A Possible Solar Cycle Dependence to the Hemispheric Pattern of Filaments ?

D.H. Mackay[1]

Abstract.

The origin of the hemispheric pattern of filaments is considered for both the rising and declining phases of the solar cycle. This is carried out by using a magnetic flux transport model which considers how bipoles interact with surrounding polar fields. For the rising phase of the cycle a range of initial twists and tilt angles of the bipoles consistent with observations can be found which reproduces the observed hemispheric pattern. For the declining phase no such range can be found. To determine whether there is a cycle variation to the hemispheric pattern new detailed observations are required.

1. Introduction

For many years it has been known that solar filaments and their birth grounds, filament channels have a surprising hemispheric pattern (Martin et al. 1994). In the northern hemisphere filament channels (and filaments) are predominately dextral. In the southern hemisphere they are predominately sinistral. A dextral/sinistral filament channel (filament) is one in which the axial magnetic field component points to the right/left when viewed from the positive polarity side. The organizational principle behind this orientation has still to be identified.

The aim of this paper is to use a flux transport model in order to determine the origin of the hemispheric pattern of filaments. This will be considered through bipolar flux regions interacting with polar fields in both the rising and declining phases of the solar cycle (van Ballegooijen et al. 2000). In contrast to previous simulations the restriction of using an initial coronal field which is potential is removed. Bipoles are considered which are independent from the surrounding polar field and also have an initial twist of positive or negative helicity (Pevtsov et al. 1995). This twist includes essential new physics into the evolution of the coronal field. In addition to helicity the dependence of the hemispheric pattern on the tilt of the bipoles axis is also considered.

2. The Model

To evolve the Sun's magnetic field ($\mathbf{B} = B_r, B_\theta, B_\phi$) the flux transport model of van Ballegooijen et al. 2000 is used. In this model the photospheric magnetic

[1]School of Mathematical Sciences, University of St Andrews, St Andrews, Fife, Scotland, KY16 9SS.

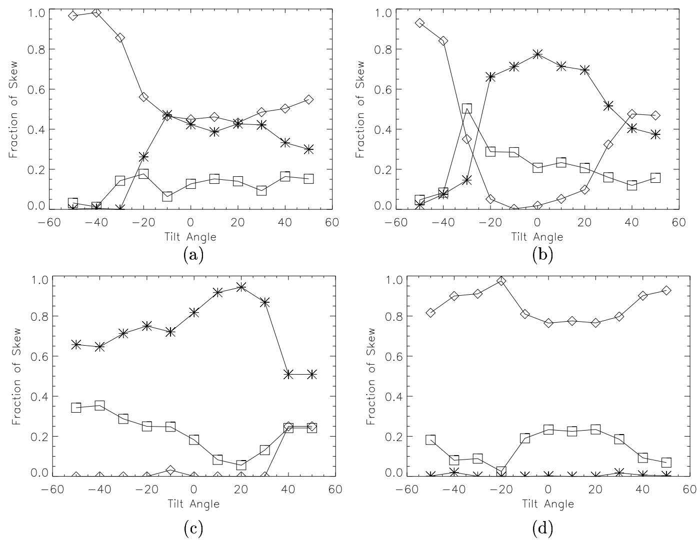

Figure 1. Fraction of skew produced along the PIL in the rising phase for (a) an initial potential field, (b) an independent untwisted bipole, (c) a negatively twisted independent bipole and (d) a positively twisted independent bipole. In each case stars represent dextral skew, diamonds sinistral and the squares weak.

field is acted upon by the flux transport effects of differential rotation, meridional flows and supergranular diffusion. Reconnections of the field are only allowed on the photospheric base so in the coronal volume an ideal evolution is considered. The ideal evolution is carried out by a magnetofrictional relaxation method which produces non-linear force-free magnetic fields. Full details of the numerical method, boundary conditions and form of differential rotation, meridional flows and supergranular diffusion used can be found in the papers by van Ballegooijen et al. 2000 or Mackay et al. 2000.

The purpose of the present paper is to understand how bipolar active regions interact with pre-existing coronal fields as their initial helicity and tilt angle varies. We will consider a volume of the Northern Hemisphere so the production of a dextral axial magnetic field is required to match the hemispheric pattern. In the region considered the background field of the Sun is assumed to be that of the polar field. A untitlted/tilted bipole is then emerged into the background field. Three sets of models with different assumptions about the initial condition of the bipole and coronal field are considered. In the first set the initial coronal field is assumed to be potential (i.e., current free, Figure 2a). In the second case, shown in Figure 2c, a potential field is first constructed from the polar flux, and then an untwisted bipole is allowed to emerge into the polar field. The bipole forms a separate magnetic flux system that is initially not connected to the pre-existing coronal field. The coronal field for this case is non-potential. The third type of configuration is that of an independent bipole with nonzero twist. Negative/positive values of twist produce dextral/sinistral skew within

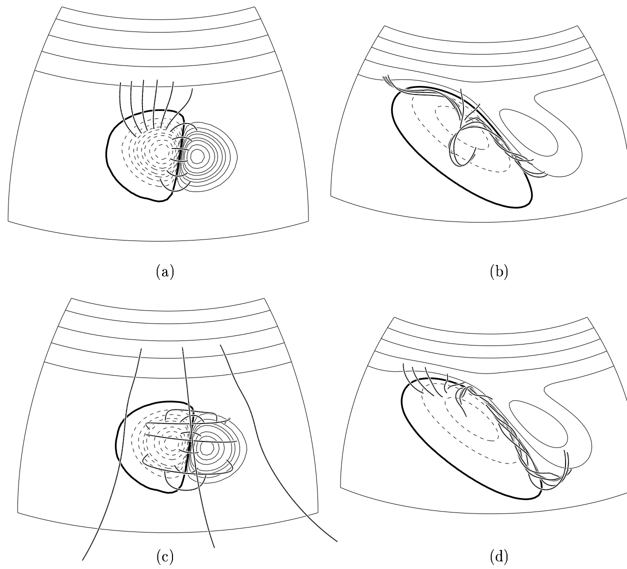

Figure 2. Field line structure in the rising phase for (a) an initial potential field and (b) the field evolved for 27 days. Similar plots are shown in (c) and (d) for an independent untwisted bipole

the bipole. The flux transport effects of differential rotation, meridional flow and diffusion are allowed to act on the magnetic field for a period of 54 days (2 solar rotations). After 54 days the skew of the field is calculated everywhere along the Polarity Inversion Line (PIL). The type of skew produced by single bipoles in the rising and declining phases of the cycle is described below.

3. Single Bipole in the Rising Phase

The interaction of a single bipole with the polar field is now considered for the rising phase. Figure 1a shows the results for an initial potential field. The fraction of the PIL that has dextral (*stars*), sinistral (*diamonds*) and weak skew (*squares*) is plotted as function of the initial tilt of the bipole axis. No hemispheric pattern of dextral skew is found. Figure 1b shows the corresponding graph for an independent untwisted bipole emerged within the polar field. In this case there is a range of tilt angles (-20 to +30°) where dextral skew is by far the most dominant. This range covers the dominant tilt angles observed on the Sun (-10 to +30°, see Wang and Sheely 1989).

The effect of adding a twist to the field of the bipole is now considered. To begin with, negative values are considered. Negative values are chosen because the observations by Pevtsov et al (1995) and others have shown that negative helicity dominates for active regions in the northern hemisphere. It can be seen (figure 1c) that the initial helicity strongly affects the results because dextral skew is now by far the most dominant over all tilt angles. Therefore, by adding negative twist to the bipoles a skew consistent with the hemispheric pattern of filaments is produced. Simulations with positive helicity are now considered.

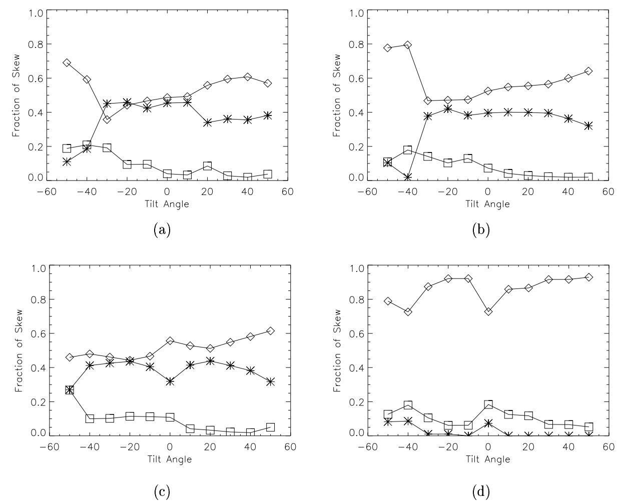

Figure 3. Same as Figure 1 but for the declining phase.

This produces a sinistral skew within the initial field of the bipole. After the field has been evolved for 54 days sinistral skew is the most dominant (Figure 1d). This produces the wrong chirality for the Northern Hemisphere, but one should keep in mind that only a minority of the active regions in the Northern Hemisphere have positive helicity.

From Figures 1a and 1b it is clear that the different configurations of the initial coronal magnetic field produce very different results. To illustrate why this is the case, we now consider a bipole with a tilt angle of $+10°$. Figure 2a shows the initial configuration for a potential field, and Figure 2b shows the evolved field after 54 days. Note that in Figure 2a there are strong connections between the polar field and the follower flux of the bipole. After the field lines have been evolved for 54 days a strong skew develops along the entire length of the PIL, dextral along the diagonal part and sinistral on the east-west. Equal amounts of dextral and sinistral skew are always produced, because of the initial orientation of the arcades.

Figure 2c shows the initial configuration for an independent untwisted bipole, and Figure 2d shows the corresponding field after 54 days. Since the bipole is initially isolated from the polar field, all of the flux in the bipole connects in an East-West direction and there are no longer any North-South connections. Differential rotation acting on the bipole produces dextral skew along the diagonal part of the lead arm. However, along the east-west section of the PIL the follower flux cancels with the polar flux and connections are made between the polar field and bipole. These connections have a dextral skew due to the initial East-West connectivity of the bipole. Therefore, the dextral skew is able to progress much further along the PIL and to higher latitudes than in the previous case (compare Figs. 2d and 2b). This is a result of the orientation of the bipole relative to the polar field.

4. Single Bipole in the Declining Phase

A single bipole interacting with the polar field is now considered for the declining phase of the solar cycle. In Figure 3a the fraction of skew produced as a function of the tilt angle can be seen for the potential field. As expected after 54 days of evolution there is no hemispheric pattern of dextral skew. In Figure 3b the corresponding results are shown for the untwisted bipole. Surprisingly this time no hemispheric pattern of dextral skew is found, even though one was for the rising phase. Even when negative helicity is added to the bipole (Figure 3c) the correct hemispheric pattern cannot be reproduced. Adding positive helicity (Figure 3d) yields dominantly sinistral fields, which is incorrect for the Northern Hemisphere.

It can be seen that very different results are obtained in the declining phase of the cycle compared to the rising phase. In the declining phase no hemispheric pattern that matches the observations can be produced even when helicity that should give the correct axial component is added. By considering the evolution of the field lines it will be shown why the declining phase of the cycle prefers the formation of sinistral skewed field lines in the Northern Hemisphere. To begin with the potential field configuration is considered. In Figure 4a the initial configuration can be seen and in 4b the evolved field after 27 days. In the declining phase the polar field has the opposite sign to the rising phase so the PIL follows a different path. As described previously, a dextral skew is formed on the return arm and sinistral skew is formed on the lead arm (Figure 4b).

However, if an independent untwisted bipole is considered, the type of skew formed does not change. In Figure 4c the initial configuration is shown, where all of the leader flux of the bipole connects to the follower flux. In contrast to the rising phase this now produces a sinistral field along the east-west section of the lead arm. As the flux diffuses out and interacts with the polar field, the initial East-West component of magnetic field along the lead arm is maintained and a sinistral axial component is produced (Figure 4d).

5. Conclusions

A systematic survey of the way in which bipoles interact with polar fields has been carried out. The survey aimed to determine the origin of the hemispheric pattern of axial components within filaments. The simulations were conducted in the Northern Hemisphere, but the results can be easily generalised to the Southern. This showed that the hemispheric pattern could be easily reproduced in the rising phase of the solar cycle, but not in the declining phase.

For the rising phase and a single, untwisted bipole there was a range of tilt angles (-20 to +30°) consistent with the observed tilt angles (Wang & Sheeley 1989) that gave the correct axial component. Furthermore, if the bipole was twisted with the dominant sign of helicity for each hemisphere, then the hemispheric pattern could be reproduced over all relevant tilt angles.

In contrast, for the declining phase of the solar cycle no definite hemispheric pattern could be reproduced even with the addition of the correct sign of helicity. This was a natural consequence of the orientation of the field inside the bipole which was very difficult to overcome.

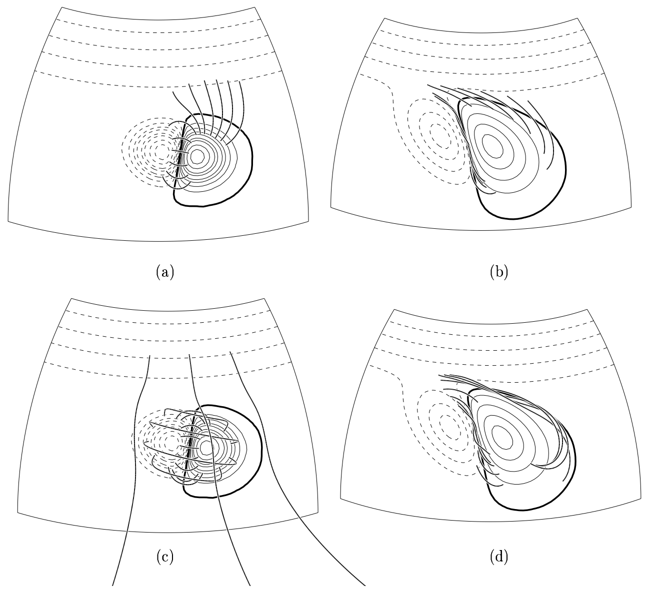

Figure 4. Same as Figure 2 but for the declining phase.

The simulations above show a clear distinction between the rising and declining phases of the solar cycle. To clarify this issue and verify that the hemispheric pattern indeed exists in both rising and declining phases, new measurements of prominence magnetic fields are needed. The present data sets are weighted towards the rising phase. Detailed information about the location and chirality of each filament needs to be recorded. Without such information it is impossible to determine whether existing models are consistent with the observations or not.

Acknowledgments. Financial support for the work was given by PPARC. The numerical simulations were carried out on the PPARC-funded Compaq MHD Cluster in St. Andrews.

References

Mackay, D. H., Gaizauskas, V., & van Ballegooijen, A. A. 2000, ApJ, 544, 1122

Martin, S. M., Bilimoria, R., & Tracadas, P. W. 1994, in *Solar Surface Magnetism*, ed. R. J. Rutten & C. J. Schrijver (New York: Springer-Verlag), 303-338

van Ballegooijen, A. A., Priest, E. R., & Mackay, D. H. 2000, ApJ, 539, 983

Pevtsov, A.A., Canfield, R.C., & Metcalf, T.R. 1995, ApJ, 440, L109

Wang, Y.-M., & Sheeley, N.R., Jr. 1989, Solar Phys., 81, 124