Title:	Merging flux ropes with BOUT++
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Model

A simple 2D zero-β model of merging flux ropes is used here in cylindrical geometry

$$\frac{\partial U}{\partial t} = -\mathbf{v}_{E\times B}\cdot\nabla U + \mathbf{b}\cdot\nabla J_{||} + \nu\nabla_\perp^2 U \tag{1}$$

$$\frac{\partial \psi}{\partial t} = -\mathbf{b}\cdot\nabla\phi + \eta J_{||} \tag{2}$$

$$\nabla_\perp^2\psi = -J_{||} \tag{3}$$

$$U = \nabla_\perp^2\phi \tag{4}$$

This is implemented in terms of Arakawa bracket operators. In particular, because axisymmetry is assumed the derivatives along the magnetic field only contain a term from the "poloidal" field:

$$\mathbf{b}\cdot\nabla f = -\left[\psi, f\right] \tag{5}$$

The model is therefore implemented as:

$$\frac{\partial U}{\partial t} = -\left[\phi, U\right] + \left[\psi, f\right] + \nu\nabla_\perp^2 U \tag{6}$$

$$\frac{\partial \psi}{\partial t} = \left[\psi, \phi\right] + \eta J_{||} \tag{7}$$

$$\nabla_\perp^2\psi = J_{||} \tag{8}$$

$$U = \nabla_\perp^2\phi \tag{9}$$

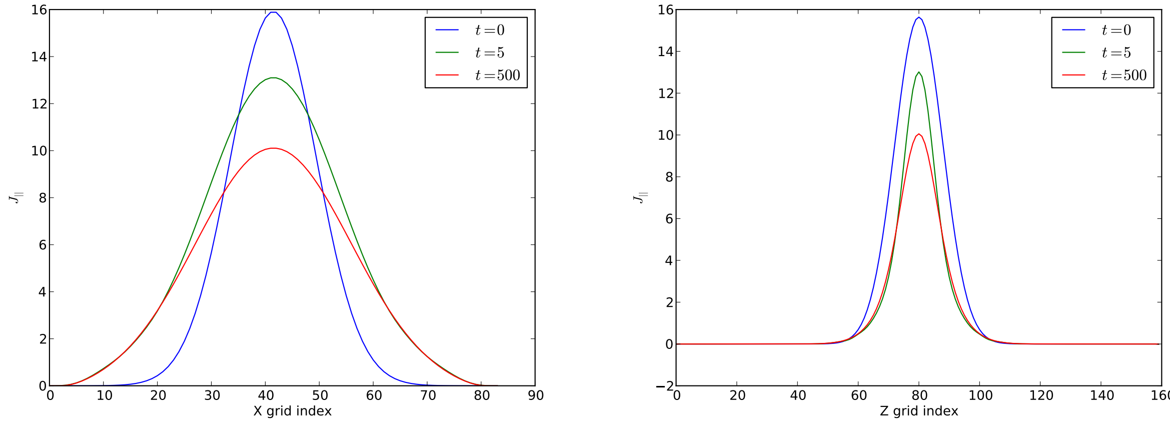
(note change of sign on $J_{||}$).

Boundary conditions are $\psi = 0$ and $\phi = 0$, on a rectangular domain which is twice as high as it is wide.

In all simulations here the normalised viscosity is fixed at $\nu = 10^{-2}$.

Single current filament

First test starts with a single current filament. The initial current density is a circular Gaussian. There are some rapid transients during which the shape of the filament changes slightly, followed by a slow relaxation when finite resistivity is included. This is shown in figure 1 for a case with a single current filament and a normalised resistivity of $\eta = 10^{-5}$. The effect of resistivity on a single current filament is shown in figure 2, where the flux ψ at the centre of the filament is shown against time. This test indicates that the numerical resistivity is small on the timescales examined here; a negligible change in flux is seen if the resistive term is turned off.



(a) Parallel current profile in x

(b) Parallel current profile in z

Figure 1: Single filament at centre of rectangular domain with normalised $\eta = 10^{-5}$. Transient change in shape over first $t \sim 5$, followed by resistive relaxation

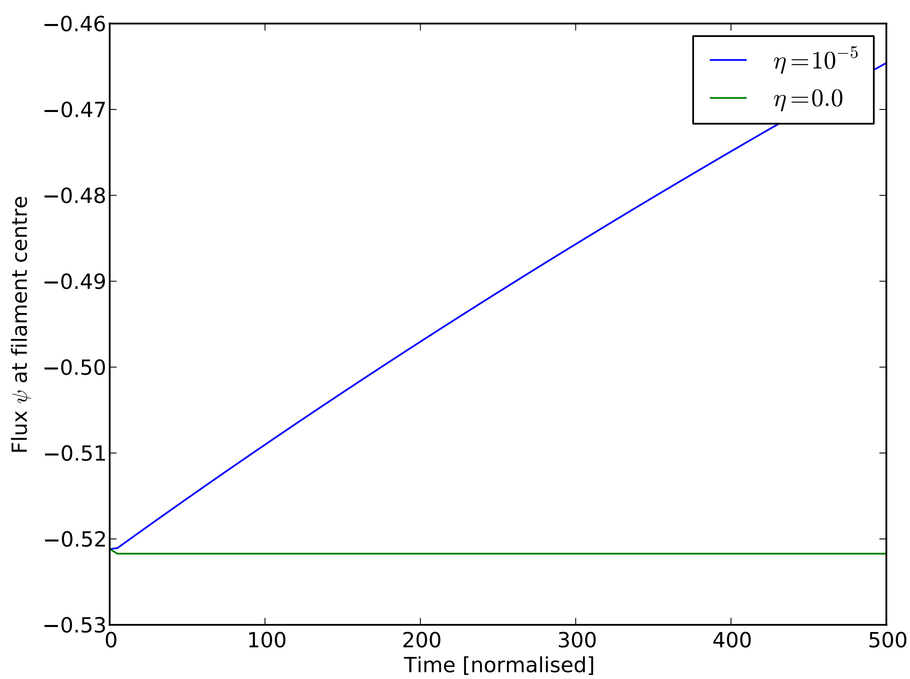


Figure 2: Flux against time for a single current filament, comparing a case where $\eta = 0$ against $\eta = 10^{-5}$. Finite resistivity results in slow diffusion of flux out of the domain so ψ relaxes towards zero.

Merging current filaments

We now run a simulation with two current filaments, initial state shown in figure 3. The

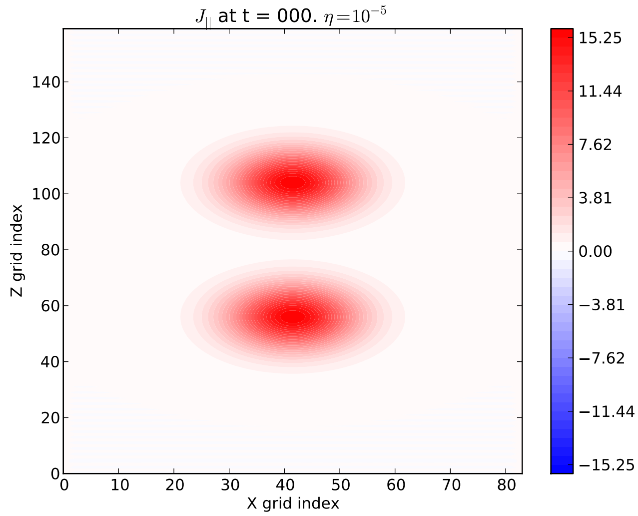


Figure 3: Initial condition for merging current filament simulations

flux at the centre of the domain is shown as a function of time in figure 4 The case with no

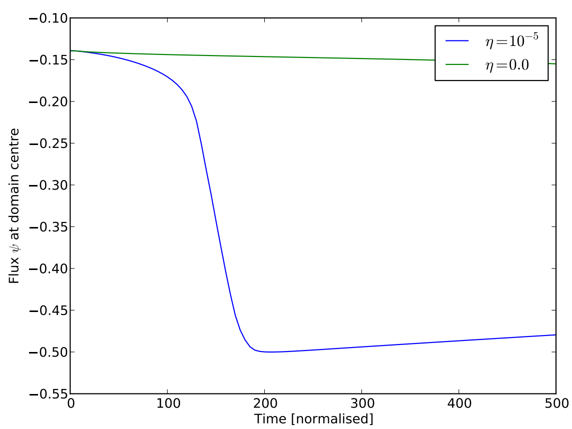


Figure 4: Flux ψ as a function of time, for merging current filaments with $\eta = 0$ and $\eta = 10^{-5}$.

resistivity shows a slow change in ψ, with the current at the end of the simulation shown in figure 5 A narrow layer is seen where the filaments meet.

In the simulation with finite resistivity, the formation of this layer leads to a rapid reconnection between $t = 100$ and $t = 200$ (in figure 4). The parallel current profiles for this case are shown in figure 6.

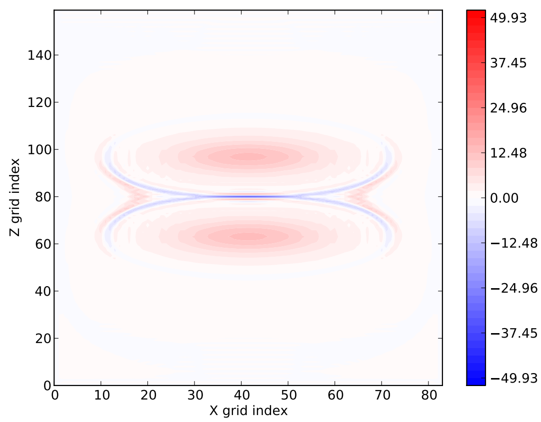
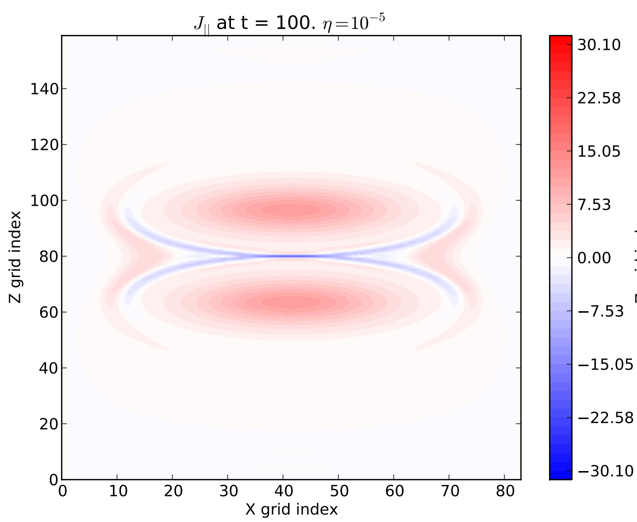
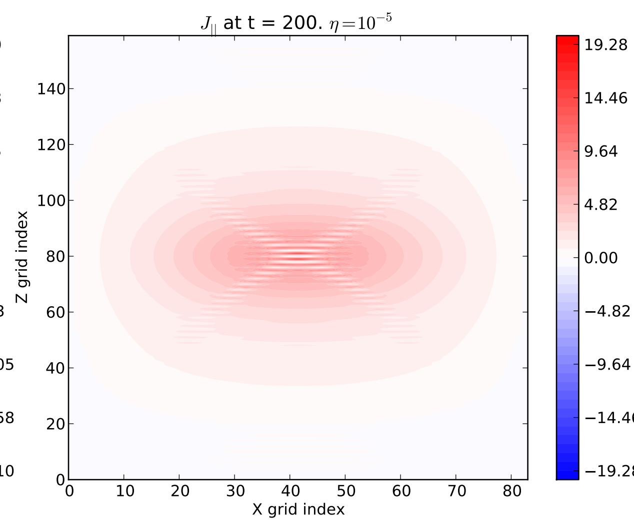


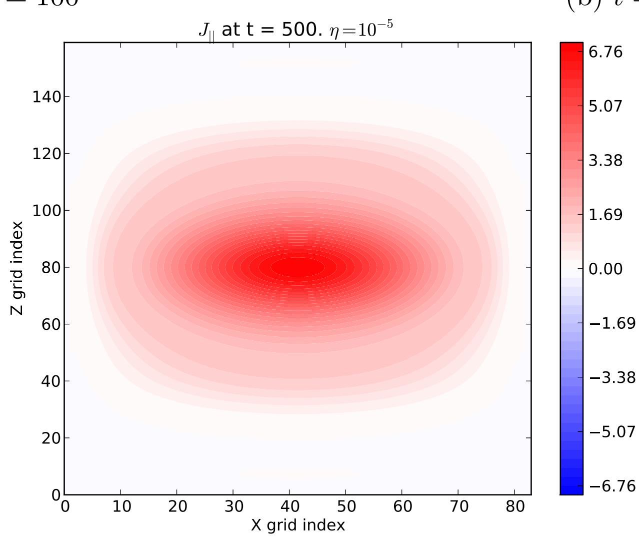
Figure 5: Parallel current $J_{||}$ at $t = 500$ for case without (added) resistivity



(a) $t = 100$



(b) $t = 200$



(c) $t = 500$

Figure 6: Evolution of $J_{||}$ for two merging current filaments, with normalised $\eta = 10^{-5}$