TURBULENT TRANSITION IN SOLAR SURGES

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Abstract. It has been suggested that a surge can be modelled as a jet travelling in a sheared magnetic field, and that the transition to turbulence of this "MHD tearing jet" can explain several key observed features. In this paper we present our preliminary results of the transition to turbulence via secondary instabilities of the MHD tearing jet. Our results confirm that turbulent transition can decelerate the surge, with decay times which compare well with surge data. Furthermore, we find that the turbulent MHD tearing jet forms magnetic field-aligned velocity filaments similar to those often observed in the surge flow field.

Key words: Solar surges – magnetohydrodynamics – turbulence

1. Introduction

Solar surges are collimated mass eruptions often associated with sites of magnetic field parasitic polarity. Carbone et al. (1987) have suggested that the surge can be modelled as a jet travelling in a sheared magnetic field, which we call a “MHD tearing jet”. Using an analytic turbulence model, their research indicated that transition to turbulence could explain several features of the surge, including deceleration and the early time correlation with Type III radio bursts. In this paper we present some preliminary results of our extended studies of this simplified surge model. We show elsewhere that the MHD tearing jet can transition to turbulence via a secondary instability process (Dahlburg and Karpen 1993). There are three steps in this process: [1] the 1d primary quasi-equilibrium is first destabilized by a linear 2D resistive primary disturbance (e.g., Einaudi and Rubini, 1989); [2] the primary disturbance grows until it saturates to form a 2D secondary equilibrium state (Ofman et al., 1993); and then [3] the secondary equilibrium state is destabilized by a 3D secondary instability which grows on the Alfvénic timescale (Dahlburg and Karpen, 1993). In this paper we consider what happens as the secondary mode attains a finite amplitude, and relate this process to the evolution of the surge.

2. Methodology

Following Carbone et al., we model the surge as an incompressible jet travelling in a sheared magnetic field. The mean velocity and magnetic fields are specified, respectively, to be: $U_0(z)\hat{e}_z = \text{sech}z\hat{e}_x$, and $B_0(z)\hat{e}_z = \tanh z\hat{e}_x$. Primary perturbations of this system are determined by an equation of the Orr-Sommerfeld type (Einaudi and Rubini, 1989), of which the fastest growing modes are 2D (Michael, 1955). We initialize our 3D calculations with a
dose of the unstable 2D primary mode large enough that the system begins close to a secondary equilibrium. Then we add a smaller amount of a 3D primary mode to initiate activity in the third direction. The numerical simulations are performed with a semi-implicit Fourier collocation - Fourier pseudospectral algorithm which we have generalized from its previous application to neutral sheets (Dahlburg et al., 1992).

3. Results

Figure 1 shows the time evolution of the total kinetic energy, $E_v$, for a run with $R = R_m = 200$, and streamwise ($x$) and spanwise ($y$) wavenumbers equal to $0.5$. There is a slight increase in $E_v$ around $t = 100$, followed by a very rapid decay phase initiated at about $t = 260$. The kinetic energy subsequently decays to about 30% of its initial value in roughly 200 Alfvén times, reflecting the rapid deceleration of the jet. Figure 1 also shows the perturbed kinetic energy, $E_p$, of the jet. The secondary mode is evident in $E_p$ around $t = 90$. The perturbed kinetic energy increases its value by a factor of about 20 within 220 Alfvén times, followed by a rapid decrease in value of 80%. A comparison of $E_v$ with $E_p$ indicates that the perturbed velocity field is a significant fraction of the mean velocity field, with $\Delta v/v \approx 1/2$ or larger for the later portions of the simulation.

To illustrate better the morphological evolution of the surge model, we next show two plots of the velocity field magnitude ($|v|$), with isosurfaces chosen at 90% of the peak velocity magnitude. Figure 2 shows a velocity magnitude isosurface at $t = 90$. The cross-stream direction ($z$) is here vertical, so the contours vary strongly in this direction. At this time the velocity