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Is solar convection responsible for the local amplification and structuring of magnetic fields? (Observational test of the hypothesis)

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Abstract. Full-vector magnetograms and Dopplergrams of selected areas of the solar photosphere are used to compute the vertical component of the right-hand side of the vector induction equation. We attempt to find a criterion for the action of the convective mechanism of amplification and structuring of magnetic fields using the distributions of this quantity and of the vertical magnetic-field component.

Keywords. Sun: magnetic fields, convection, MHD

Introduction. Based on a simple kinematic model, Tverskoy (1966) suggested that convection cells in an electically conductive fluid can locally amplify the magnetic field and form magnetic configurations typical of sunspot groups. Much later, Getling (2001), Getling & Ovchinnikov (2002), and Dobler & Getling (2004) investigated this possibility numerically. They have shown that such a convective mechanism of the amplification and structuring of magnetic fields can produce various magnetic regions, from unipolar to multipolar ones. The amplification process is due to the very topology of the cellular convective flow, so that the mechanism can operate on a wide range of scales.

Recent observation yielded direct evidence in favour of this convection mechanism: a movie demonstrated by Title (2006) in his lecture at the 26th General Assembly of the IAU in Prague clearly shows that small-scale magnetic bipoles frequently originate in the inner parts of supergranules.

The convective mechanism is an alternative to the widely known rising-tube mechanism of the emergence of bipolar magnetic regions. We analyse here some observational data for the flows and magnetic fields in active regions with the aim of elaborating a criterion for distinguishing between these two mechanisms in reality.

Distinctive features of the convective mechanism. In the case where the rising-tube mechanism operates, the magnetic field is the primary factor in the surface processes; its dynamics is likely controlled by an agent located deep in the convection zone and hidden from the observer. Therefore, in the observable layers of the Sun, the action of the magnetically originated forces should dominate over the effect of electromagnetic induction. The dynamics of the magnetic field itself will be mainly controlled by the disturbances coming from deeper levels, and the induction process will not be so pronounced against this background. Alternatively, in the case of the convective mechanism,

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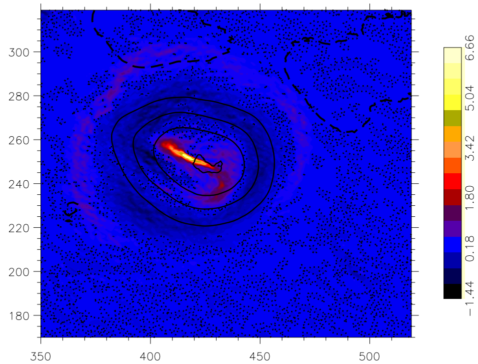

Figure 1. The vrhs in arbitrary units (filled contours; dotted curves indicate zero values) and the vertical magnetic field (solid and heavy dashed curves are contours for negative and zero values of the vertical magnetic field, respectively; contour increment is 250 Gs) in an active region observed on 8 December 2005. The coordinates are measured in pixels.

plasma motion is a primary factor, so that the dynamics of the magnetic field should be controlled by the *in situ* velocity field via the induction equation.

In a highly conductive medium, the behaviour of the magnetic field is governed by the electromagnetic-induction equation

$$\frac{\partial \mathbf{H}}{\partial t} = \nabla \times [\mathbf{v} \times \mathbf{H}],$$

in which the derivatives $\partial H_z/\partial z$ and $\partial v_z/\partial z$ are not known (we assume that the z axis is directed vertically); in general, this may also refer to v_x and v_y, not to speak of their derivatives with respect to x and y. In view of this, we introduce the assumptions that, in the observed layers of the Sun, (1) the derivatives with respect to z are small; (2) the advection of the magnetic field is weak, so that $\partial H_z/\partial t \approx \mathrm{d}H_z/\mathrm{d}t$; and (3) the measured value of H_z is proportional to $\partial H_z/\partial t$ (which should be true at early stages of the development of the active region). Then

$$H_z \propto \frac{\partial (v_z H_x)}{\partial x} + \frac{\partial (v_z H_y)}{\partial y}.$$

We calculate the last expression from observational data and use it as an approximate form of the vertical component of the right-hand side of the induction equation (vrhs). Accordingly, we regard agreement between the distributions of H_z and the vrhs as evidence in favor of the convective mechanism.

In addition, some qualitative features of the velocity field and magnetic field can be indicative of the presence of one mechanism or another.

Observations. We analyse concurrently recorded series of full-vector magnetograms and Dopplergrams obtained with the Solar Magnetic-Field Telescope at the Huairou Solar Observing Station, Beijing Astronomical Observatory. In addition, we use Dopplergrams recorded by the SOHO/MDI instrument. The data pre-reduction included the alignment of consecutive images and time averaging needed to reduce the effect of five-minute oscillations.

Results. We present here some observational results for two active regions. Figure 1 shows the distributions of the vertical magnetic field and vrhs for an active region observed on 8 December 2005 (the Dopplergram was not properly calibrated in this case; for this reason, we present here only the vrhs as a differential characteristic of the fields).

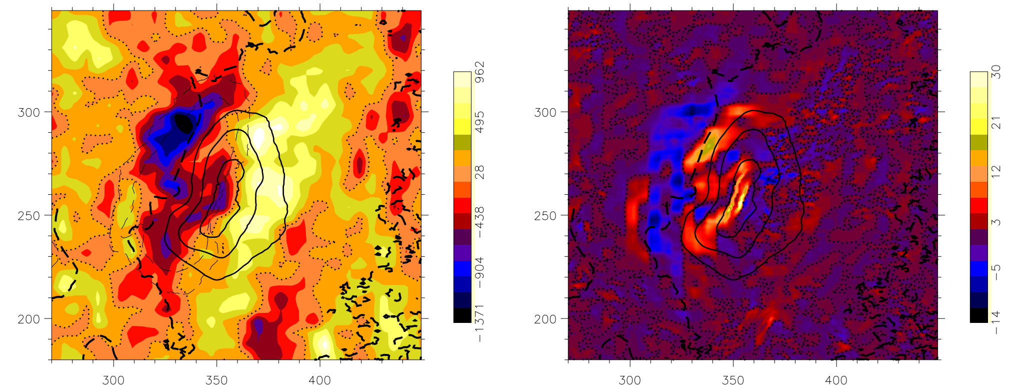

Figure 2. *Left:* The vertical velocity (filled contours; dotted curves indicate zero values) and the vertical magnetic field (solid and heavy dashed curves are contours for negative and zero values, respectively; contour increment is 200 Gs) in an active region observed on 8 June 2006. Light dashed curves are contours of the modulus of the horizontal component of the magnetic field for values of 500 and 750 Gs. *Right:* The vrhs in arbitrary units (filled contours; dotted curves indicate zero values) and the vertical magnetic field (represented as in the left panel) in the same region. The coordinates are measured in pixels.

The patterns of physical quantities for another active region, observed on 8 June 2006, are given in figure 2.

We can see the following remarkable features of the obtained maps:

(i) In figure 2, the extremum of B_z is offset with respect to the extremum of v_z, being located in between the main upflow and downflow.

(ii) In figure 2, the contour $v_z = 0$ intersects the region of a fairly strong magnetic field, so that oppositely directed motions are present in the region throughout which the magnetic field has the same polarity.

(iii) In both cases, agreement can be noted between the peak of B_z and the peak of the vrhs in their positions and shapes.

Feature (i) suggests that the formation of the magnetic field largely depends on the velocity shear, as can be expected if the convective mechanism plays a determinant role. Feature (ii) can be considered an argument against the idea of the rising-tube mechanism, since it implies that oppositely directed flows are present in the same flux tube. Finally, according to the above reasoning, feature (iii) is consistent with the assumption that the convective mechanism dominates.

Conclusion. As our tentative analysis indicates, the pattern of velocity and magnetic field in the two arbitrarily chosen active regions seems to contradict the rising-tube model, being more consistent with the convective mechanism.

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