The Role of Solar Active Region Decay in Energising the Corona

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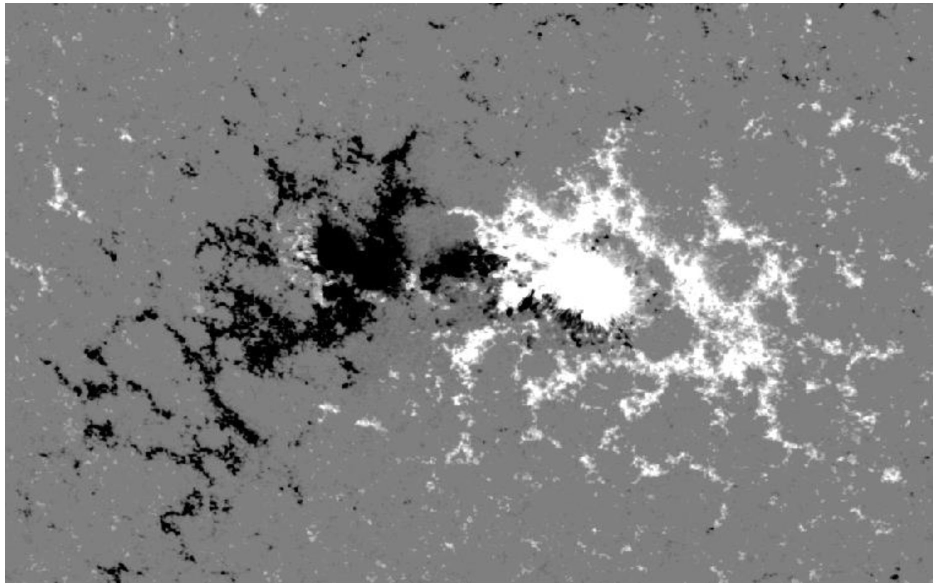
Aims

- Model active region surface magnetic field evolution, including:
  - Global processes (e.g. differential rotation)
  - Local processes (e.g. convection, moat flow, “magnetic carpet”)

- Model and analyze resultant coronal magnetic field evolution

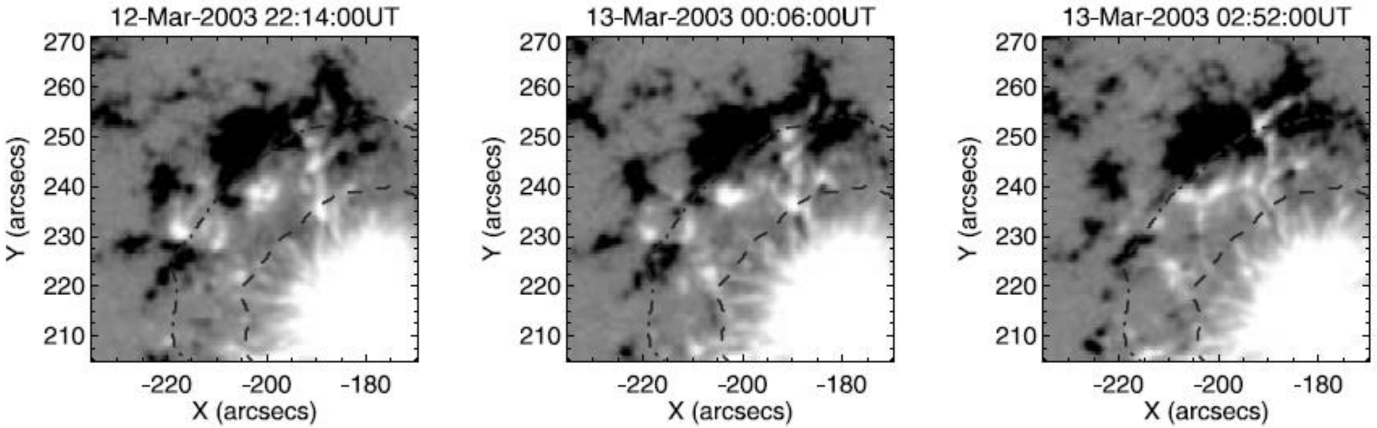


Active Region Decay

- Decay rate: $2 - 8 \times 10^{20}$ Mx day^{-1}

(e.g. Hagenaar & Shine, 2005; Deng et al., 2007; Kubo et al. 2008; Louis et al. 2012; Sheeley et al., 2017; Norton et al. 2017)

- AR “gnawed away” by convective cells (Dacie et al. 2016)
- Flux transported by moving magnetic features (MMF) in moat (Kubo et al. 2007)
- Cancellation at boundary of moat (Kubo et al. 2008)



Moat flow (Kubo et al. 2007)

Magnetic Carpet Model

Meyer et al. 2011, Meyer et al. 2016:

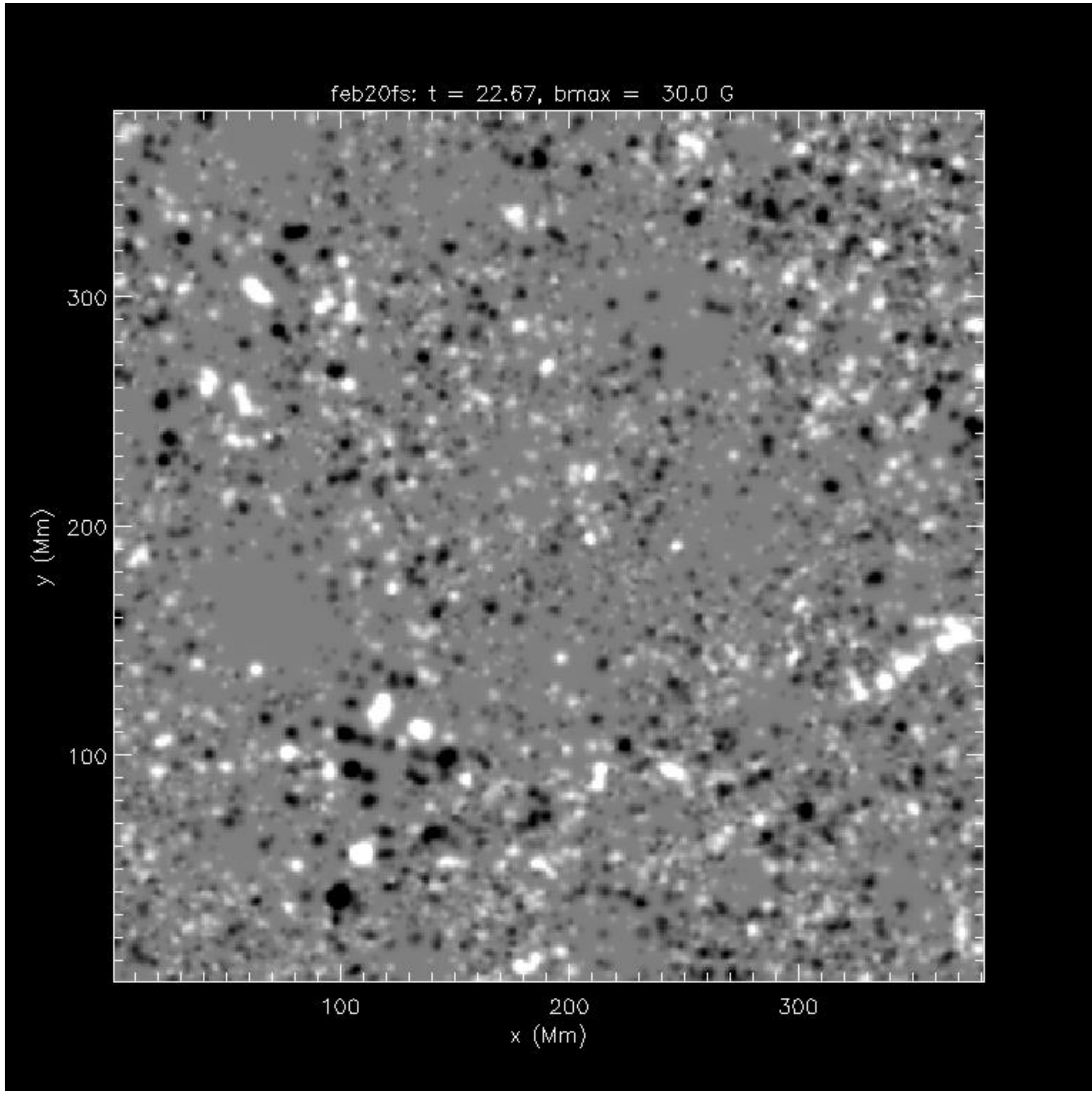
We impose:

- Supergranulation
- Emergence, cancellation, coalescence, fragmentation
- Flux emergence from observations

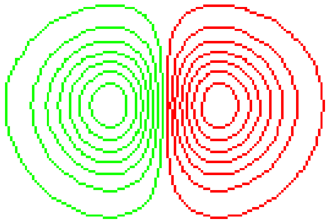
(Thornton & Parnell, 2011)

Resulting flux dist. agrees with observations

(Parnell et al. 2009)



Active Region Representation

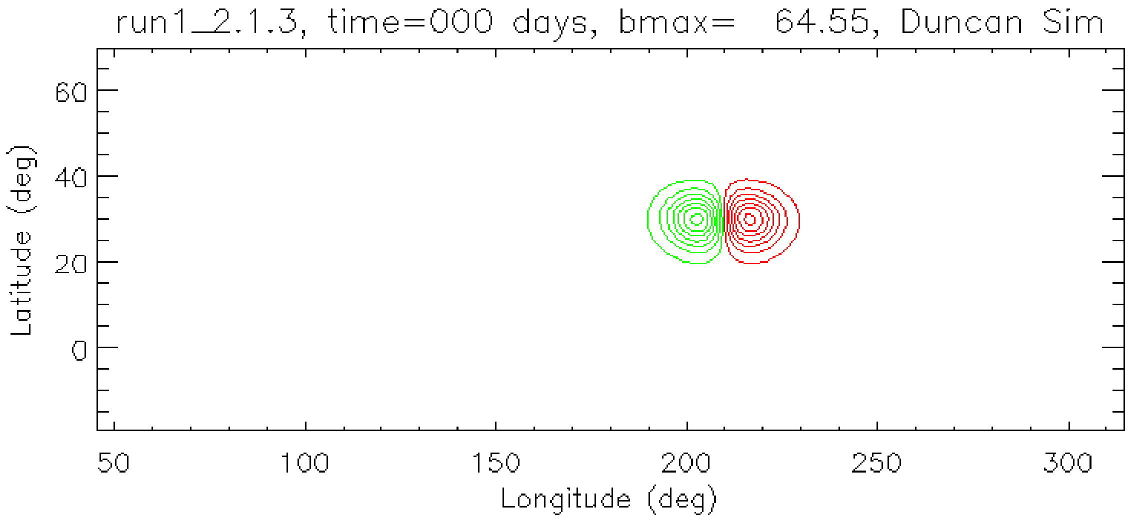


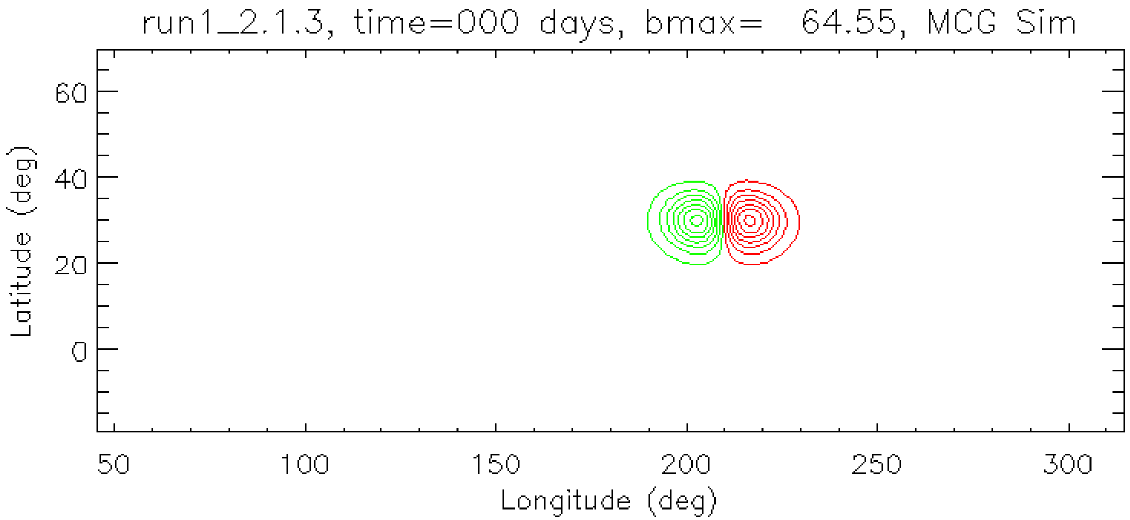
- Idealised AR from Mackay SFT model

(Mackay et al. 2002; Yeates et al. 2007; Mackay et al., 2014)

$$B_r = -B_0 e^{0.5} \frac{x}{\rho} \exp\left[-\left(\frac{x^2/2 + y^2}{\rho^2}\right)\right],$$

- Instead we split into many elements
- Simulate their evolution
- Result including only differential rotation – agrees with Mackay





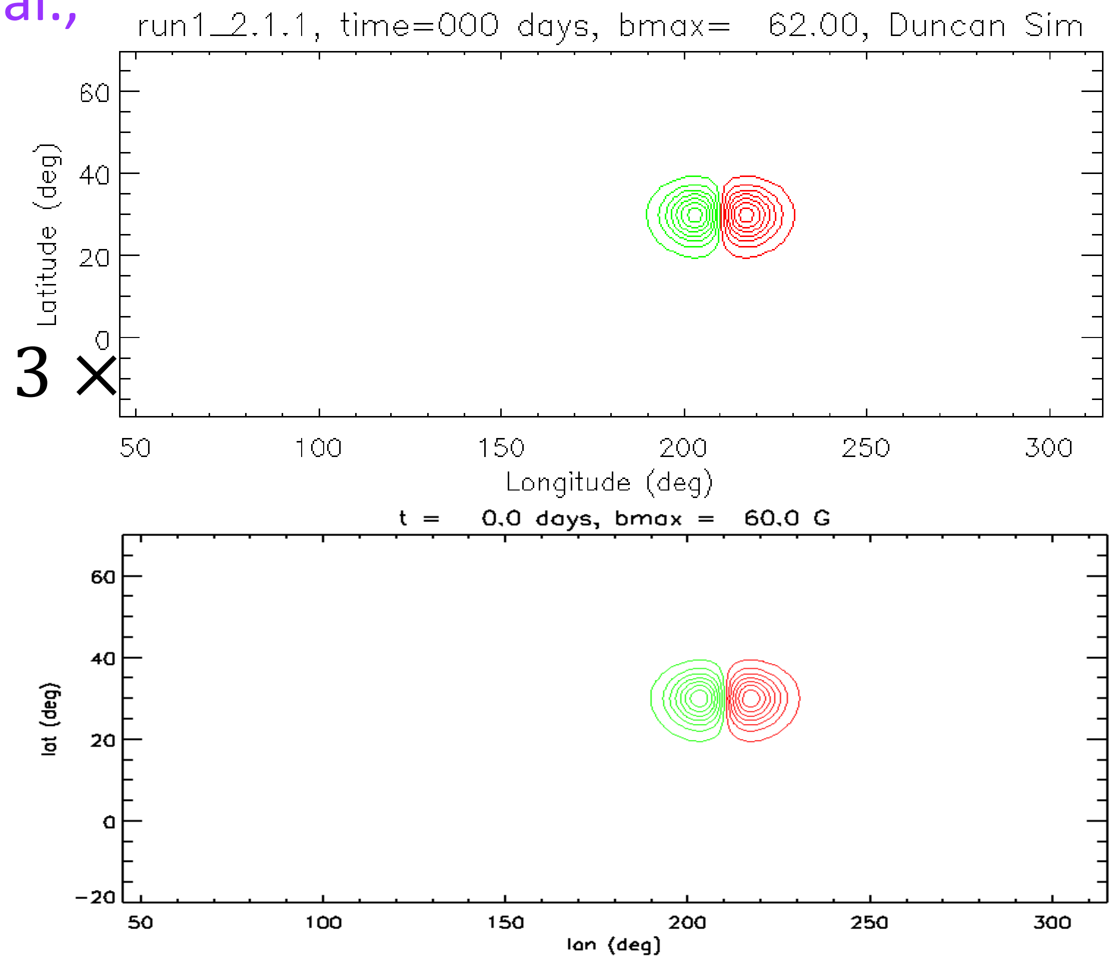
Modelling Active Region Decay

Standard SFT model includes diffusion coefficient

(e.g. DeVore et al., 1985; Wang et al., 1989; Yeates et al., 2007)

In our model we add:

- Shedding of elements from spot (Decay rate 3×10^{20} Mx/day)
- Moat flow $v_r = \left(\frac{r}{r_0}\right) \exp\left(1 - \frac{r^2}{r_0^2}\right)$
- Supergranulation outside moat



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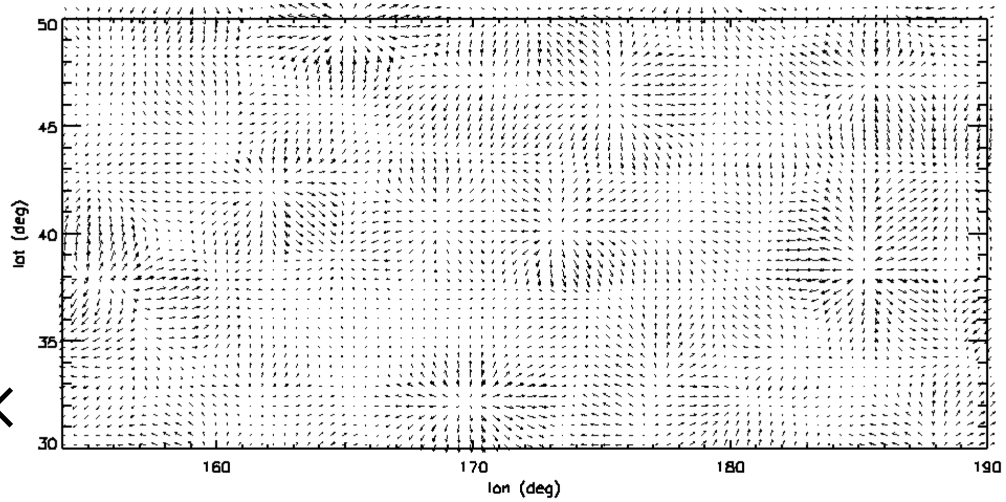

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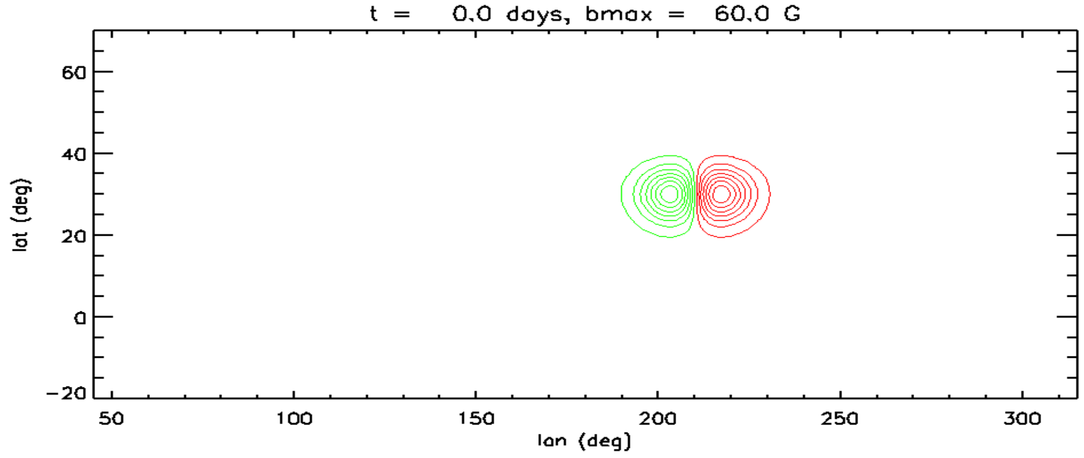
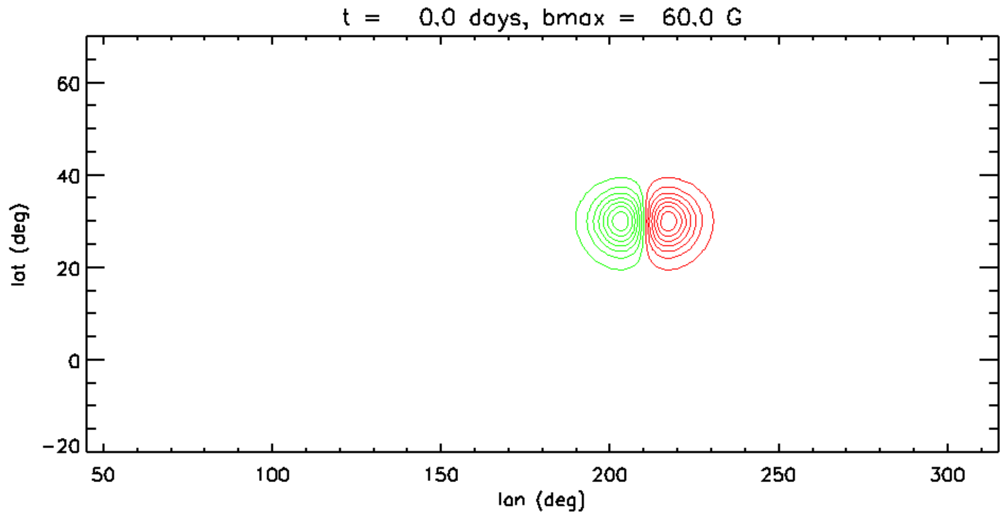


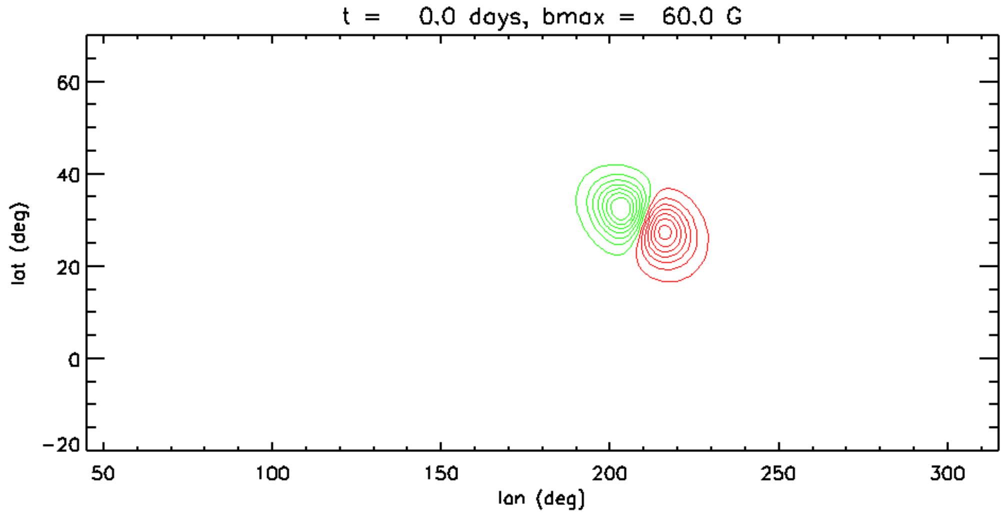
Fragmentation, Cancellation and Coalescence

After breaking off, elements are handled by the magnetic carpet model

Here we add:

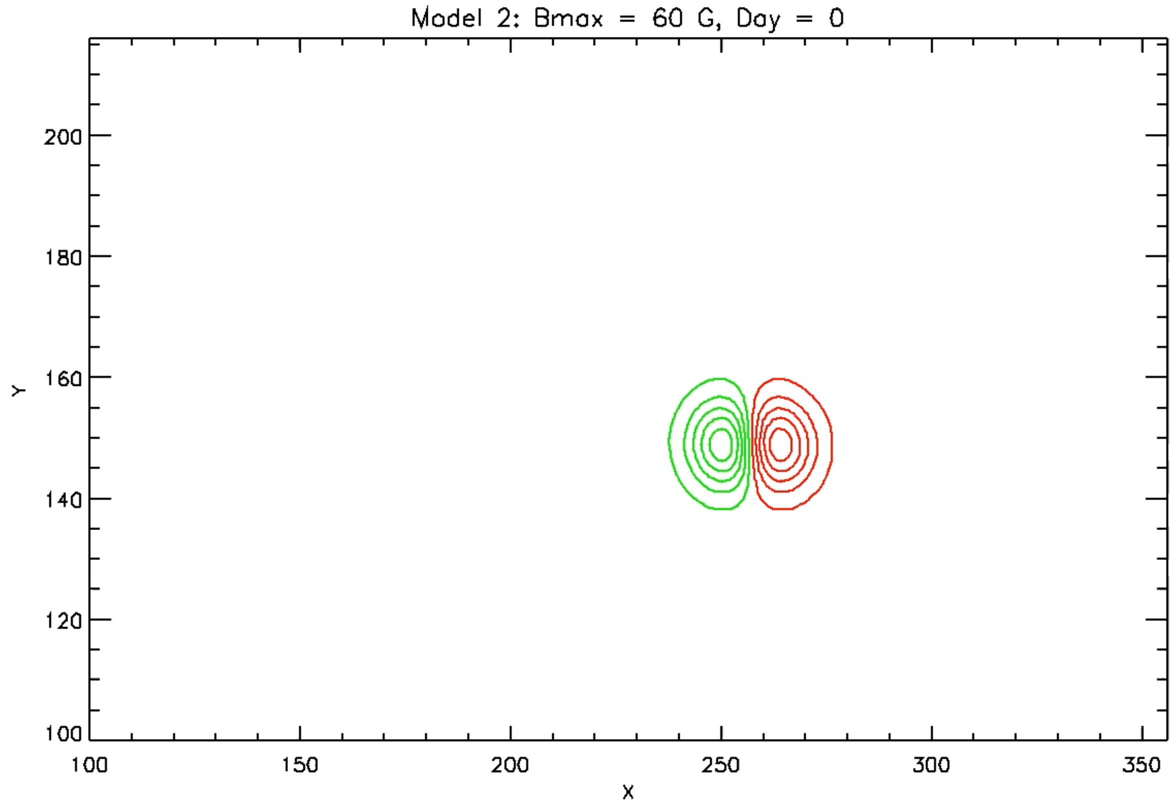
- Fragmentation
- Cancellation or coalescence with a nearby element

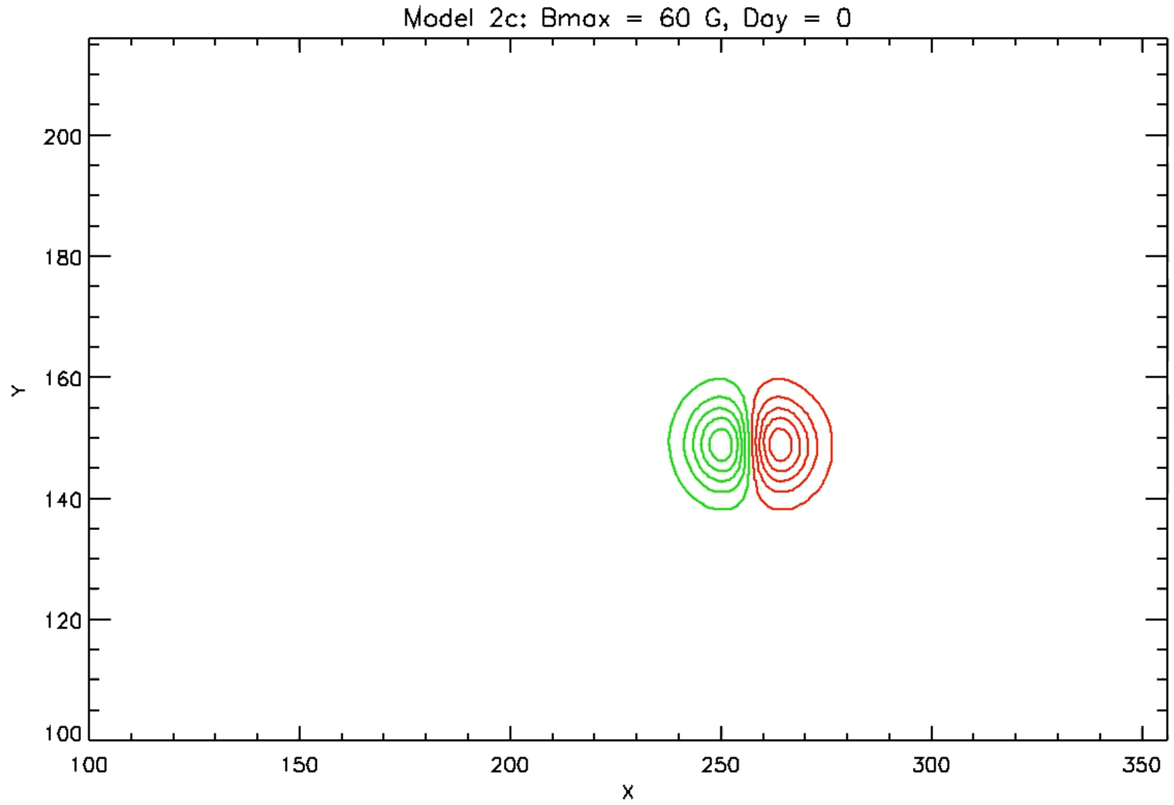




Question

What is the effect of these 'smaller scale' active region decay processes (moat flow, supergranulation and magnetic carpet interactions) on the evolution of the coronal magnetic field?



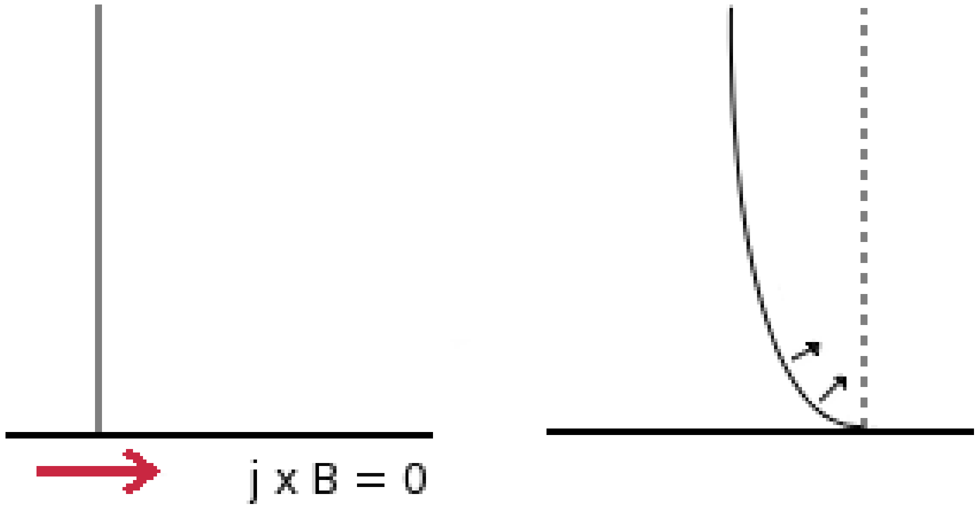


Coronal Magnetic Field Simulations

- Magnetofrictional relaxation from initial potential field

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

$$\text{where} \quad \mathbf{B} = \nabla \times \mathbf{A} \quad \text{and} \quad \mathbf{v} = \frac{1}{\nu}\mathbf{j} \times \mathbf{B}$$



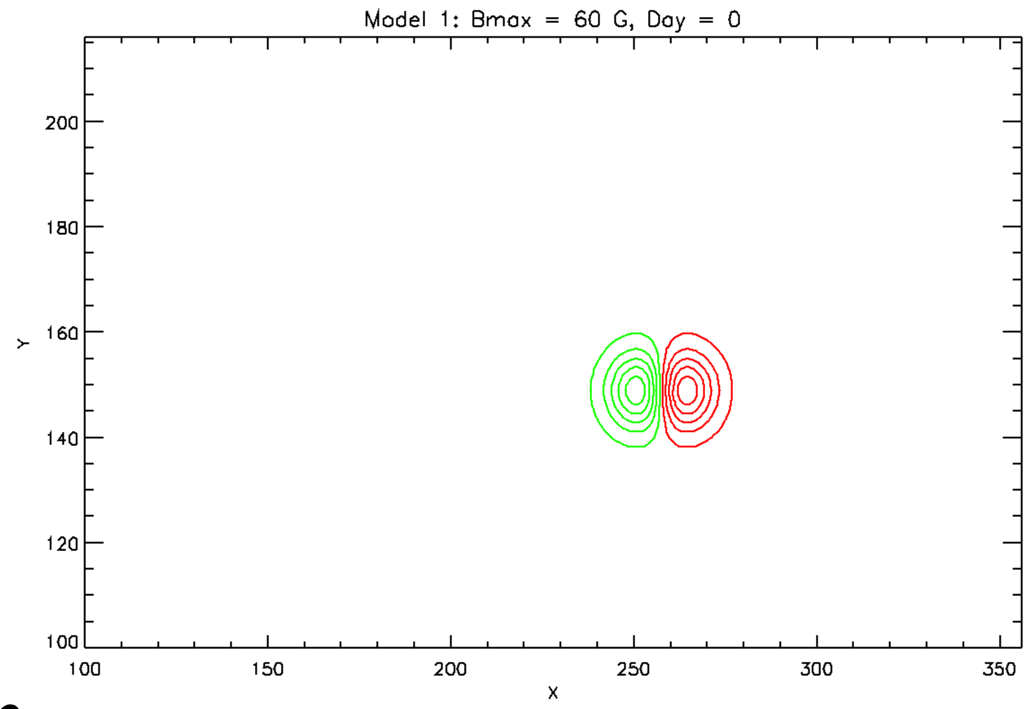
- Cartesian, $456 \times 316 \times 250$ grid cells, resolution 866 km

- Time step 1 day (500 relaxation steps in between), 89 days total

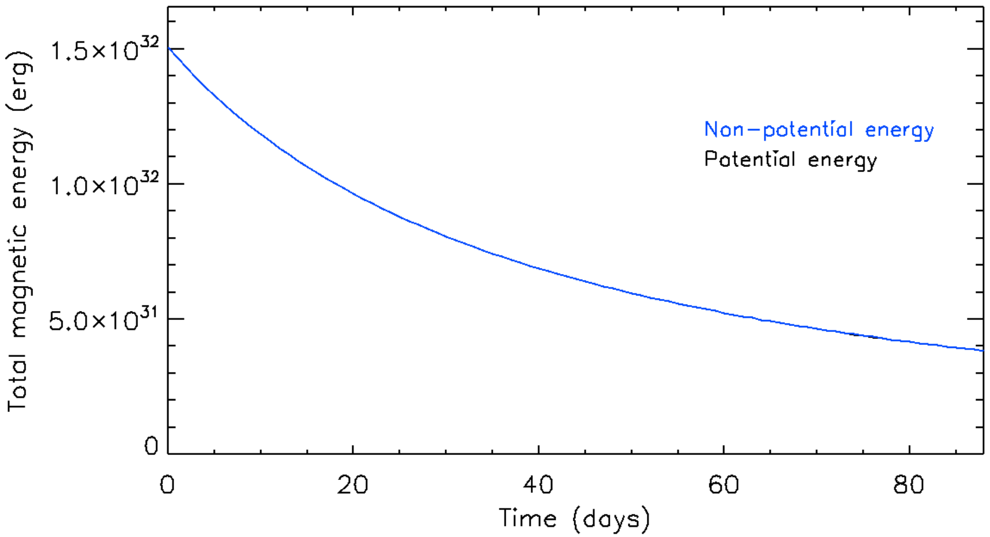
Coronal Magnetic Field Simulations

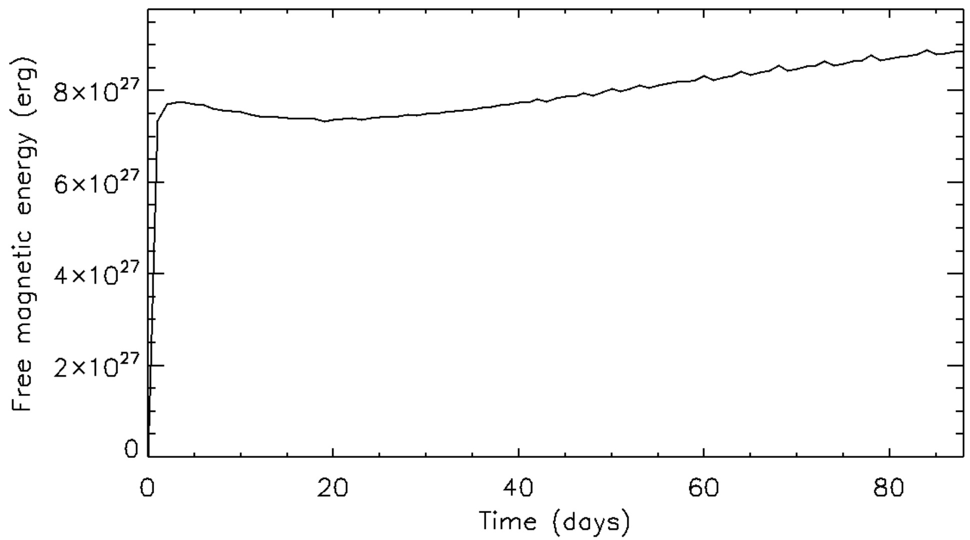
Same initial condition for all: idealized bipole

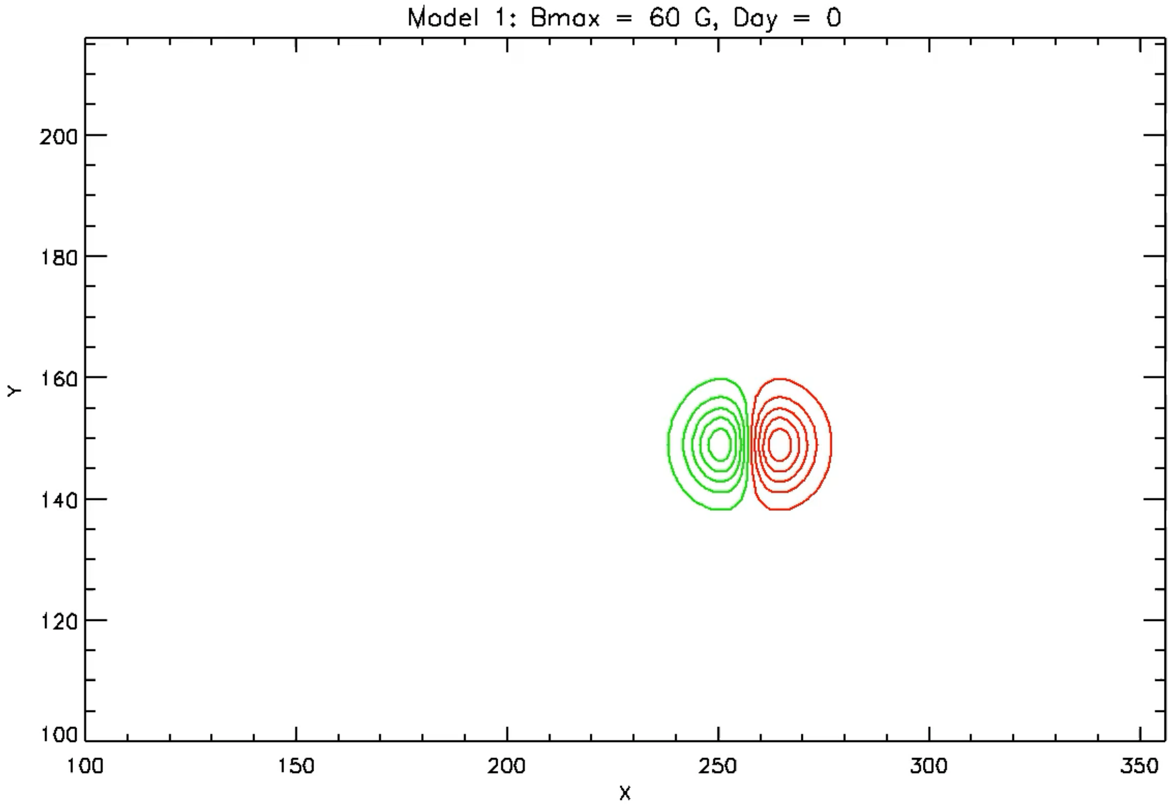
- **Model 1**: diffusion term only
- **Model 1a**: moat flow + s/g
- **Model 1b**: as 1a + cancellation + coalescence
- **Model 1c**: as 1b + fragmentation
- **Model 2**: differential rotation + diffusion term
- **Model 2c**: as 1c + differential rotation



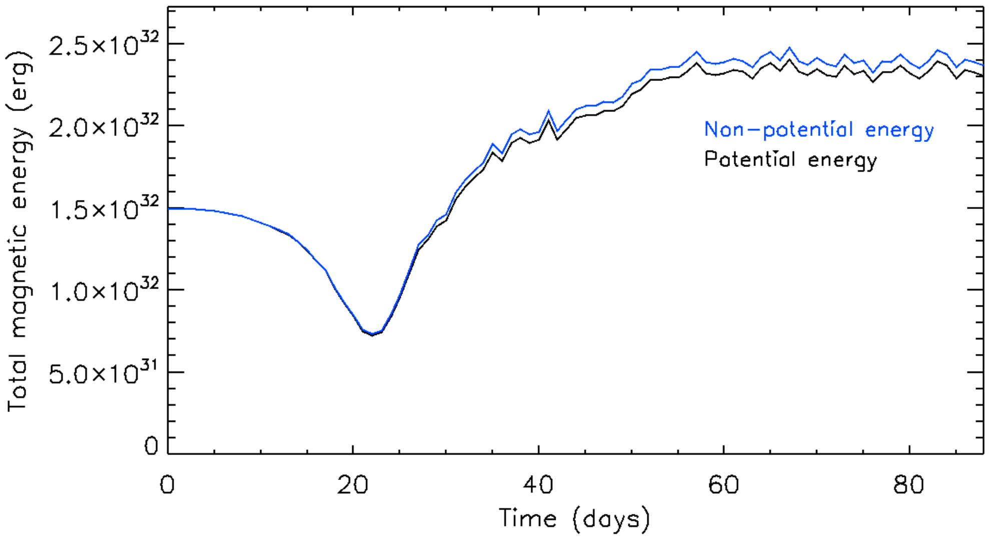
Model 1: Diffusion Only

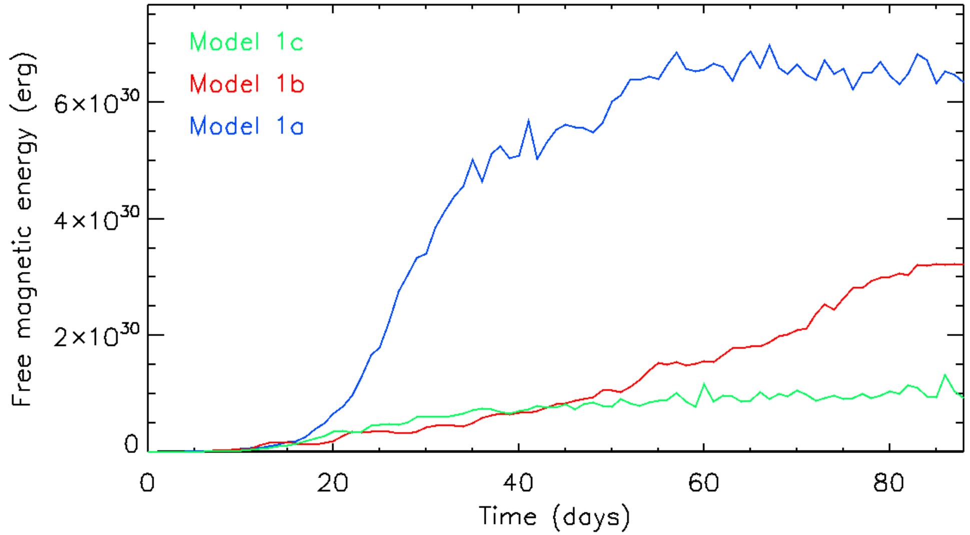


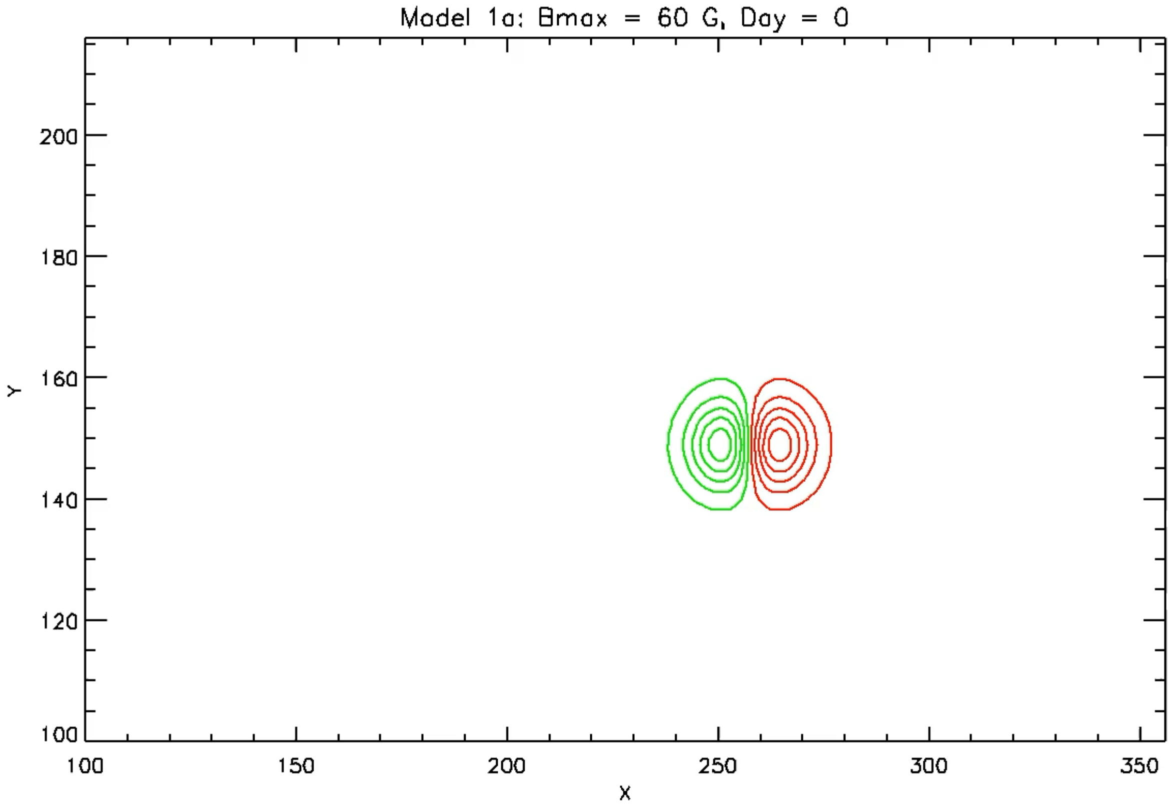




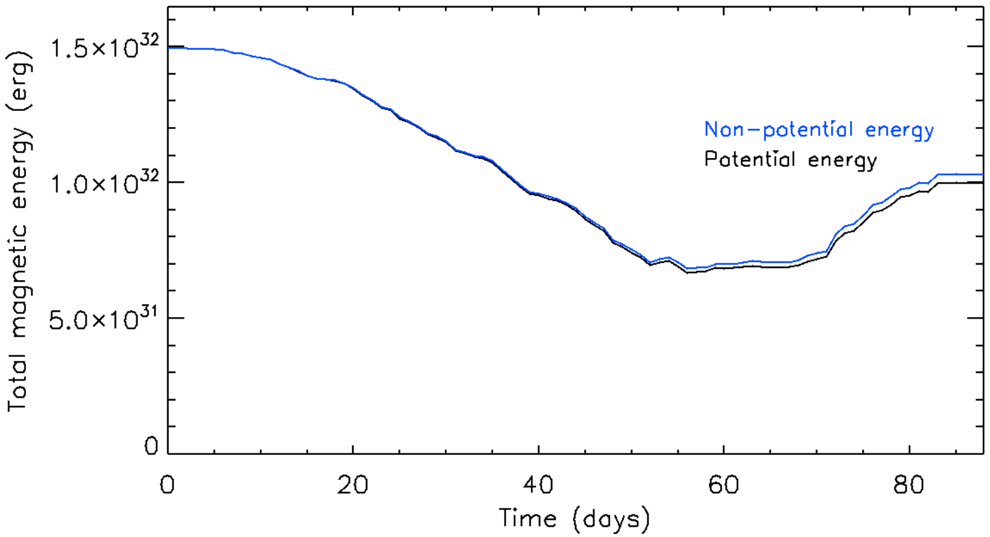
Model 1a: moat flow + supergranulation

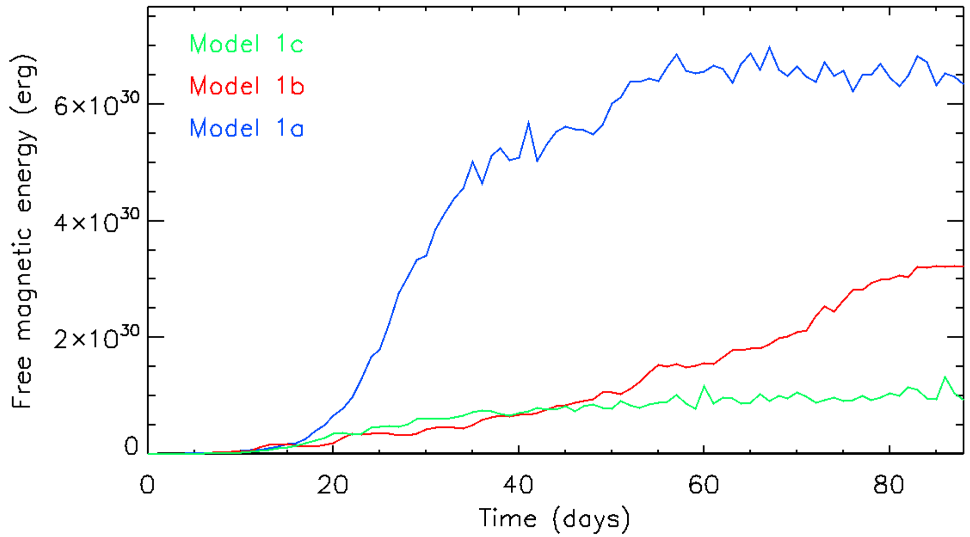


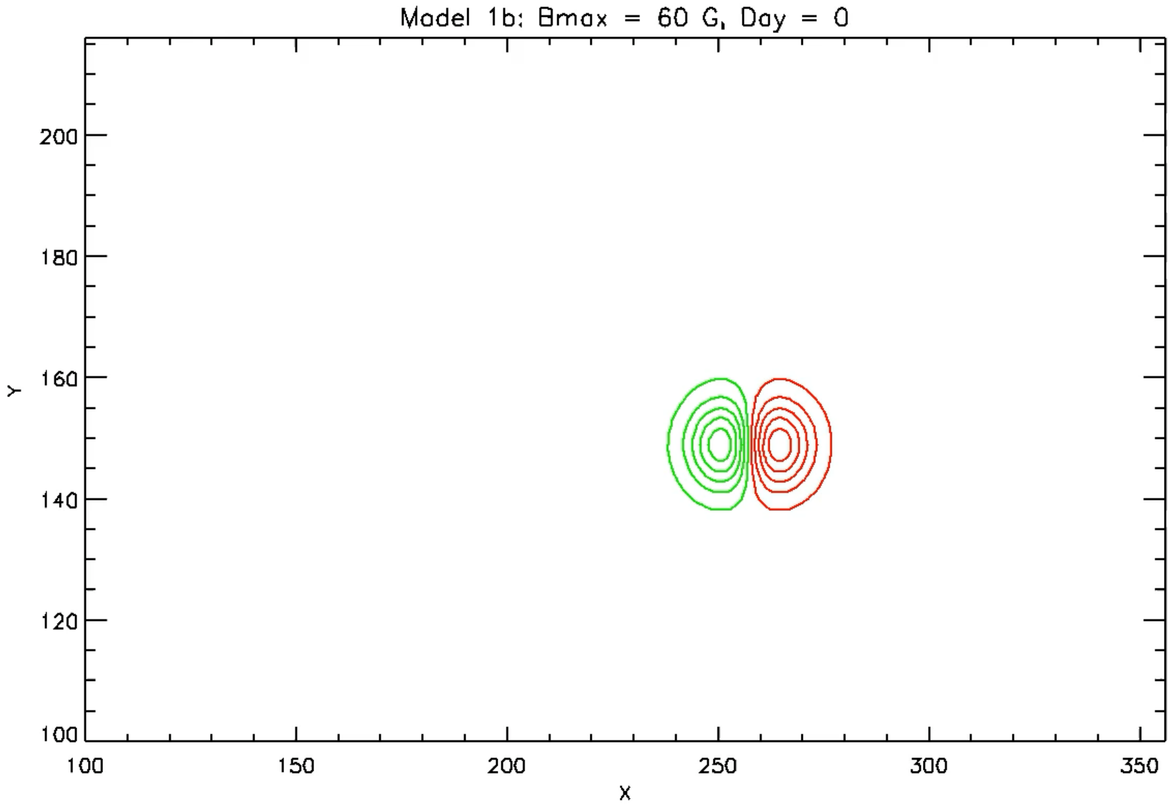




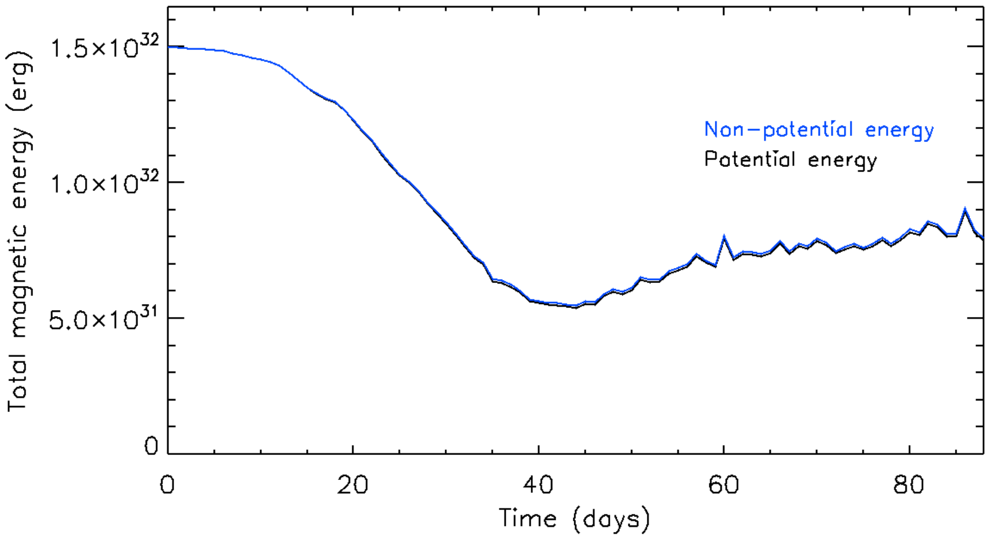
Model 1b: as 1a + cancellation + coalescence

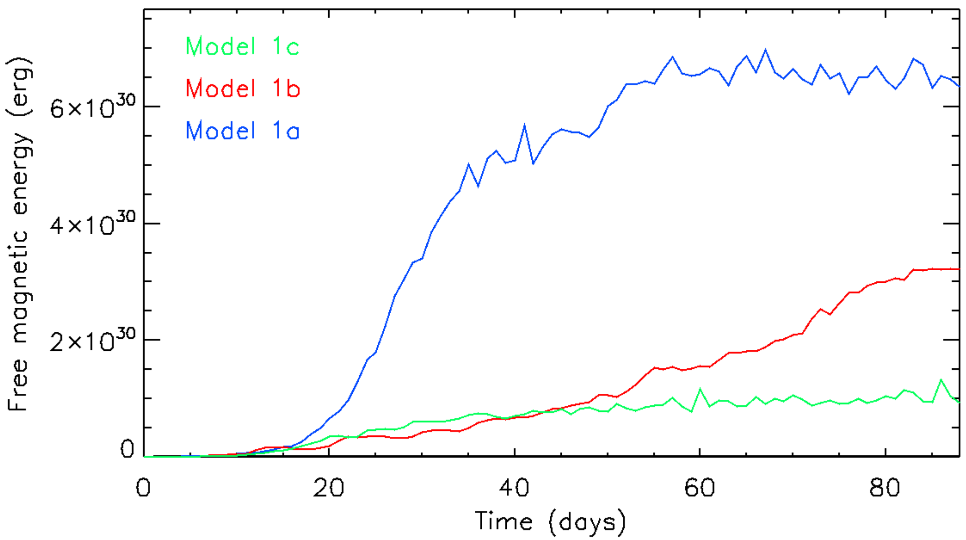


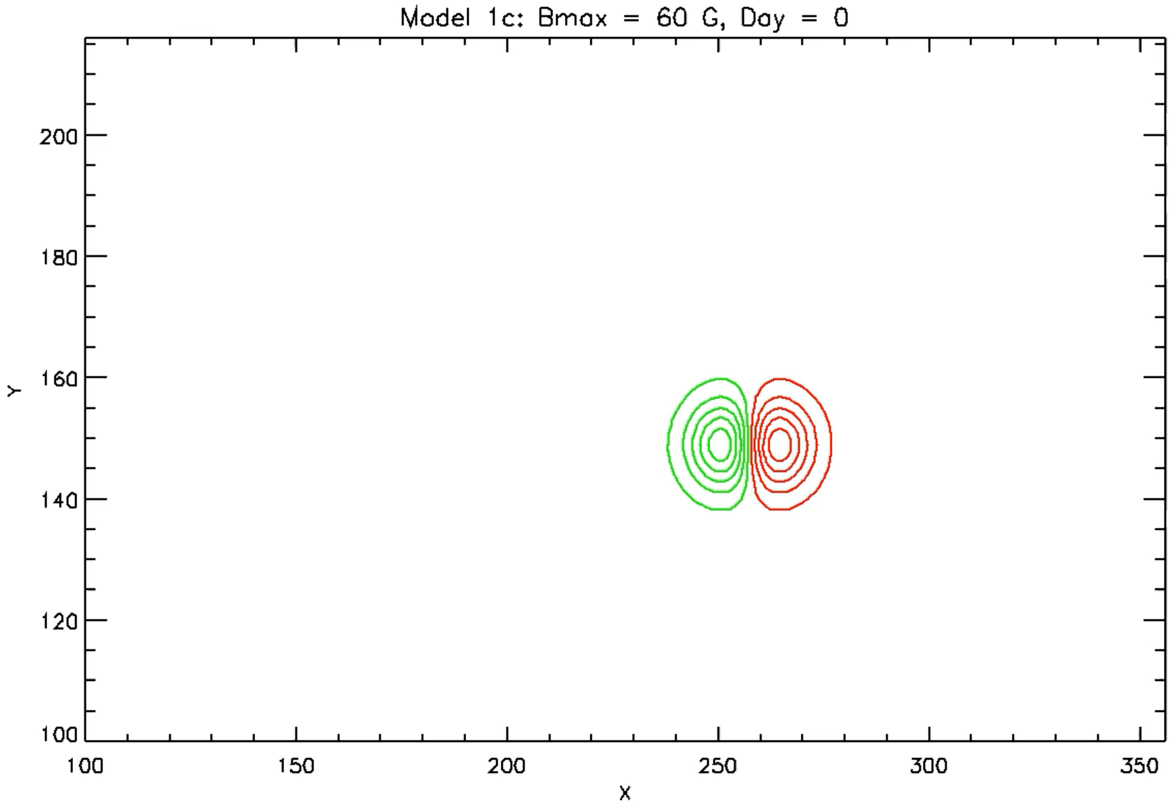




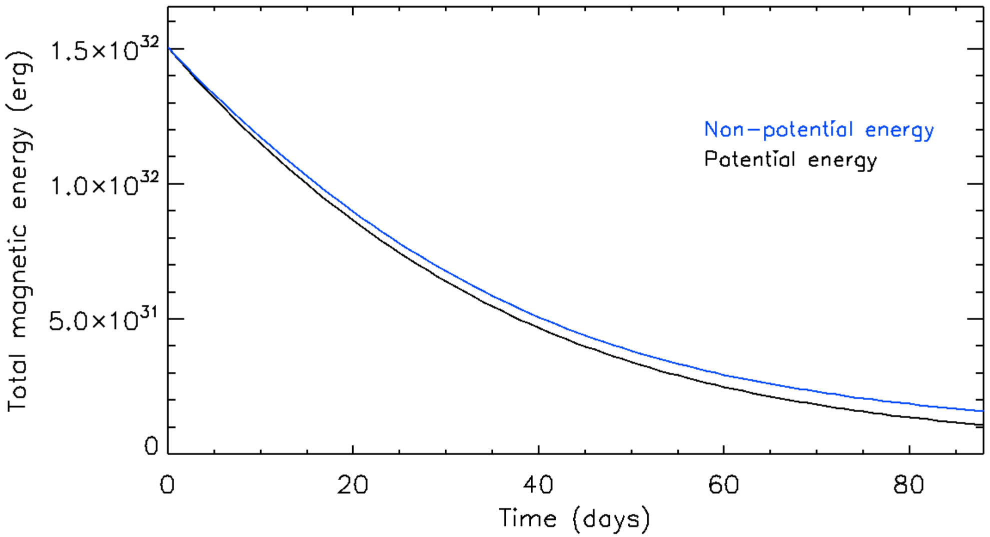
Model 1c: as 1b + fragmentation

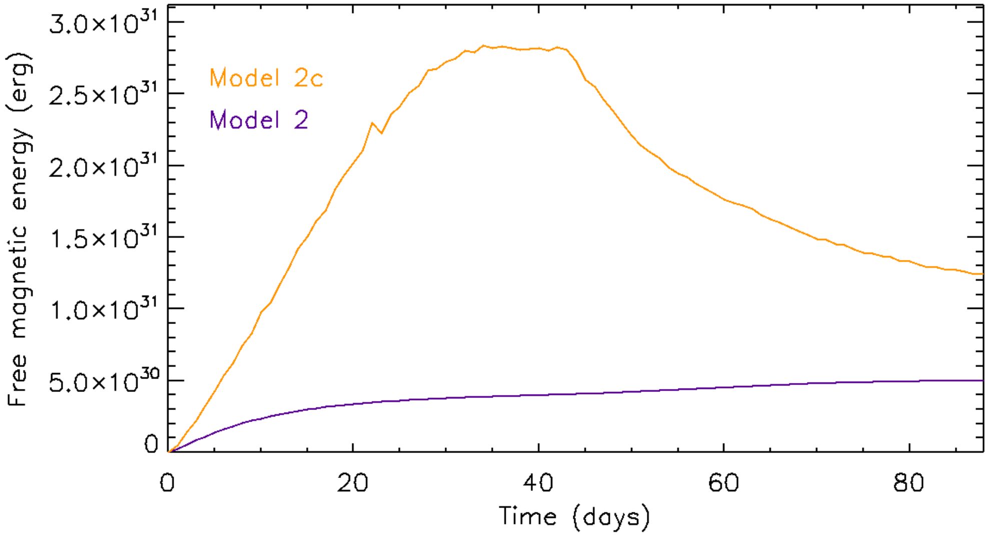


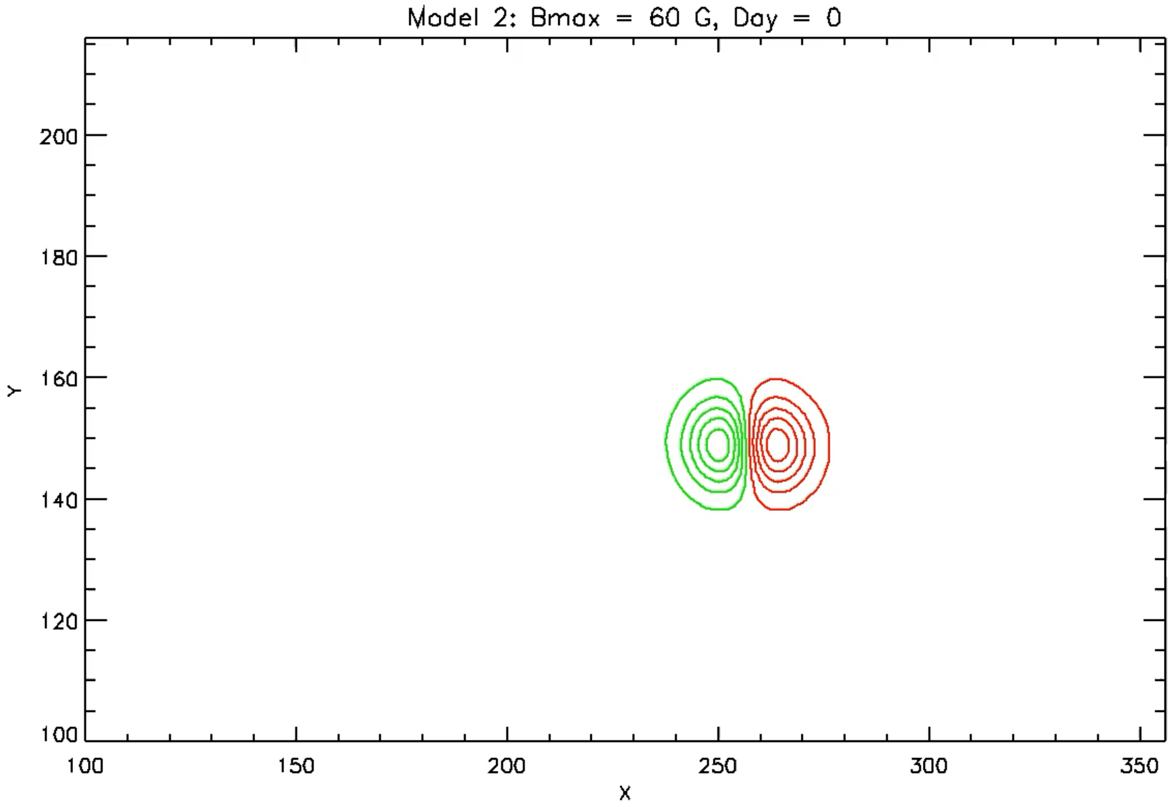




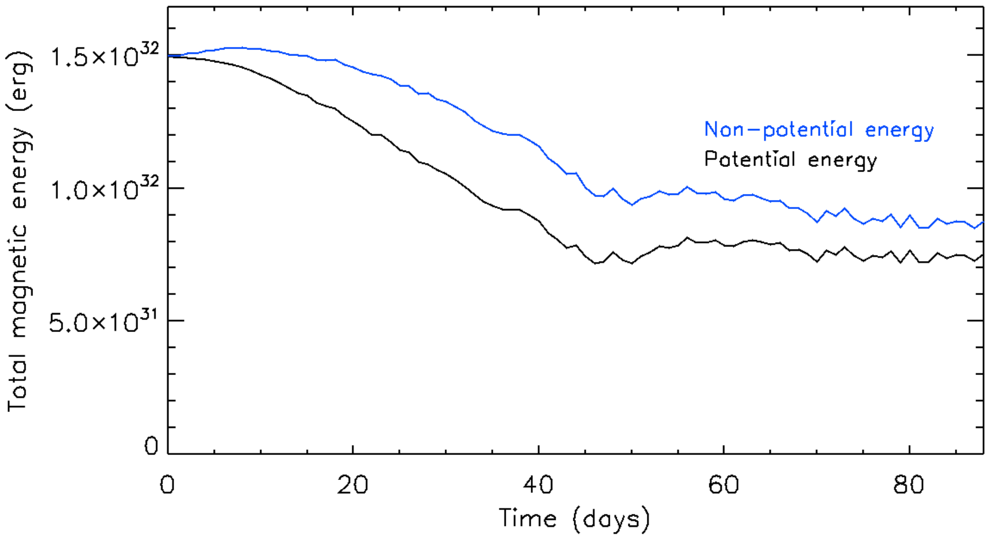
Model 2: differential rotation + diffusion

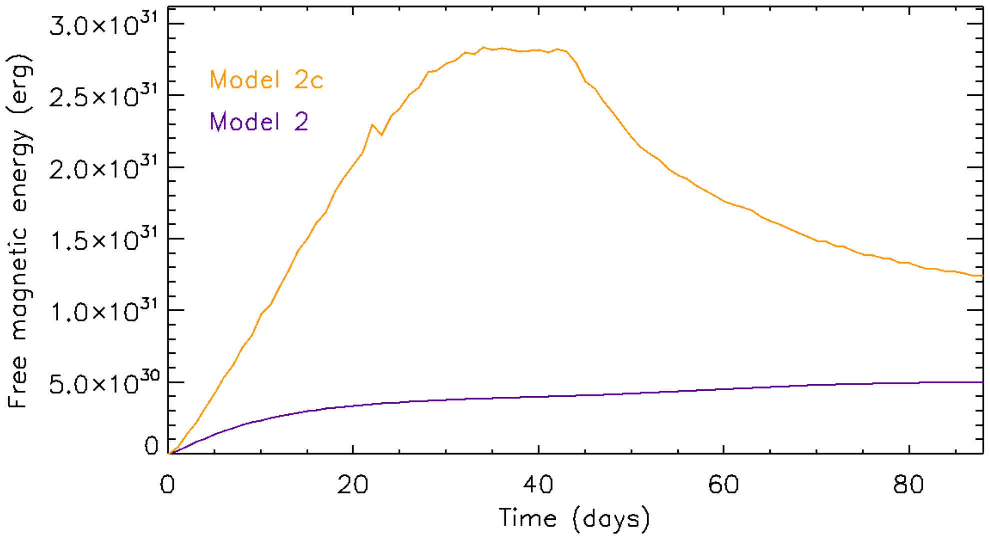


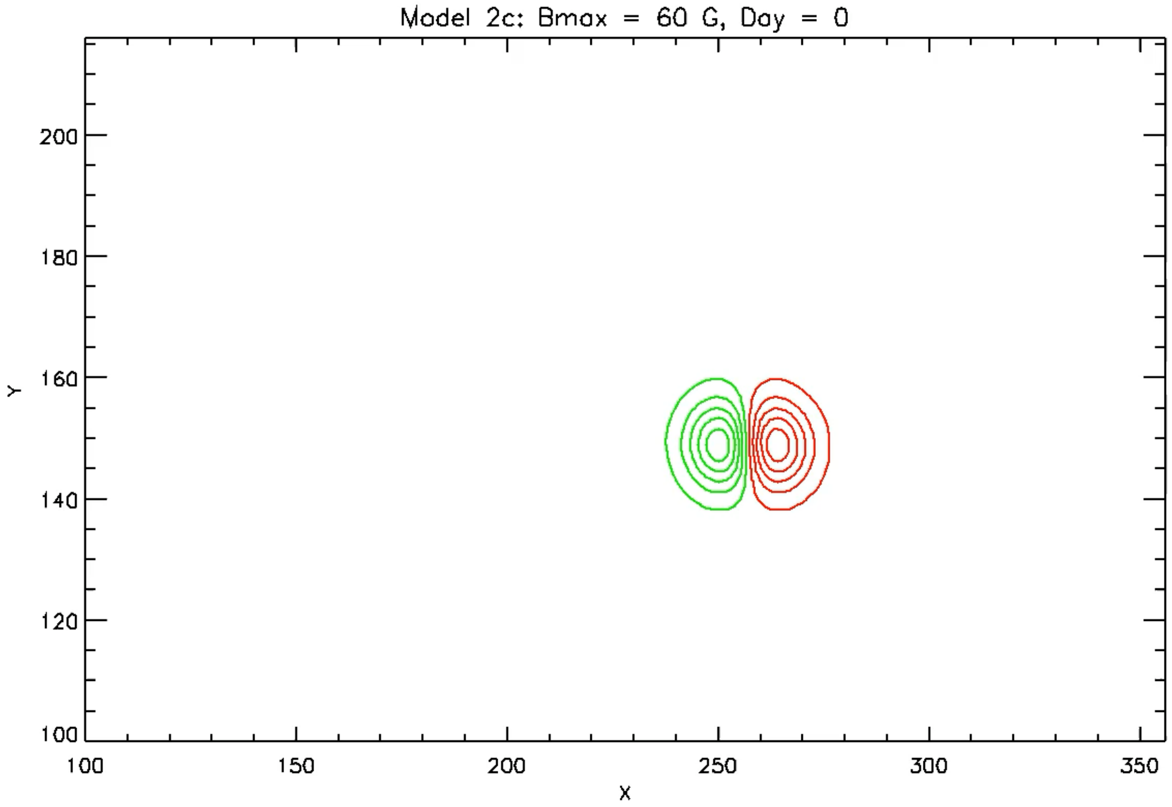




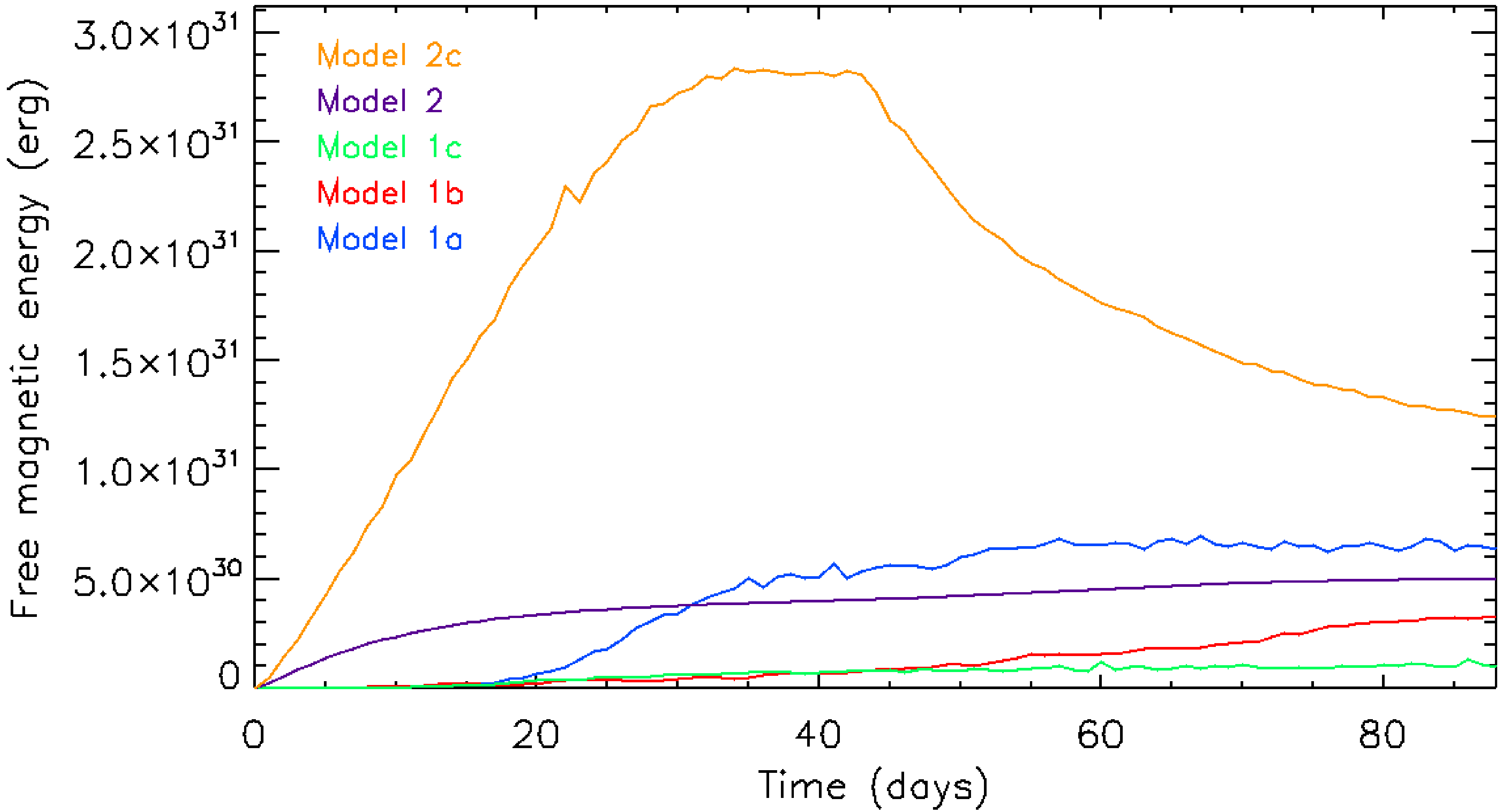
Model 2c: as 1c + differential rotation







Free Magnetic Energy



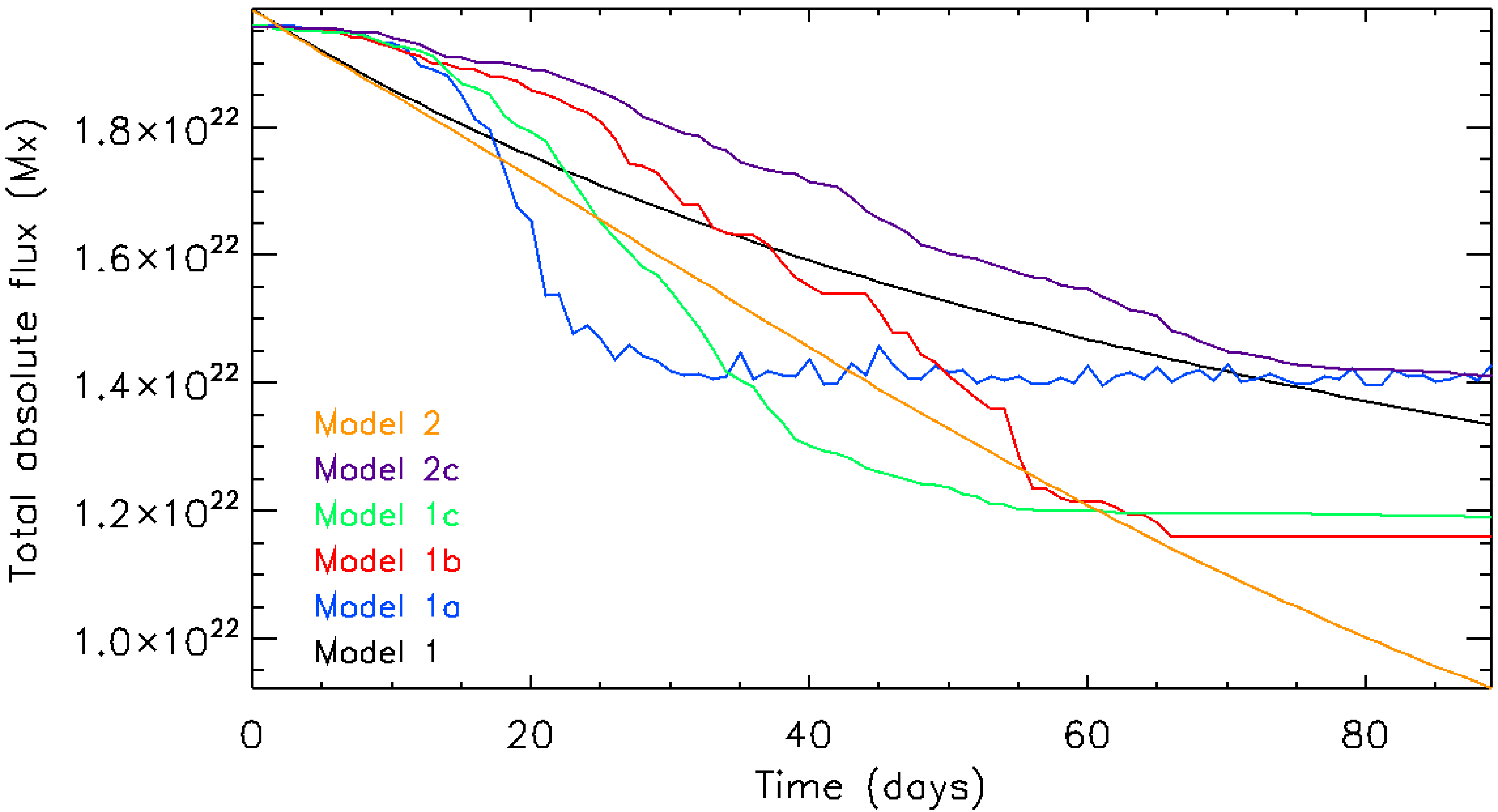
Summary

- 2D model includes effects of 'smaller scale' processes on AR decay:
  - Moat flow and supergranulation
  - Cancellation, coalescence, fragmentation

- Effect in corona: including these processes builds up significant free magnetic energy – same order of magnitude as including differential rotation.

- Future work:
  - Consider other properties of coronal field, e.g. structure, helicity, …
  - Interaction with pre-existing quiet Sun features

Total Flux



Total absolute flux (Mx)
1.8×10^{22}
1.6×10^{22}
1.4×10^{22}
1.2×10^{22}
1.0×10^{22}
0
20
40
60
80
Time (days)
Model 2
Model 2c
Model 1c
Model 1b
Model 1a
Model 1