OBSERVATIONS AND INTERPRETATION OF SUPERGRANULE VELOCITY AND MAGNETIC FIELDS

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Abstract. I have studied the observed concentrations of vertical velocity and vertical magnetic field in the corners of the coarse network. Using a horizontal velocity inferred from the vertical velocity, I have computed the possible rate of concentration of the field. The rate turns out to be much higher than observed. I conclude that the observed motions in supergranules are not concentrating the observed field at the corners of the network. I have suggested four possible alternate situations consistent with the observations.

I am going to discuss an interpretation of observations of quiet region magnetic fields. I will start with observations and try to see what physical situation the observations compel one to believe in.

Magnetograph observations give the longitudinal components of both the velocity and the magnetic field. These furnish only a partial description of a magnetohydrodynamic flow, but even this partial description can provide some useful information.

The most questionable assumption which I make is that the magnetograph measurement may be interpreted as a velocity and magnetic field at some height in the solar atmosphere. The measurements can at best be only weighted averages of these quantities.

When my observational program at Sac. Peak was held up due to instrumental difficulties Dr. Edward Frazier graciously provided me with the results of his observations. These are a portion of the work which he has described earlier in this session. I used the results for the neutral iron line at 5233, which is formed in the upper photosphere. The area of each of Frazier's scans contains about 20 super granules, and each supergranule contains about 300 measured points. Each measured point is the average of two pairs of successive observations taken $2\frac{1}{2}$ min apart in order to eliminate the effect of the five minute oscillations.

The most conspicuous feature of the observations is the correspondence between strong features in the velocity and magnetic fields. I have taken the product of the velocity and magnetic field and chosen the ten largest local extrema. In all cases these correspond to conspicuous features in both fields separately. I have superimposed these features, averaged them, and also averaged over various azimuths.

Figure 1 shows the results of this process for the average vertical component of the magnetic field. The center of the coordinate system corresponds to a vertex of the coarse network. The signs of two of the ten magnetic fields used were negative. I have reversed the signs of these fields before averaging.

Figure 2 shows the average vertical velocity. This is downward in all cases regardless of the sign of the magnetic field.

Howard (ed.), Solar Magnetic Fields, 289–292.

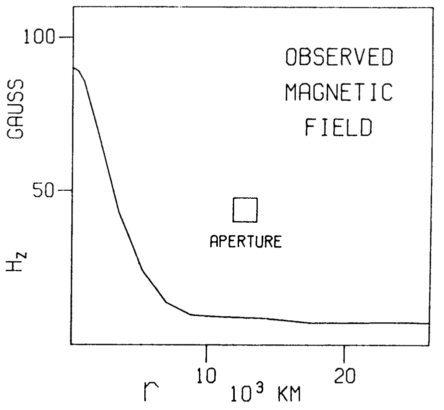

Fig. 1.

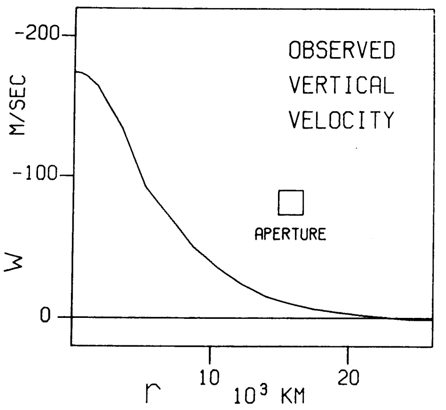

Fig. 2.

I will now describe a method for deriving the horizontal component of the velocity from the vertical one. Consider the continuity equation:

$$\frac{\partial \varrho}{\partial t} + \nabla \cdot \varrho \mathbf{v} = 0, \tag{1}$$

where ϱ is density, t is time, and $\mathbf{v}$ is velocity. A scale analysis for large slow flows reveals that the first term is much smaller than the second. Also, in a cylindrical coordinate system with r and u the radial coordinate and velocity and z and w the vertical coordinate and vertical velocity, this can be written as:

$$\frac{1}{r}\frac{\partial}{\partial r}(r\varrho u) + \frac{\partial}{\partial z}(\varrho w) = 0 \tag{2}$$

for the case of axial symmetry. If one assumes that the density ϱ does not vary with r and that

$$\frac{\partial}{\partial z}(\varrho w) = -\alpha \varrho w, \tag{3}$$

then the horizontal velocity can be found by

$$u(r, z_0) = \frac{\alpha(z_0)}{r}\int_0^r r' w(r', z_0)\,\mathrm{d}r' \tag{4}$$

where z_0 is the observed level and α is assumed to be independent of r. This is equivalent to assuming a separable solution to a partial differential equation. Or, expressed in a different way, that the form of the components of velocity is the same at all heights.

The horizontal velocity derived from Equation (4) is shown in Figure 3. The value of α has been chosen to fix the maximum at 500 m/s in agreement with independent measurements. The horizontal velocity shown is one integral of the continuity equa-

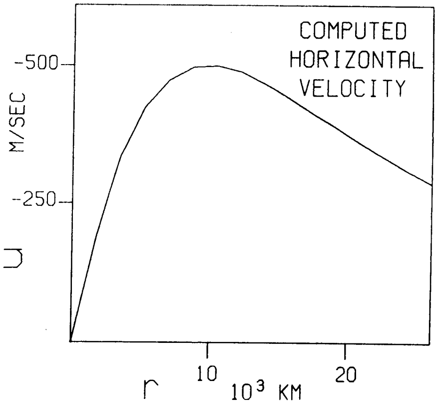

Fig. 3.

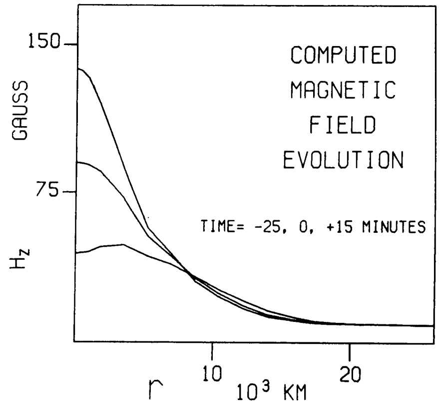

Fig. 4.

tion. It is not *the* unique integral as I have had to assume some information about the vertical structure of the velocity field.

I will now consider the effect of this velocity on the magnetic field. The magnetic diffusion time for this problem is on the order of months so that the field can be considered as 'frozen in'. The induction equation can be written as:

$$\frac{\partial \mathbf{H}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{H}). \tag{5}$$

The vertical component of this equation in the case of axial symmetry is

$$\frac{\partial H_z}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left[r\left(wH_r - uH_z\right)\right], \tag{6}$$

where the subscripts r and z denote the radial and vertical components of the magnetic field. We know that $|w| < |u|$, and there is good evidence for $|H_r| < |H_z|$, so that if we assume that $|wH_r| \ll |uH_z|$ Equation (6) can be integrated for $\partial u/\partial t = 0$. The result is shown in Figure 4. The consequences of concentration are very marked, observable changes in the field strength should occur in less than an hour. No one has reported changes of this magnitude taking place in so short a time. Thus it appears that the observed velocity field is not in the process of concentrating the observed magnetic field.

I will outline briefly four possible alternate physical situations which are more consistent with the observations. This list is not meant to be exhaustive or the items on it even mutually exclusive.

Situation Number 1. The electrical conductivity is several orders of magnitude less than believed so that the field is no longer 'frozen in'.

Situation Number 2. The velocity cannot be described by a simple separable solution of the continuity equation. That is, although there may be a horizontal velocity of

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500 m/s it is not where I have predicted. This can be checked by observation away from the center of the solar disk. I am planning such observations.

Situation Number 3. The flow is along the field lines. In most cases this would also imply Situation Number 2.

Situation Number 4. The magnetic field is concentrated in knots, and the material flows around the knots.

Discussion

Leighton: Is the vertical velocity field seen in the photosphere simply the downward extension of the chromospheric infall of matter seen in Hα?

Musman: This would be a consistent interpretation of the photospheric observations. It would also be included under Situation Number 3 which I have suggested.

Cowling: I suggest that you do not observe the concentration of fields simply because the filaments of strong field are relatively permanent, and the further concentration is unnecessary.

Musman: I agree. If concentration is not currently going on it must have occurred at some other time or place.