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Flux transport dynamo coupled with a fast tachocline scenario

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Abstract. The tachocline is important in the solar dynamo for the generation and the storage of the magnetic fields. A most plausible explanation for the confinement of the tachocline is given by the fast tachocline model in which the tachocline is confined by the anisotropic momentum transfer by the Maxwell stress of the dynamo generated magnetic fields. We employ a flux transport dynamo model coupled with the simple feedback formula of this fast tachocline model which basically relates the thickness of the tachocline to the Maxwell stress. We find that this nonlinear coupling not only produces a stable solar-like dynamo solution but also a significant latitudinal variation in the tachocline thickness which is in agreement with the observations.

Keywords. Sun: dynamo, Sun: tachocline, Sun: magnetic fields.

1. Introduction

The tachocline is a thin layer located at the base of the solar convection zone where the rotation changes from differential to the rigid rotation. However the thinness of this layer made the confinement of the tachocline an intriguing problem. One plausible explanation for the confinement of the tachocline was that the Maxwell stress of the dynamo generated magnetic fields can provide a strong anisotropic angular momentum transport in the horizontal direction. This is known as the *fast tachocline* mechanism (Forgacs-Dajka & Petrovay 2001, 2002; Forgacs-Dajka 2003).

In the fast tachocline scenario, the thickness of the tachocline depends on the magnetic field in a nonlinear way. On the other hand, the thickness of the tachocline is an important input parameter of flux transport dynamo models which is successful in explaining many important aspects of the solar cycle (Chatterjee, Nandy & Choudhuri 2004; Choudhuri & Karak 2009; Karak 2011; Karak & Choudhuri 2011, 2012; Choudhuri & Karak 2012; Karak & Nandy 2012). The objective of the present work is to couple the simple feedback formula capturing the essential physics of the fast tachocline model in a flux transport dynamo model and to see its response in flux transport dynamo model. Details can be found in Karak & Petrovay (2012).

2. Results

Following Forgács-Dajka & Petrovay (2001) the approximate relation between the mean (cycle averaged) tachocline thickness and Maxwell stress can be written as

$$d_t^2 = \frac{C\eta_t}{\bar{B}_p(\theta,t)\bar{B}(\theta,t)}. \tag{2.1}$$

where $C \approx 2 \times 10^{15}\ \mathrm{G}^2{\cdot}\mathrm{s}$, η_t is the mean diffusivity in the tachocline and $\bar{B}$ and $\bar{B}_p$ $(= \sqrt{B_r^2 + B_\theta^2})$ are the local radially averaged values of the toroidal and the poloidal

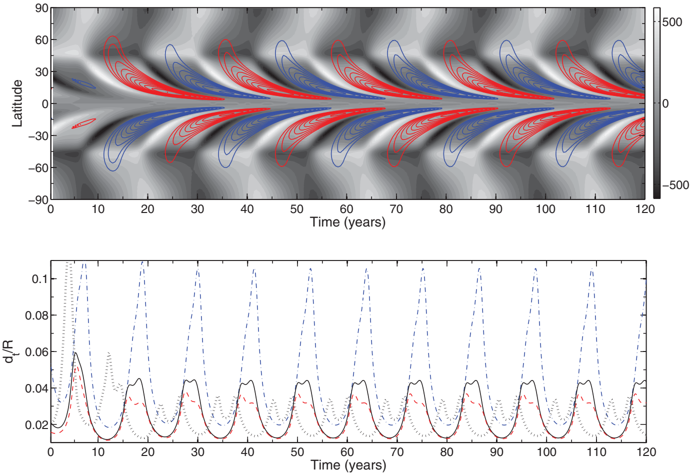

Figure 1. Top: butterfly diagram of magnetic fields for variable d_t as given by Eq. (2.1). Contours show the butterfly diagram of the toroidal field in the tachocline. The background shows the radial field on the solar surface. Bottom: variation of d_t with time. The dash-dotted, solid, dashed and dotted lines are the values at 75^0, 60^0, 45^0, and 15^0 latitudes, respectively.

field. We use this relation for the tachocline thickness in a flux transport dynamo model. For the dynamo calculations we use the *Surya* code (Chatterjee, Nandy & Choudhuri 2004) with modified parameters presented in Karak & Petrovay (2012). The result is shown in Figure 1. It is interesting to note is that this produces a stable solar-like dynamo solution. In addition, it produces a significant variation in the tachocline thcikness with latitude and time. The thickness of the tachocline varies from $0.02R$ to $0.1R$ as we move from low to high latitudes which is in agreement with the observations (e.g., Antia & Basu 2011). However the solar cycle variation of tachocline thickness is quite significant, and somewhat higher than what the observational constraints suggest.

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