Bull. Astr. Soc. India (1996) **24**, 285–289

Structure of turbulence in the Solar Convection Zone

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Abstract. Based on the inverse cascade of energy in a turbulent medium, a model of the solar granulation, encompassing all spatial scales, has been proposed. The predicted spatial energy distribution tends to agree fairly well with that inferred from the observations of the photospheric motions. The model depends heavily on the presence of helicity fluctuations in the turbulent medium. Helicity is an invariant of a 3-D system. In case, the net helicity is zero, its second moment may be nonzero, then another invariant 'I' can be defined, the cascading properties of which in the inertial range give the spectral distribution of energy. The helicity is related to the mass density through a function analogous to the Bernoulli function. It is hoped that with the quality data obtained from GONG, we will be able to test some of these theoretical ideas.

Key words: Solar granulation, turbulence, Convection

1. Introduction

Coherent structures, correlated motions and well defined patterns are observed on a variety of spatial as well as temporal scales. Organized states of matter and motion can be seen in, a convection cell, cloud complexes, a tornado, a cyclone, zonal flows on planetary surfaces, the Red spot of Jupiter, convective flows on stellar surfaces, spiral patterns in galaxies and perhaps ourselves. What is common among all these disparate situations is that they comprise of nonlinear nonequilibrium open systems in which dissipative organized structures form through the development of sustained correlations among fluctuations. We believe that the solar convection zone qualifies to be such a system and the observed cellular velocity patterns are a result of the dissipative self-organizing processes. The convection zone is in a state of turbulence, supporting several interacting length and time scales through the excitation of instabilities. The scales are constrained by boundaries, buoyancy and dissipation. That, in a 3D hydrodynamic turbulence, the energy cascades from large scales to small scales with the $K^{-5/3}$ law, is well known. But, what if we drop the assumptions of homogeneity and isotropy?

2. 3-D turbulence

The inverse cascade i.e. the energy flow from small scales to large scales is known to occur in 2-D hydrodynamic and 3-D magnetohydrodynamic turbulence. That the inverse cascade can occur in a 3-D hydrodynamical system is a recent revelation. We have proposed that in the solar convection zone, most of the energy resides in small scales and its distribution in the form of granules, meso - and supergranules and giant cells, takes place, through the process of inverse cascade (Krishan, 1991). The essential ingredient for this to happen is the presence of helicity fluctuations. By using the mass and momentum conservation equations, one can find the helicity conservation law (Moffat and Tsinober 1992):

$$\frac{\partial h}{\partial t} + \vec{\nabla}.\vec{F}_h = o \tag{1}$$

where h $= (\vec{\nabla} \times \vec{V}).\vec{V}$ is the helicity, $\vec{V}$, the velocity and $\vec{F}_h$, the helicity flux is given by

$$\vec{F}_h = \vec{V}h - (\vec{\nabla} \times \vec{V})Q \tag{2}$$

where

$$Q = \frac{V^2}{2} - e - \psi$$

e is the enthalpy per unit mass and ψ is the gravitational potential. If the average total helicity H $= \int hd^3r$ is zero, but its higher moments are constant and influence the flow of energy, one can characterize the flow by the statistical helicity invariant I represented by conserved mean square helicity density.

$$I = \int < h(\vec{x})h(\vec{x} + \vec{r}) > d^3r \tag{3}$$

For a quasi-normal destribution of helicities, I can be written as

$$I = A\int [W(k)]^2 dk \tag{4}$$

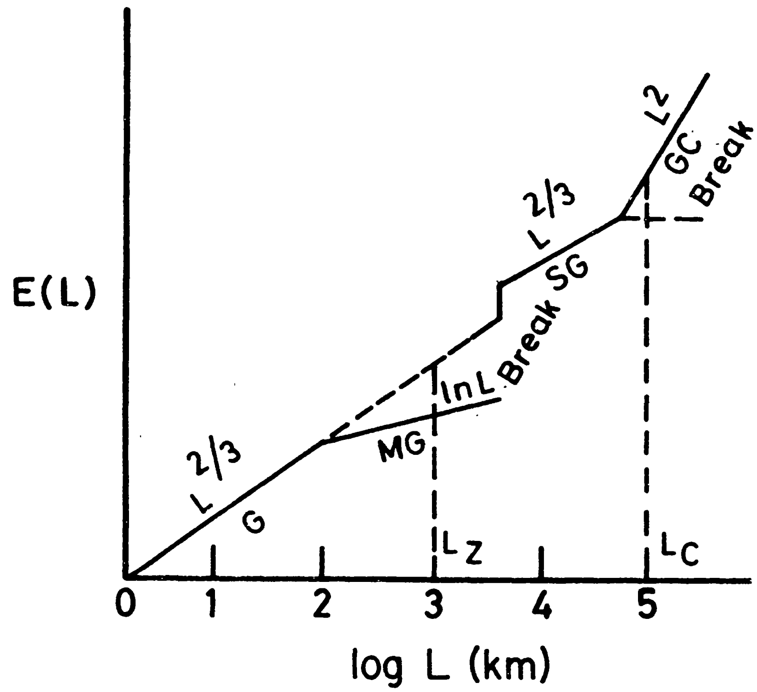

Figure 1. Turbulent energy spectrum. L_z - scale of the first break due to anisotropy; L_C - scale of the second break due to the Coriolis force; G - granule; MG - mesogranule; SG - supergranule; and GC - giant cell.

where A is a constant. Using Kolmogorovic arguments acknowledging the development of anisotropy and including the role of coriolis forces, a complete energy spectrum has been derived (Krishan 1991, Levich and Tzvetkov 1985) as shown in figure (1).

The quality observations obtained at Pic-du-Midi indicate the existence of a continuum of sizes instead of one or two dominant sizes in the solar granulation. It is encouraging to find that the energy spectrum of granulation motions deduced from observations does show a branch with $K^{-5/3}$ which turns into a $K^{-0.7}$ law towards small K (Figure (2)).

This agrees fairly well with the predictions of the inverse cascade model where the Kolmogorov branch $K^{-5/3}$ (or $L^{2/3}$ develops into a K^{-1} (or ln L) law towards large spatial scales. Further evidence for the $K^{-5/3}$ spectrum and its flattening comes from the radial spatial power spectra of intensity fluctuations (Fig.3) (Keil et al. 1994).

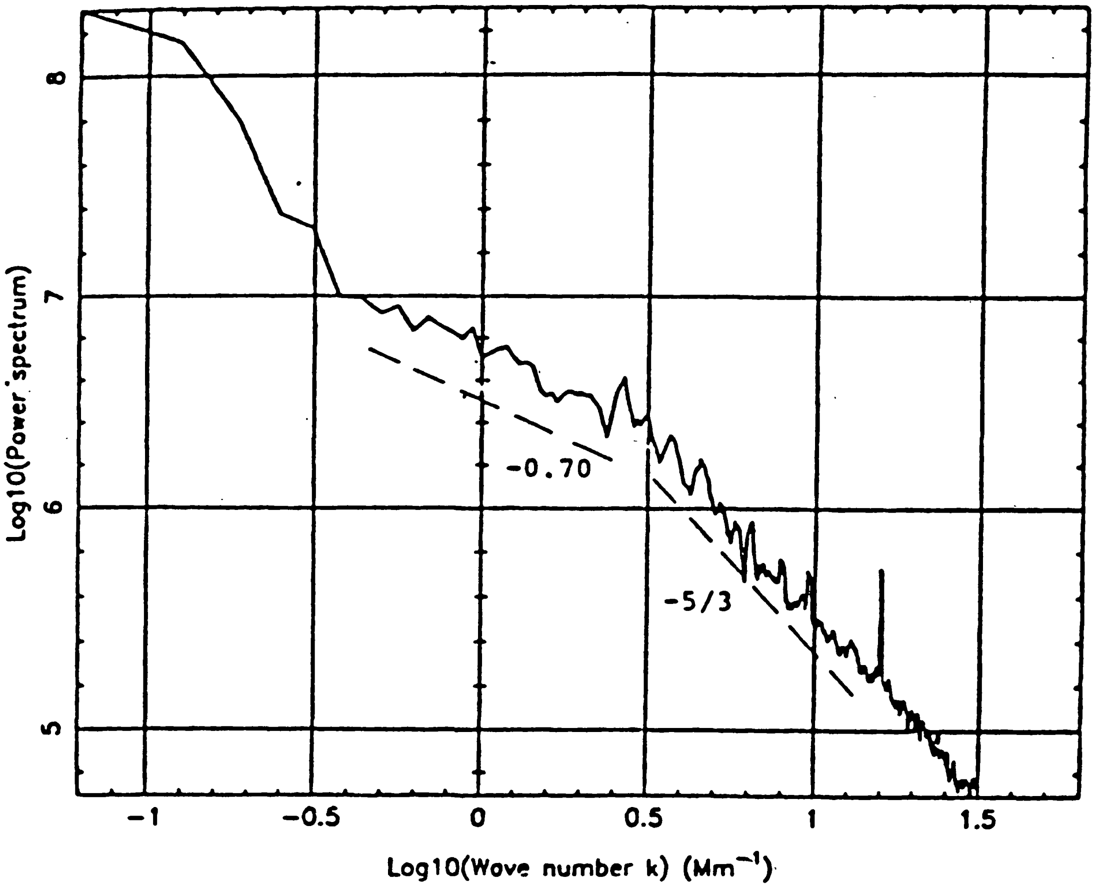

Fig.(2.) : Power spectrum of the solar photospheric motions (Zahn, J.P., 1987, in *Solar and Stellar Physics,* p55).

Komm, Matig and Nesis (1990) infer a $K^{-5/3}$ spectrum going into $K^{-1.30\pm0.10}$ with height, from intensity power spectrum observed in Mg 5173Å, C5380Åand Fe 5576Å. Thus, it appears that the granulation scales may be generated through the action of inverse cascade processes.

3. Conclusion

The photospheric fluid motions have been recognised to possess vorticity, but the attendant existence of helicity has not been appreciated. it would be worthwhile to determine helicity - helicity correlation on various scales as well as its variation with height, since the theory predicts that large structure have their velocity and vorticity vectors aligned. Further the relationship of flow divergence with helicity must be studied

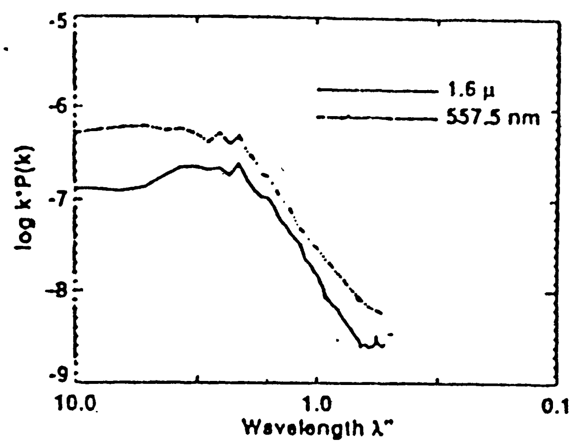

Fig.3 Radial spatial power spectra, averaged over the 55 min observing sequence.

in detail, theoretically as well as observationally, since the two are related through a Bernouli like function.

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