CONVECTIVE OVERSHOOTING IN THE SOLAR PHOTOSPHERE; A MODEL GRANULAR VELOCITY FIELD

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The solar granulation, with its horizontal temperature fluctuations, and its associated velocity field, is a consequence of overshooting convective motions. Theoretical estimates of the magnitude of the temperature fluctuations and mass fluxes involved were obtained in a recent paper (Nordlund, 1976, Astronomy & Astrophys. 50, 23). Here, a simple model of the instantaneous granular velocity field is presented, and the effects of this velocity field on photospheric spectral lines are described.

The vertical velocity component is modelled by a simple, parameterized expression:

$$\rho v_z\ (x,y,z) = \psi_o(\pi^2/2)\ \sin\ (\pi x/d)\ \sin\ (\pi y/d) e^{-z/z_o}/(1+e^{-z/z_o}).$$

The three parameters specify the amplitude (ψ_o) of the vertical mass flow, the horizontal size (d) of a model granule element, and a typical scale (z_o) for the vertical variation of the mass flux.

The horizontal velocities are determined from the vertical velocity by the condition of continuity. Since the granular motions are slow and approximately anelastic, the condition of continuity can be well approximated by

$$\text{div}\ (\rho \underline{v}) = 0\ .$$

This simple, quadratic pattern of alternating vertical velocities, with the corresponding horizontal velocities determined by the condition of continuity, represents a crude model of the instantaneous granular velocity field. Some important conclusions are possible, however, using this model to fit the non-thermal broadening of photospheric spectral lines:

The three parameters (ψ_o, z_o, and d) can be used to fit the observed

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half widths of a set of photospheric spectral lines, at two different center to limb distances. The values ψ_o=0.35 $kgm^{-2}s^{-1}$, z_o=100 km, d=1500 km produce a reasonably good fit. The velocity along a line of sight varies along the line of sight in the model granular velocity field. When the line of sight velocity varies, the line absorption coefficient is shifted in and out of the intensity profile of the line, and an increased absorption results. With the given parameter values, this effect is negligible for vertical sight lines. However, because of the increase of typical optical scales for increasing angles of inclination, the variation of the velocity along a line of sight becomes important with growing angle of inclination.

Due to this effect, the observed center to limb behavior of the equivalent widths of the spectral lines is also reproduced, without the need for classical microturbulence. With a classical macro/microturbulence model, the same behavior could have been achieved only by assuming a depth-dependent and anisotropic macro- and micro-turbulence.

Turbulent motions on scales smaller than granular are certainly generated by the larger scale, granular motions. However, the (apparently anisotropic) center to limb effects on the equivalent widths, which correspond to classical microturbulent velocities of the order 1 - 2 kms^{-1}, can be explained entirely as a consequence of the granular scale velocity field.

In conclusion, this study shows that the observations of line broadening and line strength are consistent with a situation where the amplitude of the velocity field is at maximum on granular scales, where the motion is being driven by convection, and with the amplitudes of smaller scale motion being progressively smaller and smaller.

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