Modeling the Hemispheric Pattern of Solar Filaments

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Abstract. New results in modeling the hemispheric pattern of solar filaments are presented. The simulations consider what type of chirality forms along the Polarity Inversion Line (PIL) lying in between two magnetic bipoles as they interact. The results demonstrate not only the origin of the dominant hemispheric pattern, but also why exceptions to it occur. The dominant hemispheric pattern may be attributed to the dominant range of bipole tilt angles and helicities in each hemisphere (Wang & Sheeley 1989; Pevtsov et al. 1995). Exceptions to the hemispheric pattern occur in cases of no initial helicity or for helicity of the minority type in each hemisphere, when large positive bipole tilt angles are used. As the simulations show a clear dependence of the chirality on observational quantities, this may be used to check the validity of the results.

1. Introduction

Solar filaments form over a wide variety of latitudes on the Sun. In recent years, it has been shown that the dominant axial magnetic fields (Leroy et al. 1983, 1984; Bommier & Leroy 1998) that thread through solar filaments display an unusual hemispheric pattern (Martin et al. 1994). In the northern/southern hemisphere at mid- to high-latitudes, dextral/sinistral filaments dominate although exceptions do occur. A dextral/sinistral filament, is one in which, when standing on the positive polarity side of the PIL and looking towards the main body of the filament the axial magnetic field points to the right/left.

The aim of this paper is to consider what type of chirality of the magnetic field is produced through the interaction of two magnetic bipoles, using a mixture of magnetic flux transport and magneto-frictional relaxation simulations. Such configurations of interacting bipoles are important for filaments as observations by Tang (1987) show that the majority of filaments form in between bipoles (Type-B) rather than within a single bipole (Type-A).

2. Model and Initial Setup

To determine the origin of the hemispheric pattern, we use a magnetic flux transport and magneto-frictional model (van Ballegooijen et al. 2000). The Sun’s magnetic field $\mathbf{B} = (B_{r}, B_{\theta}, B_{\phi}) = \nabla \times \mathbf{A}$ is evolved by the induction equation. At the photosphere the magnetic field is subject to large-scale advection due to differential rotation and meridional flows. In addition to these global flows, the field is also subject to surface diffusion (see Equations 14 and 15 of van Ballegooijen et al. 2000).
In the coronal region the magnetic field evolves through the non-ideal induction equation,

$$\frac{\partial \mathbf{A}}{\partial t} = \mathbf{v} \times \mathbf{B} - \eta_c \mathbf{j},$$

(1)

where \( \mathbf{v}(r, t) \) is the plasma velocity, \( \mathbf{j} = \nabla \times \mathbf{B} \) and \( \eta_c \) the coronal diffusion.

To ensure that the coronal field evolves through a series of force-free states a magneto-frictional method is employed (Yang et al. 1986) where,

$$\mathbf{v} = \frac{1}{\nu} \frac{\mathbf{j} \times \mathbf{B}}{B^2} + v_o e^{-(2.5R_\odot - r)/r_w} \hat{\mathbf{r}}.$$  

(2)

The purpose of the present paper is to understand how bipolar magnetic regions interact for different initial helicities and tilt angles. To do this we consider a region in the northern hemisphere where the production of dextral magnetic fields is required to match observations. A typical initial configuration of the bipoles can be seen in Fig. 1(a).

Flux transport effects are then allowed to act on the magnetic field for a period of 54 days. Three sets of simulations with different initial conditions are considered. In the first set, the initial fields of both bipoles are given a small negative twist or helicity \( \beta = -0.2 \) in non-dimensionalised units, Mackay & van Ballegooijen 2005), in the second set they are untwisted \( \beta = 0 \) and in final set a small positive twist or helicity \( \beta = 0.2 \) is used. These initial helicities only produce a small shear in the bipole and do not result in helically twisted coronal field lines. For each of these three cases the initial tilt angles \( \alpha \) of both bipoles are varied from \(-30^\circ\) to \(+40^\circ\) where positive tilt angles are consistent with Joys Law.

3. Results of the Simulations

The results of the simulations can be seen in Fig. 2. Each graph shows the fraction of dextral (stars), sinistral (diamonds) or weak skew (squares) produced along the PIL lying in between the two bipoles as a function of the initial bipole tilt angle \( \alpha \).

It is clear from Figs. 2(a)-(c) that on day 2 for all bipole tilt angles weak skew dominates and very similar results are obtained in all three cases. The reason for this is that when the bipoles are twisted, the twist, is mainly added to the inner parts of the bipole and the outer parts remain mainly untwisted. In the initial days of the simulation only the outer parts of the bipoles interact to produce field lines over the PIL, hence similar results are found for each case. A typical example of the field lines lying over the PIL between the two bipoles can be seen in Fig. 1(a) for the negative twist case and \( \alpha = 10^\circ \).
Figure 1. Field line structure for two bipoles interacting in the Northern Hemisphere for $\beta = -0.2$ and $\alpha = 10^\circ$. Figure (a) shows the field structure on day 2 after the bipoles have made cross connections, and (b) the field after 46 days of evolution. In each case solid lines represent positive flux, dashed lines negative flux and the dotted line the PIL. The solid lines connecting positive and negative flux represent the field lines.

The results are however very different for each of the three cases after 46 days of evolution. Over this period differential rotation extends the bipoles in an East-West sense, meridional flow pushes them poleward and the two bipoles converge due to the combined effects of differential rotation and surface diffusion (Fig. 1(b)). Surface diffusion plays a key role in cancelling flux between the bipoles and transporting the twisted field lines from the inner parts of the bipoles to the PIL lying in between the bipoles. In Fig. 1(b) it can be seen that a strong dextral axial field, consistent with the hemispheric pattern forms above the PIL in between the two bipoles.

In Figs. 2(d)-(f) the full results can be seen for each set of simulations. For the negative twist case (Fig. 2(d)) it is clear that dextral skew (stars) dominates over the entire range of bipole tilt angles. It should be noted that observations by Wang & Sheeley (1989) show that 80% of bipoles emerge with tilt angles ranging between $-10^\circ$ : $30^\circ$. Therefore, by considering both the dominate range of bipole tilt angles (Wang & Sheeley 1989) and dominant helicities (Pevtsov et al. 1995) the dominant hemispheric pattern may be reproduced. The results are however more mixed for the zero and positive twist cases (Figs. 2 (e) and (f)). Dextral skew is once again dominant for tilt angles ranging from $-30^\circ$ to $10^\circ$. However, outside this range for the more extreme values of positive bipole tilt angles ($\alpha > 20^\circ$), sinistral skew forms. Although this does not match the hemispheric pattern it does show how exceptions to the pattern may occur around the tail end of the dominant positive bipole tilt angles when the bipoles either have no twist or are twisted with the minority type of helicity for their hemisphere.

4. Discussion

In this paper magnetic flux transport simulations have been used to consider the origin of the hemispheric pattern of filaments. The results clearly demonstrate how the dominant chirality of Type-B filaments may be a result of the dominant
bipole tilt angles and dominant helicity in emerging bipoles. Along with this exceptions to the hemisphere pattern may occur in a natural way near the tail end of dominant positive tilt angles, when the bipoles have either no twist or the minority type for their hemisphere.

The results show a clear dependence of the hemispheric pattern (and exceptions to it) on observable quantities such as bipole tilt angles and helicity. Such a dependence may in principle be checked through a detailed comparison of theory and observations.

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References