International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Solar Supergranular Dynamics

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ABSTRACT

A dependence of the area of supergranular cells with respect to the Latitude is studied and it is found that the cells are situated symmetrically about the $\pm 25^{O}$ latitude. N-S symmetry with two minima at about 10^{0} N and 10^{0} S is noted

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Fractal dimension of the supergranular cells also shows a marginal latitudinal dependence, variation being in the range 1.6 - 1.7 in the latitudinal limits of $\pm 30^{O}$. 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.

Circularity of supergranular cells is also studied in order to understand the turbulent aspect of the cells.

Supergranular cells are essentially a manifestation of convective phenomena. They can shed light on the physical conditions in the convection zone of the Sun. Supergranules also play a key role in the transport and dispersal of magnetic fields and it is an important aspect to understand the solar cycle.

Keywords: Sun: granulation- Sun: activity - Sun: photosphere

Proximity of the Sun to our home planet Earth offers a wide range of benefits. Observation of the solar photosphere through instruments of high resolution have indicated that the surface of the Sun is not a smooth surface but is beset with a mottled appearance. These cellular velocity patterns are a visible evidence for sub-photospheric convection currents which contribute significantly to the outward transport of energy from the inner layers, thus keeping up the energy balance of the Sun steady .

Convection is the primary mode of transport in the outer layers of all cooler stars including the Sun. Convection zone of thickness about 30% of the Solar radius lies in the sub-photospheric layers of the Sun. Here the opacity is very large and hence heat flux transport is mainly by convection and not by photon diffusion.

Convection is revealed prominently on two scales. On the typical scale of 1000 km, it is granulation and on a typical scale of 30000 km, it is supergranulation. Supergranules, with a typical lifetime of 24 hours are patterns of horizontal flow diverging from the cell centre and subsiding flows at the cell borders. Such out flowing regions always show velocity of approach on the side of the cell close to the disc centre and velocity of recession on the side of the cell close to the limb. At the centre of the disc, where the horizontal flows are at right angles to the line of sight, there is a very less Dopplershift and hence this region is almost uniformly grey. The horizontal currents encompassed by supergranules carry complex filaments of magnetic field from the declining active region to the boundaries of the cell where they produce enormous heating thus giving rise to the chromospheric network.

Theoretical calculations show that an increase of the magnetic field by 15% would cause a 5% reduction in supergranular sizes) [1]. A dependence of the network size on solar cycle with a smaller size at solar maximum has been reported by Singh and Bappu

[12]. Ca network diameters are shown to be lesser by 5% at solar maximum than at solar minimum. The bright chromospheric network patterns seen in Ca II K and H_α core filtergram show a marginal dependence on the latitude when their autocorrelation sizes are measured computationally. The size pattern shows an approximate North-South symmetry with two minima at roughly 20 degree north and 20 degree south [9]

Bigger supergranular cells are found to live longer [13].

Their lifetimes depend not only on their own size but also on the presence of magnetic field. Active cells close to periphery of the plage are found to live longer than those in the field-free region[10]. The confining properties of the magnetic field may be responsible for the longer life of the active region cells [14].Temporal autocorrelation function shows a greater spread in quiet regions and may be attributed to short-lived structures in these cells and it shows a smaller spread in active regions indicating stable cell features.

The linear dependence of network size can be explained assuming that the network evolves by means of diffusion processes. Diffusion co-efficient of magnetic element shows a strong activity dependence. It is found to be 370-500 sq. km /sec in the quiet network and 135-210 sq. km/sec in the enhanced network. The difference in diffusion co-efficient of network magnetic elements could be caused by difference in speeds of network magnetic elements or in step- length or both. Since the speeds were found to be comparable, step-lengths are found to be lower in high flux density active region[14].

The distribution of cell lifetime and cell size are 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 [14].

The evolution of supergranulation over several days was studied using the space based data[2]. Recent helioseismic analysis puts a question on the origin of the supergranulation [3].

Broadly speaking supergranules are characterized by the three parameters namely the length scale ‘L’, lifetime ‘T’, horizontal flow velocity ‘v_h’ , Area ‘A’, Perimeter ‘P’. The interrelationships amongst these parameters can shed light on the underlying convective processes.

A relationship between the horizontal flow velocity and cell size has been established and the two are correlated with a relation $v_h \propto L^{1/3}$ and this can be identified with the Kolmogorov spectrum with eddy size ‘L’ [5].

A relationship between the horizontal flow velocity and cell lifetime has been established and the two are correlated with a relation $v_h \propto T^{0.5}$ and this is in agreement with turbulent convective model of the solar atmosphere [6].

The area ‘A’ and perimeter ‘P’ are well correlated with a relation $P \propto A^{D/2}$ 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 [7].

SOURCE OF DATA:

Data spread over a month obtained from the Kodaikanal solar Observatory in the year 1999 during the ascending phase of the solar cycle has been made use of. 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.

The intensity patterns are obtained with a resolution of 2$''$ which is twice the granular scale. Again, 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 suppressed by time averaging and the chosen spatial resolution. Similarly, the contributions due to p-mode vibrations are brought down after time averaging. Visual inspection helps in identifying clearly marked cells. 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 taken care of. Error due to Doppler shifts caused by the solar rotation are corrected for by subtracting the average.

TECHNIQUES OF ANALYSIS

1. Image processing techniques using IRAF (Image reduction and analysis facility) software package.
2. Data processing using IDL (Interactive Data Language)
3. Theoretical modeling of the convective flows.

METHODOLOGY

Study of individual supergranular cells leading to inter-relationships of area, perimeter, circularity and fractal dimension at different solar latitudes.

SUPERGRANULAR CELL AREA, PERIMETER AND CIRCULARITY:

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 the sum of the base sizes of the two juxtaposed ‘crests’ separated by a ‘trough’ expected in the Intensitygram. 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 [8]. The area and perimeter analysis was carried out for different cells at different Latitudes. The Latitudinal position of each one of the cells was noted. All these parameters are evaluated using IDL codes. On the sidelines of the data processing, circularity of the cells is also measured [13].

RESULTS AND DISCUSSION

1. For the solar maximum data, that of Kodaikanal, the fractal dimension variation with latitude is marginal in the range 1.15 to 1.2 (Fig 1). Investigation is done in the latitudinal limits of 30^0 N and 30^0 S
2. For the solar minimum data, that of SOHO, the fractal dimension variation with Area is again marginal in the range 1.5 to 2 as seen in Fig(2). Investigation is done in the latitudinal limits of 30^0 N and 30^0 S

3. Circularity keeps almost decreasing as the perimeter value increases (Fig 3). 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 [15].
4. For the near solar maximum data, there is an unsymmetrical variation of cell sizes with latitudes (Fig (4)). The plot shows approximately N-S symmetry with two minima at about 10^0 N and 10^0 S (Fig. 4). The size variation is more or less anticorrelated with Latitude. It is conjectured that this could possibly be due to the network field enhancements which closely follows the sunspot field [4].

Kolmogorov's theory is an asymptotic theory. It is known to work well in the limit of very high Reynold's number. It assumes that energy cascade is one way and is from large to small eddies. Experiments have shown that energy is also transferred from smaller to larger scales, a process called backscatter.

It deals with the energy spectrum of turbulence. It shows the distribution of energy amongst turbulent vortices as a function of vortex size. The wave number 'k' of vortex of spatial dimension 'L' is given by $k=2\pi/L$. The spectral form of Navier-Stokes equations indicates that energy can be transferred from two wave numbers k_1, k_2 to a wave number k_3 only if $k_3 = k_1 + k_2$ according to the selection rule. If $k_1 = k_2$, then $k_3 = 2 k_1$

Kolmogorov envisioned a process in which mixing occurs from k_{min} to k_{max}. In the inertial range viscous dissipation is not important.

If E is the energy density per unit wave number and it depends only on 'k' and energy injection rate 'ε'.

$k= 1/L$ and $\varepsilon=L^2/T^3$ and $E=L^3/T^2$

If $E(k, \varepsilon) = C k^{\alpha} \varepsilon^{\beta}$ for constant 'C'.

Dimensional compatibility requires that $L^3 = L^{-\alpha} L^{2\beta}$

$-\alpha + 2\beta = 3$

$T^{-2} = T^{-3\beta}$ and hence $-3\beta = -2$ or $\beta = 2/3$ Therefore $\alpha = 4/3 - 3 = -5/3$

Kolmogorov energy spectrum can be expressed mathematically as

$E(k, \varepsilon) = c\, k^{-5/3} \varepsilon^{2/3}$.

CONCLUSION:

According to Kolmogorov's theory, the fractal dimension of an isobar is given by the relation Dp = 2 - (1/2×4/3) = 1.33. Our data furnishes an average value of 1.25 which summarizes to supergranular flows being isobaric in nature. This is in consonance with the results of Roudier and Muller for smaller granules [11].

At about 10^0 N and 10^0 S, field enhancement seems to be slightly higher which translates to smaller size for supergranules in this latitudinal belt.

Circularity of the smaller supergranular cells is more as compared to that of the larger cells. This will have a specific connotation as regards the turbulent convective flows.

Analysis with other data sources and different resolution should corroborate our findings.

ACKNOWLEDGEMENT:

I thank my collaborator Dr.Srikanth for his support in preparing this manuscript. I thank Prof.Jagdev Singh and Prof.Vinod Krishan for their guidance in my research career.

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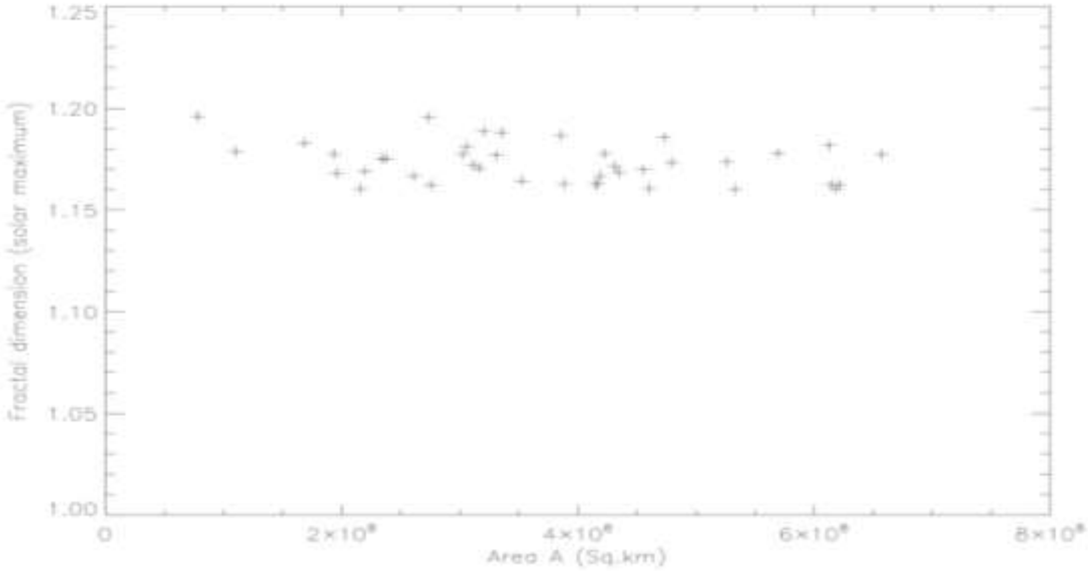
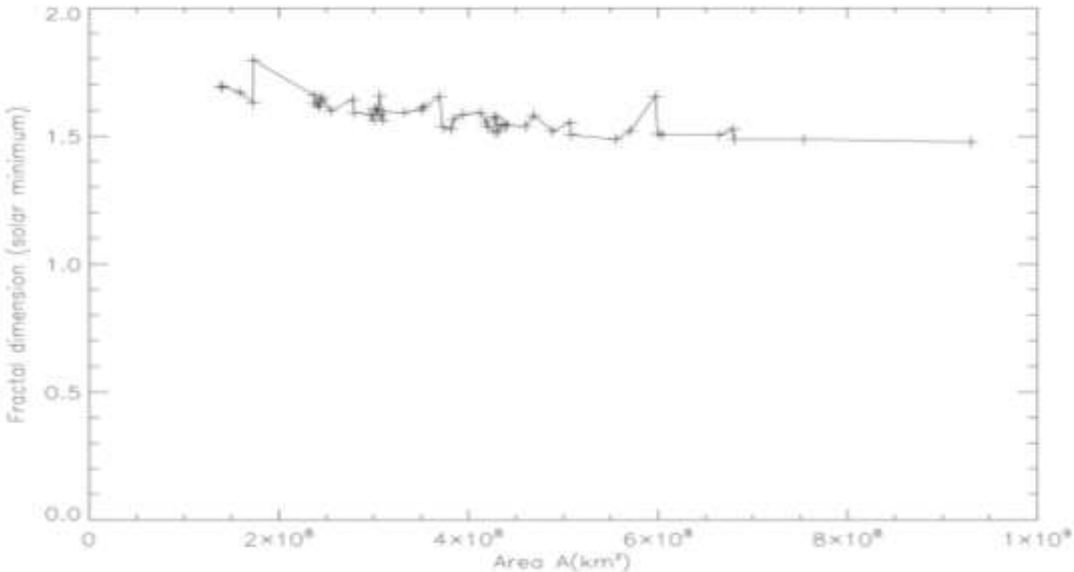
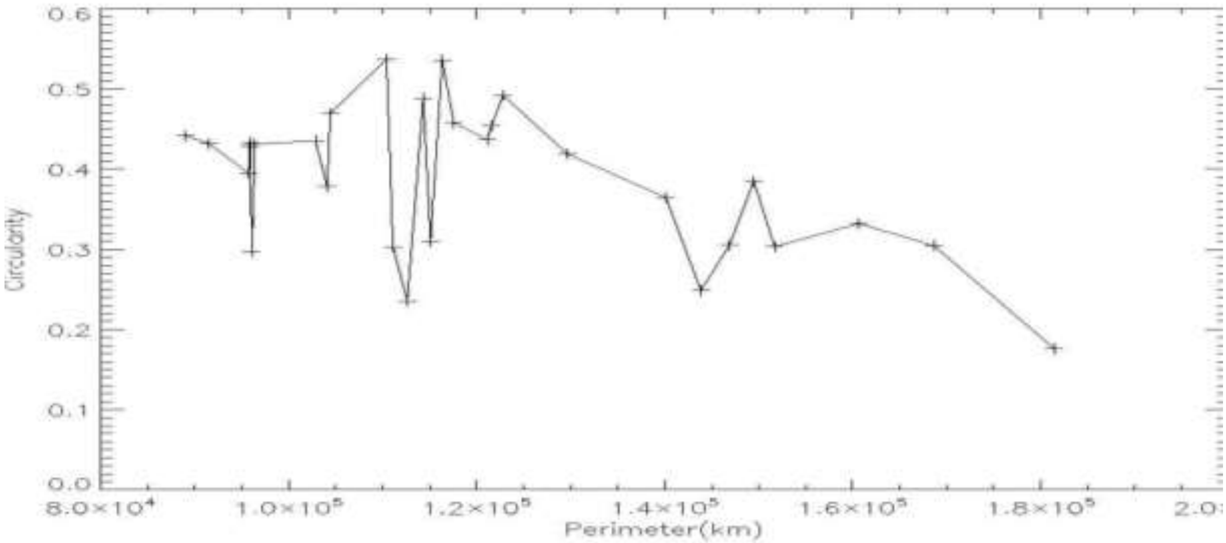


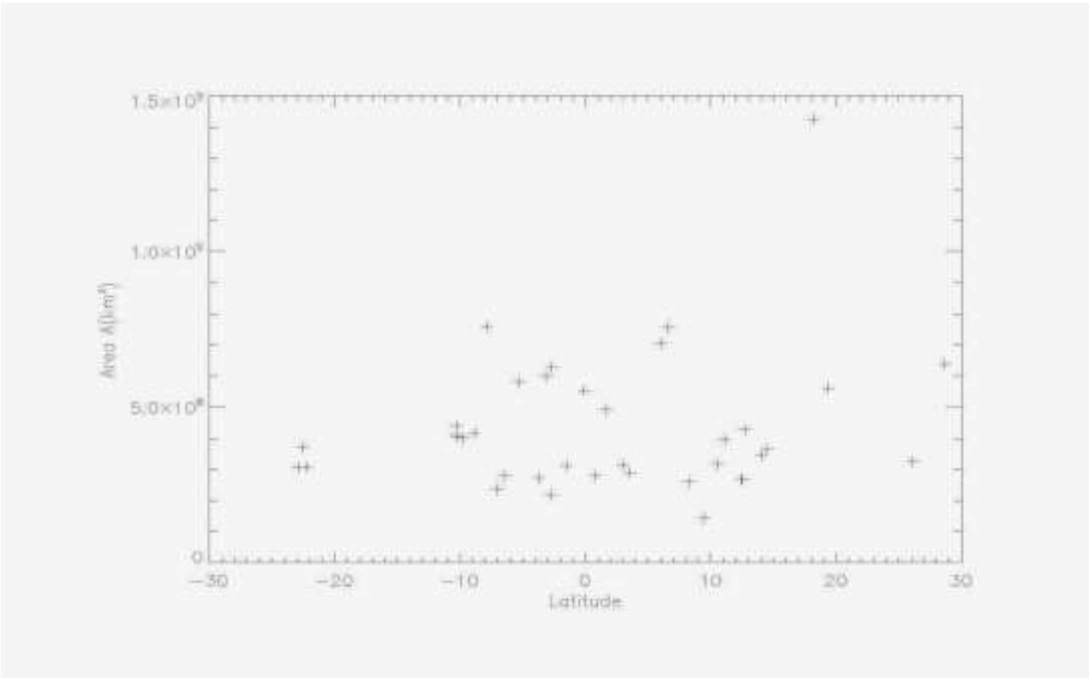
Fig(1)



Fig(2)



Fig(3)



Fig(4)

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