cells using the intensity patterns obtained from the Kodaikanal solar observatory in 1999 during the active phase of the Sun. The Data consist of visually identified supergranular cells, from which a fractal dimension 'D' for supergranulation is obtained according to the relation $P \alpha A^{D/2}$ where ‘A' is the area and ‘P’ is the perimeter of the supergranular cells. I find a fractal dimension close to about 1.2 which is consistent with that for isobars and suggests a possible turbulent origin.
I also study the supergranular area versus latitude relation.

Key Words: Sun: granulation- Sun: activity – Sun: photosphere

1 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). A convection zone of thickness 30% of the solar radius occupies 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. Convection is revealed predominantly on two scales. On the scale of 1000 km, it is granulation and on a typical scale of 30000 km it is supergranulation. The other scales of convection

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are mesogranulation on a scale of 8-10 arcsec and giant cells on a typical scale of 10^8m.

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^{-1}. 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^{-1}, taking about 5 min for a complete cycle or “five minute oscillation”. Granules appear to have a critical scale of 1.37 arc sec 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 entire energy spectrum from the 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).

The much larger convection pattern 'supergranules' are 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 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^{-1} and is fed by central upwelling and vertical downward motions which are concentrated towards the cell boundaries are typically in the range 0.1-0.2 km s^{-1}. 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 (Fig 1)

Broadly speaking supergranules are characterized by the parameters namely the length L, the lifetime T, the horizontal flow velocity $v_{h,}$ area A and perimeter $P_.$ The interrelationships amongst these parameters can shed light on the underlying dynamics (Krishan 2002; Paniveni *et al.* 2004, 2005, 2010). In this paper I report interrelationships between area and perimeter and the variation of area with latitude.

Source of data:

I used Kodaikanal data obtained in the year 1999, during the active phase of the Sun.
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. The signal due to granular velocity is largely averaged out by the spatial resolution. 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 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.

Fig 1

2. Data Processing

Supergranular Cell Area and Perimeter:

The profile of a visually identified cell was scanned as follows: I chose a fiducial y-direction on the cell and performed velocity profile scans 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 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)

Results and Discussion:

a) The log A versus log P relation is linear as shown in the Figure (2). A correlation co-efficient of 0.94 indicates a strong correlation. Fractal dimension calculated as 2/slope is found to be D = 1.2.

b) A plot of area versus latitude is as shown is Figure (3). When the area versus latitude plot is examined, it shows that cells of equal areas are symmetrically situated across the latitudes.

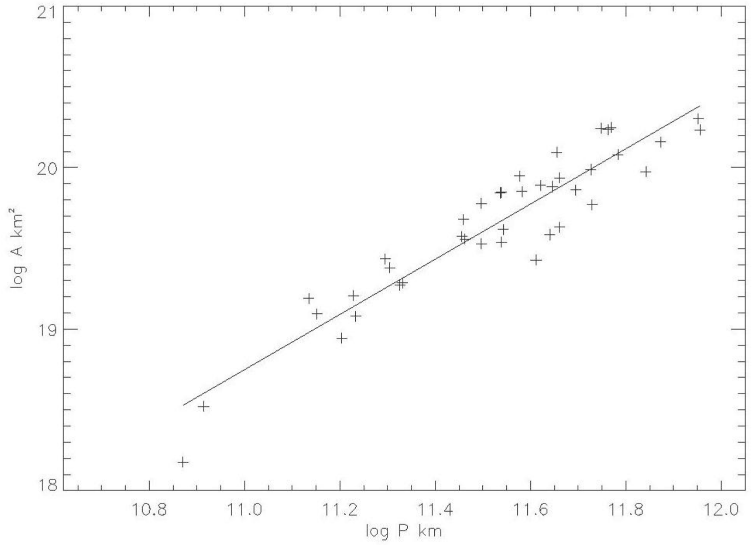

Fig (2): Plot of natural logarithm of supergranular area in km^2 versus natural logarithm of supergranular perimeter in km.

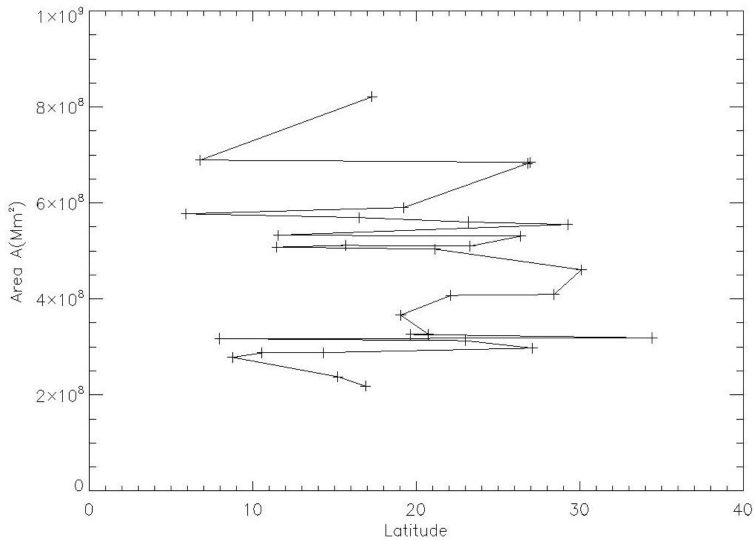

Fig (3) : Plot of area in Mm^2 versus latitude

3. Conclusions

Unlike in granules, the plots for supergranulation show that a single linear fit is suitable for the entire observed range of supergranules. 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 $<q^2>$ 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.

The pressure variance $<p^2>$, on the other hand, is proportional to the square of the velocity variance i.e. $<p^2>$ a $r^{4/3}$ (Batchelor 1953). The fractal dimension of an isobar is therefore found to be $Dp = 2 - (1/2\times4/3) = 1.33$. My analysis furnishes an evidence that the fractal nature of the supergranular network is close to being isobaric than isothermal.

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.

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