

Magneto-Convection

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1. Introduction

The structure of the solar surface and its atmosphere is controlled by turbulent convection. Magnetic flux tubes which emerge through the surface are shuffled around by the convective motions. This stresses the field whose subsequent relaxation heats the chromosphere and corona and controls their structure. Magnetic fields alter convection itself (Steiner et al. 1998). We have begun to investigate the near surface behavior of magnetic flux tubes and their emergence through the solar surface.

2. The Simulation

We simulate a small portion of the solar photosphere and the upper layers of the convection zone, a region extending 6×6 Mm horizontally and from the temperature minimum at -0.5 Mm down to 2.5 Mm below the visible surface. We solve the equations of mass, momentum and energy conservation and the induction equation for the vector potential (to ensure $\nabla \cdot B = 0$) in non-conservative form on a non-staggered mesh. The spatial derivatives are calculated using third order splines and the time advance is a third order leapfrog scheme. The code is stabilized by a hyper-viscosity which removes short wavelength noise without damping the longer wavelengths (Stein & Nordlund 1998).

We include ionization in the equation of state, since a large fraction of the internal energy is in the form of ionization energy near the solar surface. We include 3D, LTE, non-gray radiation transfer in our code, since radiative energy exchange near optical depth unity produces the entropy fluctuations that drive the convective motions.

Vertical boundary conditions are a transmitting upper boundary (at the temperature minimum) with a potential magnetic field. At the bottom of the computational domain total pressure is uniform over the boundary layer and varies in time so that the net mass flux through the bottom boundary vanishes.

The density and energy of the incoming fluid is adjusted, at constant pressure, so its entropy remains constant (in both space and time). The horizontal directions are taken to be periodic.

We have investigated two magnetic field topologies: First, where horizontal field is advected into the computational domain by plasma entering at the bottom and no restrictions are placed on the magnetic field in outflow locations, and Second where the magnetic field is initially vertical and remains so at the bottom boundary.

3. Results

Strong fields are concentrated into downflows by the diverging upflows. Where the magnetic field is initially horizontal, upflows and downflows distort the field into loops (Fig 1). In the photosphere the magnetic pressure becomes comparable to the gas pressure and the field spreads out.

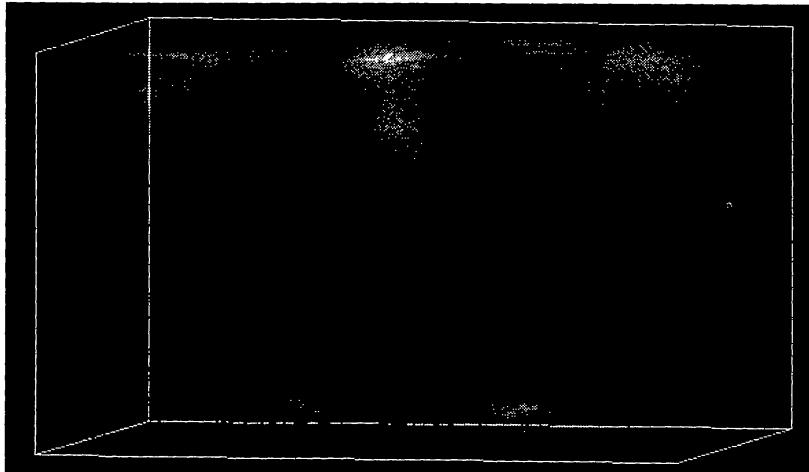


Figure 1. Image of magnetic field strength with selected field lines for the case of horizontal magnetic field advected in at the bottom. The field tends to remain primarily horizontal, except where it is drawn out into loops by the upflows and downflows. At the surface the field spreads out.

The surface magnetic field is confined to the intergranular lanes. As more flux penetrates the surface, more of the intergranular lanes are filled with strong field. The peak surface field strength (except for very large magnetic flux) is such that the peak magnetic pressure is comparable to the peak gas pressure. This gives maximum field strengths of about 2 kG. Some of the strongest surface field locations have a larger magnetic than gas pressure. Below the surface gas pressure increases inward much more rapidly than the magnetic pressure. Hence, in the interior the magnetic pressure is always small compared with the gas pressure.

The presence of a magnetic field alters the appearance of the granulation. (Fig 2).

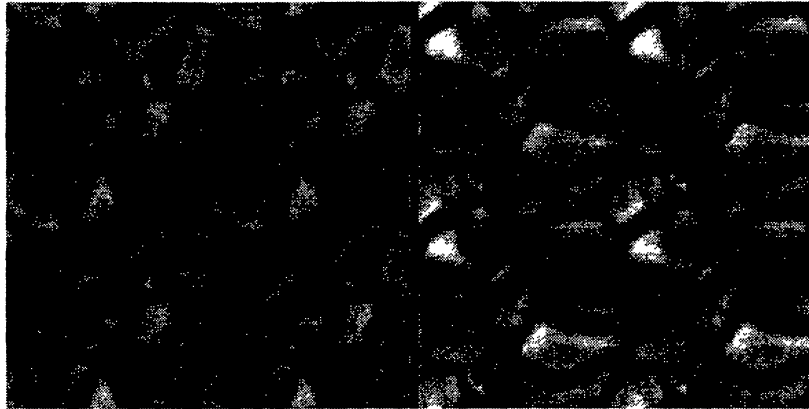


Figure 2. Emergent intensity in absence of magnetic fields (left) and in presence of magnetic fields (right). Magnetic fields become concentrated into the intergranular lanes producing both pores and bright points. The simulation domain has been doubled in each direction to make the pattern clearer.

Both bright points and pores are produced. The highest surface magnetic field locations sometimes appear dark and sometimes bright compared to the surrounding emergent intensity. Intermediate strength field locations tend to be darker than normal intergranular lanes (Fig 3). The intense magnetic flux

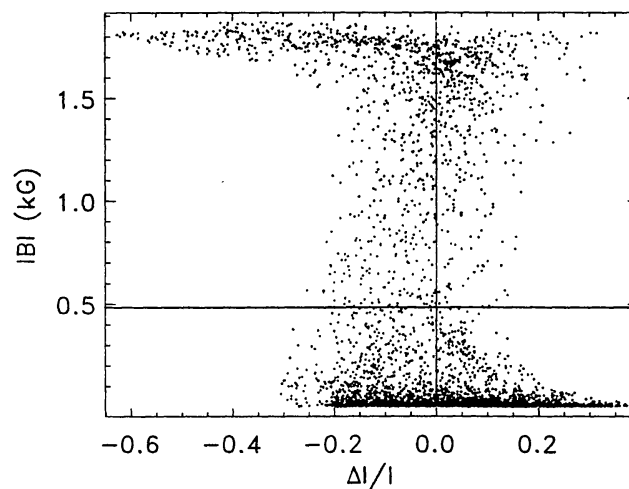


Figure 3. Correlation of surface magnetic field strength and emergent intensity for the vertical field case. Strong fields produce both dark pores and bright points.

tubes are evacuated and as a result, optical depth unity occurs several hundred kilometers deeper where the surface field is strong. Where bright points occur, the fluid velocity is not much suppressed and the surface of optical depth unity occurs at a higher temperature inside the low density evacuated flux tube. In

pores, on the other hand, the fluid velocity is significantly suppressed and the surface of optical depth unity occurs at a lower temperature inside the pore than the surroundings. A slice through an adjacent pore and bright point shows the magnetic field strength and temperature contours with the optical depth unity surface (Fig 4) and the velocity vectors in the plane and the magnetic field contours (Fig 5). The suppression of motion in the pore appears to lead to a lower temperature at optical depth unity in the pore.

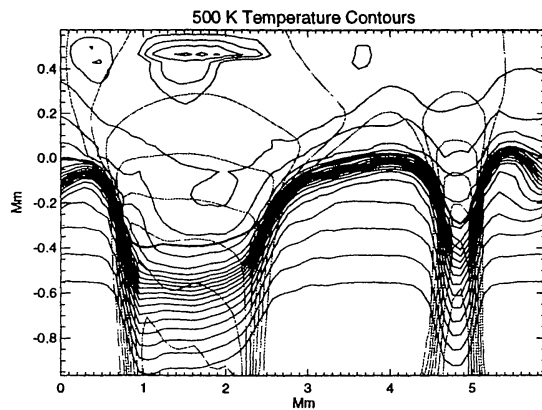


Figure 4. Vertical slice through a pore and adjacent bright point. Solid contours are temperature and dashed contours are magnetic field strength. Heavy line is optical depth unity, which occurs at a cooler temperature inside the pore and at a warmer temperature inside the bright point than in the surroundings.

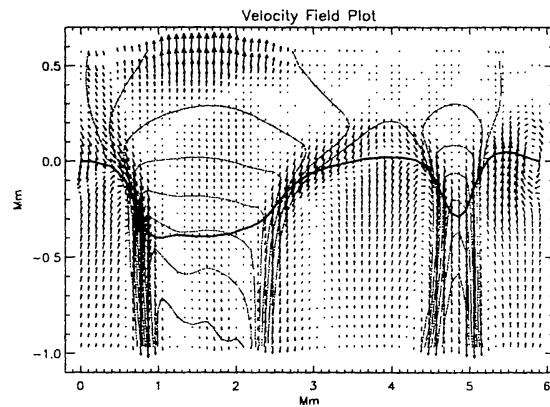


Figure 5. Vertical slice through a pore and adjacent bright point. Arrows show fluid velocity in the plane and contours are magnetic field strength. The fluid motion is significantly suppressed in the pore, but only slightly in the bright point.

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