ASYMMETRY OF EMERGING FLUX LOOPS CAUSED BY RADIAL DIFFERENTIAL ROTATION

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ABSTRACT

Observational and theoretical arguments in favor of a supposed serious asymmetry of magnetic flux loops emerging through the convective zone are briefly summarized. Results from numerical models of flux tubes moving through a differentially rotating upper convective zone are presented (plane parallel geometry, SFT approximation). In most models, especially in the most realistic ones, a remarkable asymmetry of the flux loop is found. It is concluded that in the future observational effects caused by the asymmetry may be used to put quantitative constraints on subphotospheric rotation.

1. BASIC CONCEPTS AND PRELIMINARIES

Recently it was proposed (vanDriel-Gesztelyi and Petrovay, 1989) that the apparently decelerating rotational rate of bipolar sunspot groups (e.g. Tenullo et al., 1981) can be interpreted as a purely geometrical effect arising from the asymmetrical shape and the changing emergence velocity of the magnetic flux loops causing the spots (Fig. 1). The asymmetry would be caused by the aerodynamic drag related to radial differential rotation: the upper layers of the convective zone rotate slower than the flux loops. As the drag, unlike other forces, acts on the surface of the flux tubes, the asymmetry should be stronger for thin (low flux) tubes than for thick (high flux) ones with the same field strength. This can explain the differences in the observed rotational properties of large and small spots (see Howard, 1987 and references therein). As a consequence, it can also be predicted that, on average, the magnetic 0-line will be situated asymmetrically relative to the main spots (Fig. 2); an investigation of Okayama Observatory magnetograms confirmed this result. At the same time, the common "anchoring" or "coupling depth" interpretation of spot proper motions is far more problematic from the observational point of view: after the supposed "decoupling" takes place, there would be no perpendicular forces acting on the loop, so its expansion should stop just when the rotational

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velocity begins to change, in contradiction to what is observed.

While the above observational facts strongly support the asymmetry-hypothesis, it remained to be seen whether the drag arising from differential rotation can actually produce the necessary amount of asymmetry. Petrovay et al. (1989) constructed stationary tube models in order to check this, and they found that the tilts in these crude models ($1°-5°$ for 10^{21} Mx tubes and $10°-30°$ for 10^{18} Mx tubes) produced observational effects that were in order-of-magnitude agreement with observations.

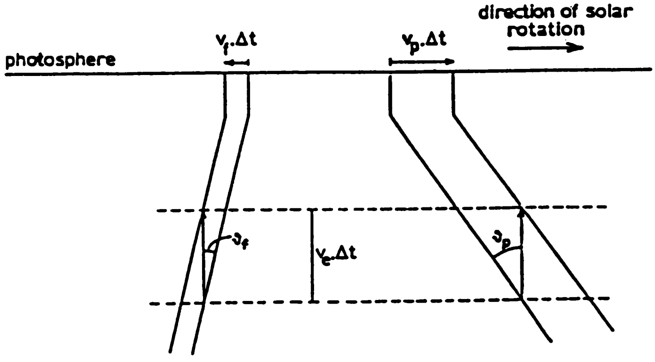

Figure 1: Schematic illustration of the effect of loop asymmetry on spot proper motions. During emergence, the apparent rotational velocity of the sunspot group will be higher than the real one by (v_p-v_f). (This and all the other diagrams are in a reference frame corotating with the loop.)

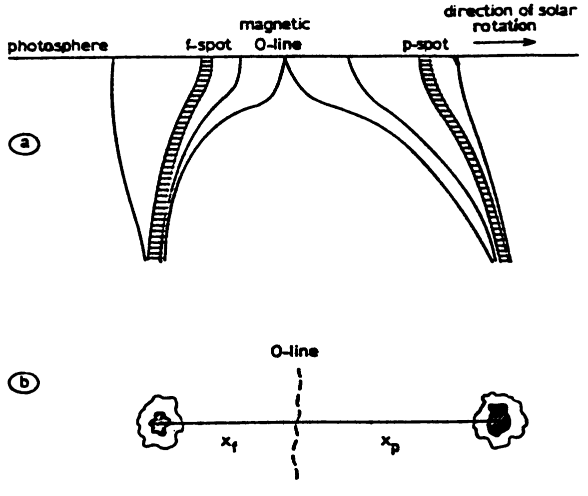

Figure 2: The higher tilt of the thin flux loops leads to an asymmetric position of the magnetic 0-line relative to the main spots.

However, as explained in Petrovay et al.(1989), these stationary models are highly unrealistic. So only nonstationary models of emerging flux loops can yield a satisfactory theoretical basis for the asymmetry-hypothesis and make possible more detailed comparisons with observations. Here we present briefly the first results from such nonstationary models; a detailed description of the numerical models will be presented elsewhere (Petrovay, 1989).

2. MODELS AND RESULTS

The models are analogous to those of Meyer et al.(1979): plane parallel geometry, slender flux tube (SFT) approximation and a "half-Lagrangian" integration method are common features of the two families of models. As the SFT approximation breaks down near the photosphere the integration was stopped before the top of the loop reached the surface.

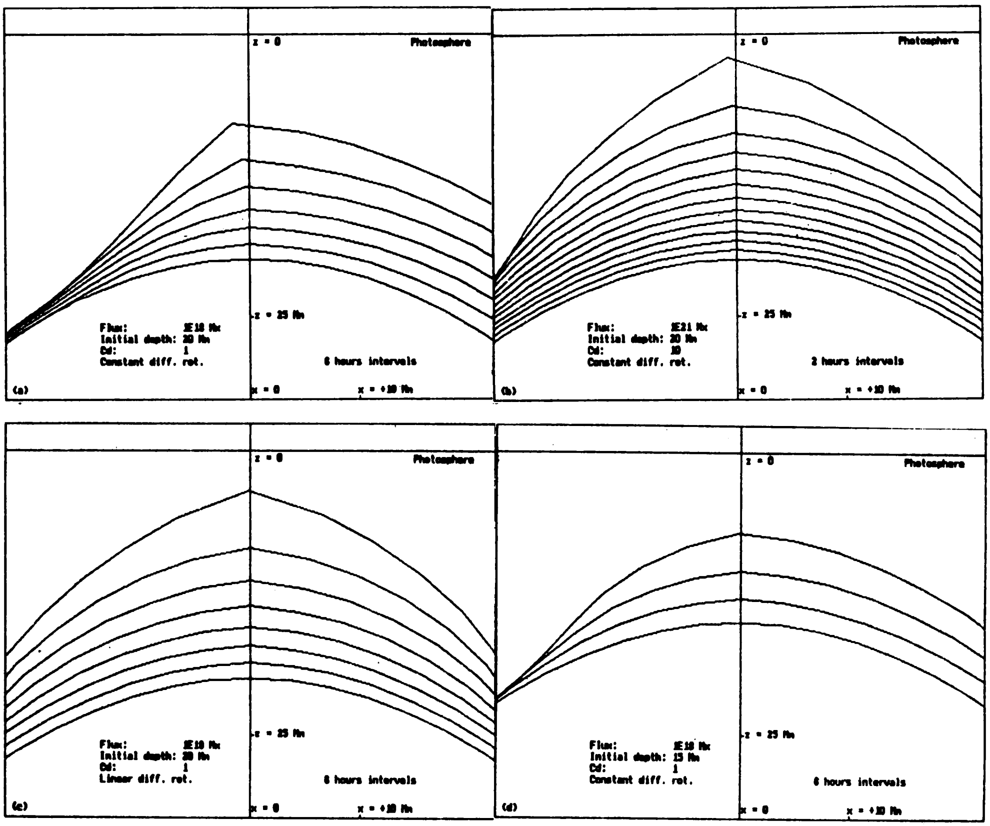

Figure 3: Models of flux loops emerging through a differentially rotating upper convective zone. On each of the four diagrams, the consecutive positions of the tube (considered to be slender) are shown in equal time intervals. Cd is the drag coefficient.

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Meyer et al.'s supergranular velocity field was of course replaced by a $v(z)$ horizontal flow with z the depth from photosphere ($v(z)$ is the difference of the rotational speed of the tube and its surroundings). Two extreme cases were examined: $v(z) = 10^4$ cm/s = constant and a linear $v(z) = 4\cdot 10^2$ cm/s $(z/10^8$ cm $- 25)$. The initial shape was a symmetrical, sinusoidal shape in a depth of z_{top} = 20 Mm (in other models, 15 Mm; 1 Mm = 10^3 km) with parameters chosen to imitate a typical loop shape in Moreno-Insertis (1986). In the models shown here the curvature was prescribed to vanish at the boundaries. In order to avoid solving the whole nonlinear MHD system of equations the B(z) field strength had to be specified in advance. We used the equipartitional field strength defined by $\rho v_c^2/2 = B^2(z)/8\pi$. The $\rho(z)$ density and the $v_c(z)$ convective velocity were taken from mixing-length models (analytic approximations were used). While the initial and boundary conditions used here give lower tilts than real, this form of B(z) yields an upper limit for the tilt, so these models are more or less representative (see Petrovay, 1989 for a more detailed analysis).

The "standard" models are shown on Figures 3(a) and (b). The high tilts obtained earlier in stationary models are confirmed. Figures 3(c) and (d) illustrate the sensitivity of the results to the parameters chosen. This sensitivity offers the possibility to put quantitative constraints on subphotospheric structure and dynamics from photospheric observations. This means that the age-old "tracer method" of the investigation of solar differential rotation might finally be developed into a genuinely exact, quantitative procedure, complementary to the oscillation method. (For details of this envisaged inversion procedure see: Petrovay et al., 1989, Fletcher, Brown and vanDriel-Gesztelyi, 1989).

REFERENCES

Fletcher,L., Brown,J.C., vanDriel-Gesztelyi,L.: 1989, in preparation.

Howard,R.F.: 1987, in: The Internal Solar Angular Velocity, eds. R. Durney and S. Sofia, Reidel, Dordrecht, p.23.

Meyer,F., Schmidt,H.U., Simon,G.W. and Weiss,N.O.: 1979, Astron. Astrophys., 76,35.

Moreno-Insertis,F.: 1986, Astron. Astrophys., 166,291.

Petrovay,K., Brown,J.C., Fletcher,L., Marik,M. and vanDriel-Gesztelyi,L.: 1989, Solar Phys., submitted.

Petrovay,K.: 1989, in preparation.

Tenullo,M., Zappala,R.A., Zuccarello,F.: 1981, Solar Phys., 74,111

vanDriel-Gesztelyi,L. and Petrovay,K.: 1989, Solar Phys., submitted.