

Solar Magneto-Convection

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Abstract. We have simulated magneto-convection near the solar surface with two topologies – (1) an initial vertical field and (2) a horizontal field carried in with the fluid entering at the base of the computational domain. We report results on the interaction of convection and magnetic fields. An MPEG video is viewable at:

<http://www.pa.msu.edu/~steinr/images/bhoriz.mpg>

1. Introduction

We strive to understand the interaction of convection and magnetic field using three-dimensional numerical simulations of compressible magneto-convection in a solar surface layer. The equations of mass, momentum and energy conservation, and the induction equation are solved in a region $6 \text{ Mm} \times 6 \text{ Mm}$ horizontally and 3 Mm vertically, extending 2.5 Mm below the photosphere. Periodic boundary conditions are used in the horizontal directions, and the vertical boundary conditions are designed to be as transmitting as possible. We use a tabular equation of state that includes excitation and ionization of hydrogen and other abundant atoms, and the formation of H_2 molecules. The radiative energy exchange is calculated by solving the transfer equation for LTE radiation using

a 4 bin opacity distribution function (Nordlund & Stein 1989, Nordlund et al. 1992).

Here we present results from two series of low resolution ($32 \times 32 \times 41$) exploratory runs. The first set has an initially imposed vertical magnetic field of increasing average strength: 50 G, 200 G, 400 G, 600 G, 800 G, and 1 kG. The field strengths were increased by progressively relaxing a given state and then adding more uniform flux. The second set of runs has incoming fluid at the bottom of the computational domain carrying in horizontal field with uniform strength 500 G and 2 kG.

2. Emergent Intensity

Increasing field strength has a dramatic effect on the simulated emergent intensities (Figure 1). When compared to the case with no magnetic field, the cases with imposed vertical field show a smaller, more irregular granulation structure for field strengths up to 400G. For higher magnetic flux levels, the field concentrates in and widens some of the intergranule lanes which become very dark. Larger, more regular horizontal cells are produced that contain small scale granulation patterns.

The horizontal field runs also show a switch from smaller to larger granulation structures. The field is again concentrated in the intergranule lanes, which appear dark where the field strength is moderate and bright at the highest field locations ($B > 1.5$ kG). At the flux levels calculated so far, they do not develop large dark regions. It should be noted that these are low resolution runs. Appropriate caution is required until the effects of increasing resolution are investigated.

The emergent intensities distribution is significantly changed by a strong magnetic field (Figure 2) as expected from Figure 1. The presence of magnetic fields alters the intensity distribution. Moderate flux levels (200 G) produce small bright points within the intergranular lanes. High flux levels (600G) produce extensive very dark regions and decrease the amount of bright material.

The correlation of the magnetic field with intensity differs between the vertical and horizontal field cases. The magnetic field concentrates in downflow regions (positive velocity) which are darker than average in both cases (Figure 3). However, the strongest fields in the horizontal field case are always brighter than average, whereas for the vertical field case, the strongest fields tend to be darker than average.

3. Horizontal Flux Evolution

The horizontal field cases were started without field to monitor how field entering through the bottom of the computational domain emerges at the surface. Figure 4 shows the time taken for flux to appear at the surface. It takes approximately forty minutes for magnetic field to ascend to the surface from 2.5 Mm below it for both 0.5 and 2 kG input field. Hence, for these field strengths, the field is advected up with the fluid, and magnetic buoyancy does not play a significant role.

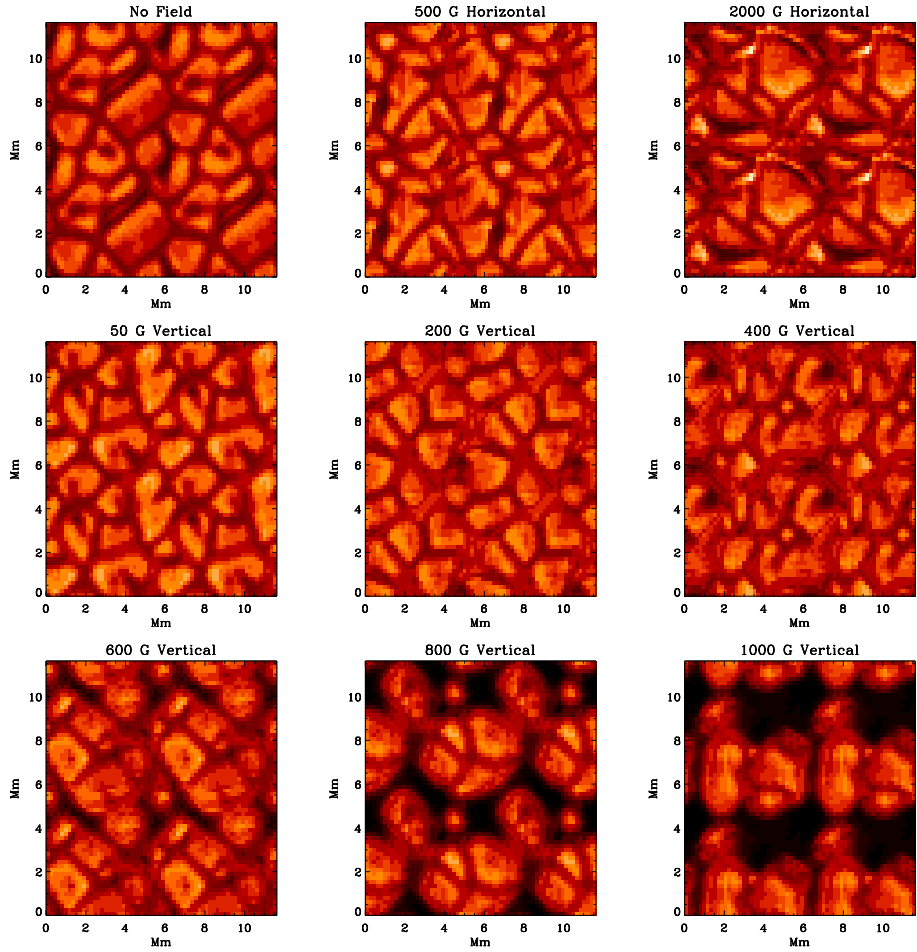


Figure 1. Emergent intensity showing the effects of magnetic field on the granulation. The computational domain has been doubled in the horizontal directions to 12 Mm \times 12 Mm to facilitate visualization of the pattern.

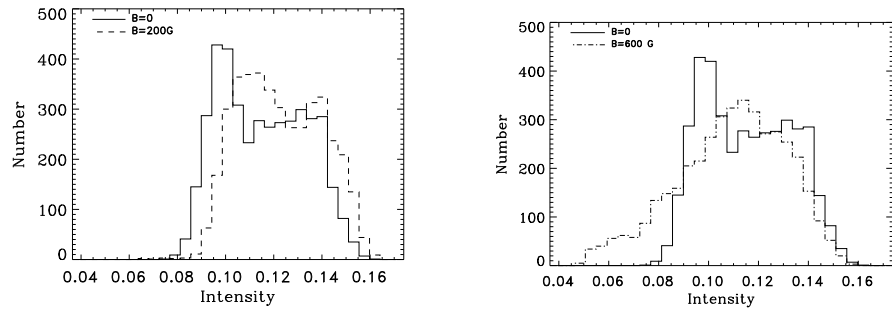


Figure 2. The intensity distributions for the cases of no magnetic field, and 200 G and 600 G vertical fields.

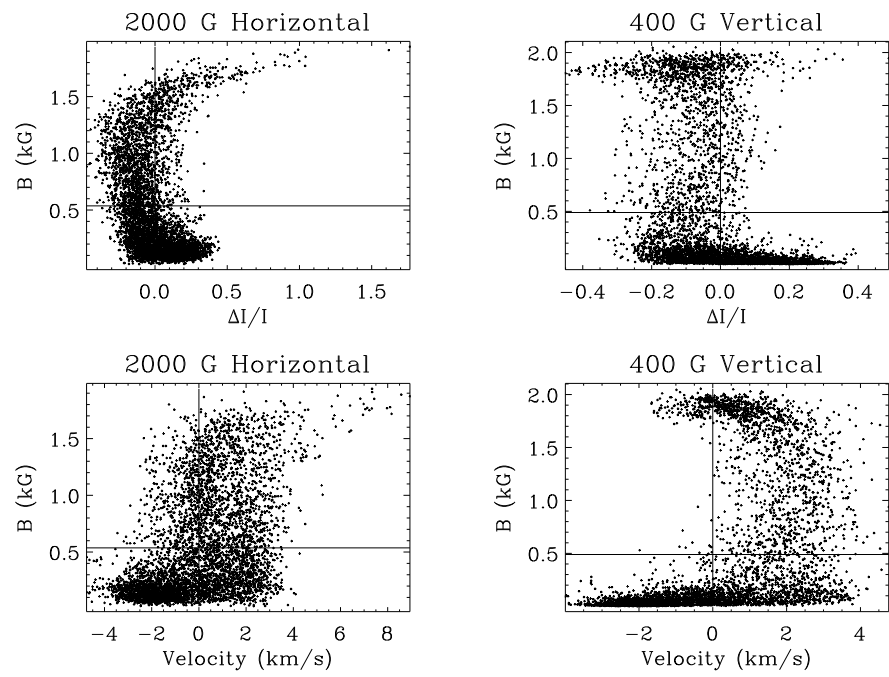


Figure 3. Correlations between magnetic field at the surface, emergent intensity and vertical velocity for the cases of 400 G vertical field and 2kG horizontal field.

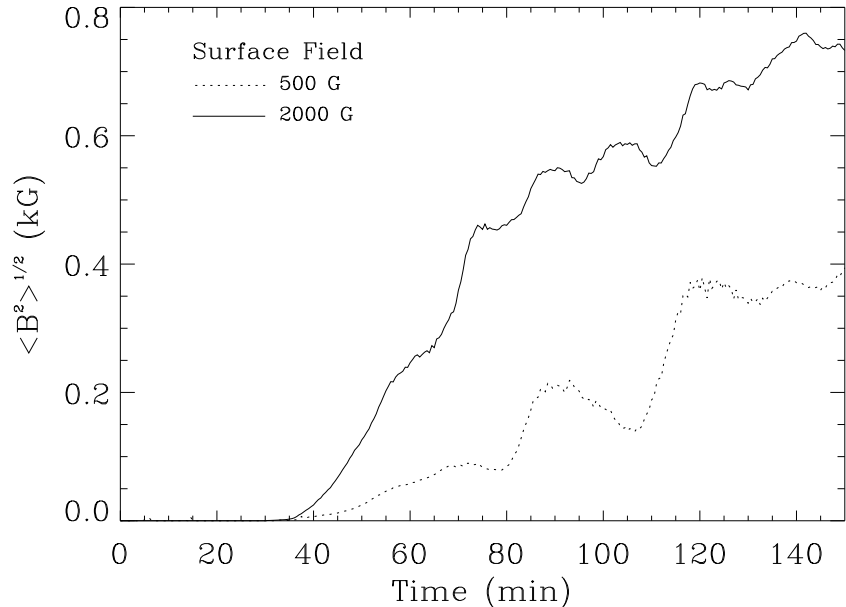


Figure 4. The time evolution of the rms surface magnetic field for the 500 G and 2 kG horizontal field simulations.

The three-dimensional evolution of magnetic field can be seen in the included MPEG movie, BHORIZ.MPG. This movie is from a 2.5 solar hour simulation starting with an initially uniform 500 G horizontal field and horizontal field carried into the computational domain by fluid flowing in from the bottom boundary. Individual frames are separated in time by 30 solar seconds. Flux tubes can be seen to rise in loop structures and emerge at the surface where they open up (frames 55-68 & 219-246). Instances of flux loops closing down and being pulled back down below the surface are also seen (frames 185-205 & 249-282).

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References

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