RESEARCH ARTICLE

Latitudinal Dependence of Supergranular Area and Fractal Dimension

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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 $\pm 25^0$ latitude.

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 $\pm 30^0$. Fractal dimension D for supergranulation is obtained according to the relation $P \propto A^{D/2}$ where 'A is the area and 'P' is the perimeter of the supergranular cells. A difference in the fractal dimension between the active and quiet region cells is noted which is conjectured to be due to the magnetic activity level.

Supergranular cells are essentially a manifestation of convective phenomena. They can shed light on the physical conditions in the convection zone of the Sun. Moreover, supergranules play a key role in the transport and dispersal of magnetic fields as it is an important step in our quest to understand the solar cycle.

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

1. Introduction

Convection is the basic means of transport of heat flux in the outer layers of all cool stars such as the Sun. Convection zone of thickness 30% of the solar radius lies in the sub-photospheric layers of the Sun (Noyes, 1982). Here the opacity is so large that heat flux transport is mainly by convection and not by photon diffusion.

Convection is revealed most frequently on two scales. On the scale of 1000 km, it is granulation and on the scale of 30000 km, it is supergranulation.

Supergranules, with a typical lifetime of 24 hours are regions of horizontal flow diverging from the cell centre and subsiding flows at the cell borders. The importance and the extent of significance of horizontal motion was fully realized by Leighton and his collaborators (Leighton, Noyes and Simon, 1962).

The horizontal currents associated with supergranules sweep up any flux tubes of magnetic field from the declining active region to the boundaries of the cell where they produce excess heating, thus forming the chromospheric network. 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).

doi: 10.18063/eoaa.v2i1.347

Since 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 patterns. Several tools and parameters were developed to measure the size, lifetime, flow speed and so on.

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

A relationship between the horizontal flow velocity and cell size has been established and the two are correlated with a relation $\mathbf{v_h} \propto \mathbf{L^{1/3}}$ 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 $\mathbf{v_h} \propto \mathbf{T^{0.5}}$ 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 $\mathbf{P} \propto \mathbf{A^{D/2}}$ 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 (Paniveni et al., 2005).

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 (Paniveni et al., 2005).

Fractal dimension is a valuable mathematical tool to quantify the turbulent aspect of the supergranular features. 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.

2.Source of data

About a month long data obtained from the Kodaikanal solar Observatory in the year 1999 during the ascending 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°/mm near 3930 A°. 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

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 arcsec 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 time averaging and 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. Well defined cells lying between 15° and 60° 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 addressed.

3.Supergranular Cell Area and Perimeter

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. 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 (Krishan et al., 2002). 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 (Srikanth, 1999).

4. Results and Discussion

1) For the near solar maximum data, there is an unsymmetrical variation of cell sizes with latitudes (Figure 1). The plot shows approximately N-S symmetry with two minima at about 10° N and 10° S (Figure 1). 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 (Harvey et al., 1994).

2) For the ascending phase of solar cycle data that has been used for the analysis, fractal dimension variation with latitude is minimal with the variation being in the range 1.6–1.7 in the latitudinal limits of 30° N and 30° S (Figure 2).

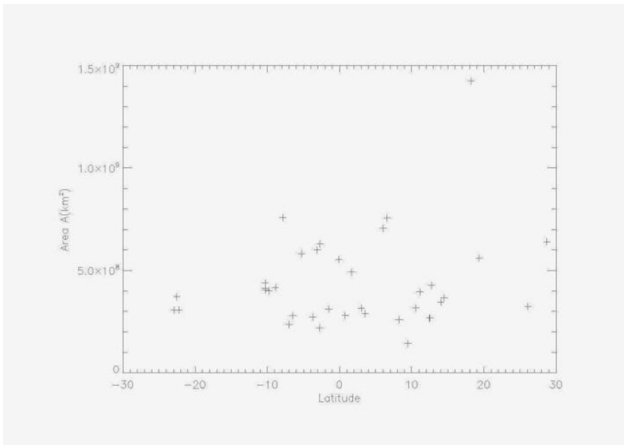

Figure 1. Variation of Area with Latitude

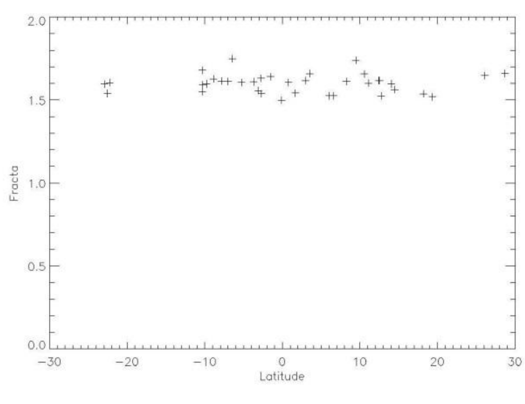

Figure 2. Variation of Fractal dimension with Latitude

Variation of Fractal dimension with Latitude is minimal with the variation being in the range 1.6–1.7 in the latitudinal limits of 30° N and 30° S (Figure 2). 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 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.

Rimmele and Schroter (1989), based on Fourier analysis of supergranular velocity fields, find evidence of decreasing cell diameter towards higher latitudes. The minimum cell size has been seen at about 45 deg latitude. Berrilli et al. 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).

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) and hence the fractal dimension.

5. Conclusions

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

Also, fractal dimension varies marginally in the latitudinal limit of ±30°. There is a non-monotonous variation of the fractal dimension with area. So, it appears that while most authors agree that the supergranular sizes vary from the equator to poles, the question of the dependence of cell length scales on the solar activity is yet to be ascertained. Also the variation of the fractal dimension with solar cycle is an important result which is yet to be firmed up.

The results reported in this paper slightly differ from those of other authors who have done similar work due to 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 sizes along various latitudinal belts would be presented.

Acknowledgements

I thank Dr. Jagdev Singh for providing Kodaikanal Ca II K Intensity data. I am thankful to Dr. R. Srikanth for his great deal of support and for his comments that have helped to considerably improve the paper. My thanks are due to the referee from Journal of Astronomy and Astrophysics whose critical comments have helped to improve the paper significantly.

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