Scanning for Breakout Topologies

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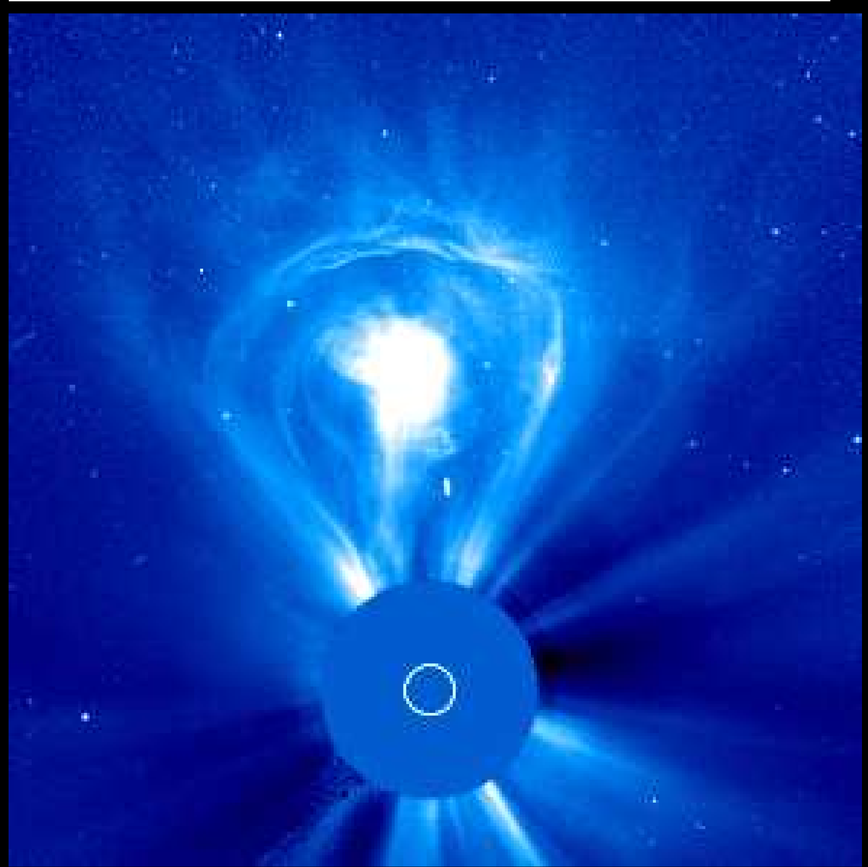
Motivation and Aims

The Breakout model was originally developed by Antiochos et al. (1999) to explain a possible method of C.M.E. initiation involving magnetic reconnection. The model has been extensively developed through numerical simulations, and has proven to be widely accepted as one of the models for possible C.M.E. initiation. In my project I will simulate two full solar cycles and match the flux of these with observations taken from Kitt Peak magnetograms. Using this data I will then scan my simulation for characteristics similar to the initial configuration of the breakout topology. Upon finding these I will compare my results with statistical variations of C.M.E. numbers to find one of two possible outcomes:

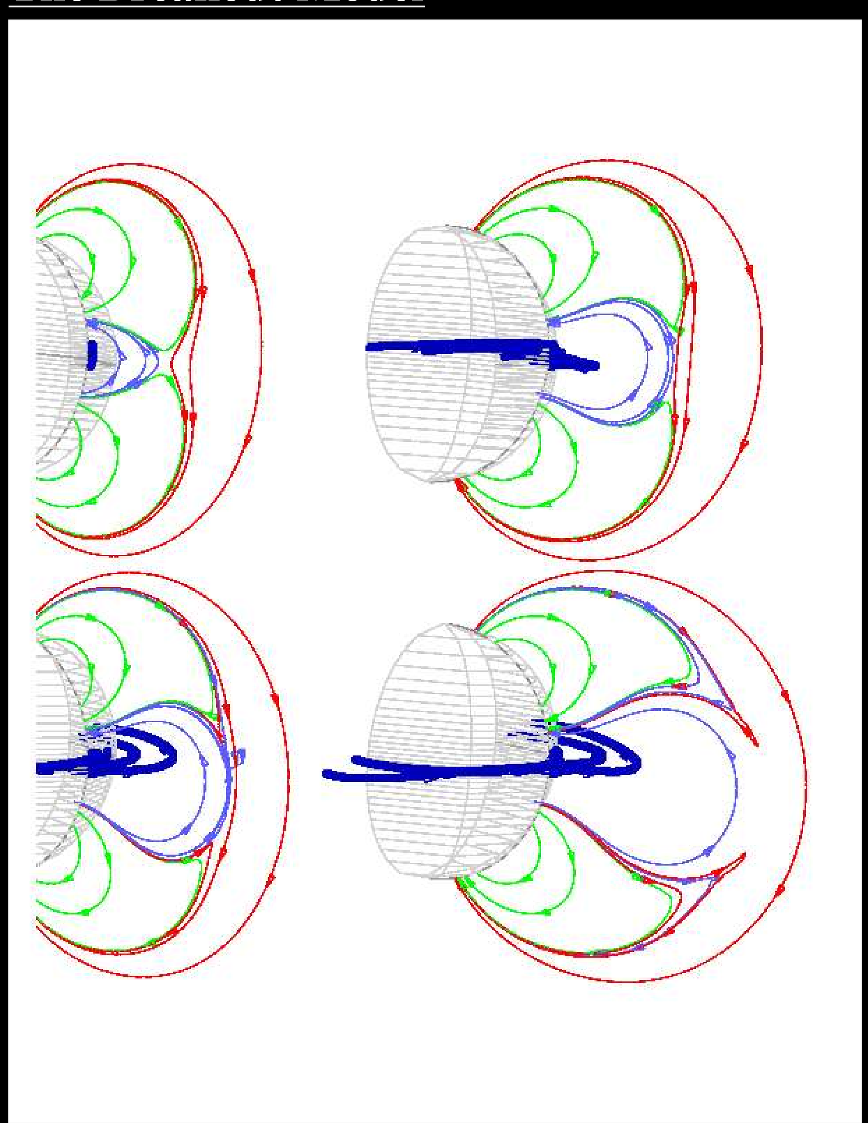
- A high correlation between C.M.E. numbers and the number of initial breakout topologies that exist, indicating that it is a good model for C.M.E. initiation, or
- A low correlation between the number of C.M.E.'s and initial breakout topologies, indicating that a better model may need to be concieved.

Consequences of Coronal Mass Ejections



- Huge ejection of mass (10^{16}kg) into interplanetary space
- Many effects including satellite damage, communications disruption and danger to astronaut
- Can cause the Aurora

The Breakout Model



An initial potential field is taken and then a shear flow is inserted between $\pm 15^\circ$, which drives the model from potential. This shear causes magnetic pressure and tension forces to become unbalanced and field lines begin to rise up towards the x point, where they begin to reconnect. As more pressure builds up, field lines rise faster and "Breakout". This breakout is due to reconnection turning the x point into a thin current sheet, which ejects plasmoid out into interplanetary space.

Steps and Method

1. Create our flux transport simulation, which will be manipulated so that the levels of flux that we have over the whole surface and at various latitudes will approximately match observations taken from Kitt Peak Magnetograms.

2. Use our transport simulation to extrapolate a potential field out to 2.5 solar Radii.

3. Develop a scanning code that searches our simulation for characteristics of a breakout topology, logs these and plots field lines to show the configuration of the field at this point.

4. Apply the scanning code and compare the results of this with statistical variations of C.M.E. numbers to draw one of our conclusions.

Simulation

When creating our flux transport simulation we create our solar surface by evolving forward the radial component B_r of the magnetic field (this is due to the boundary conditions that we impose on our simulation). This is done using,

$$\frac{\partial \mathrm{B}_r}{\partial \mathrm{t}} = \frac{1}{\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta(-\hat{U}\mathrm{B}_r + \hat{D}\frac{\partial \mathrm{B}_r}{\partial\theta})) - \Omega\frac{\partial \mathrm{B}}{\partial\phi} + \hat{D}\sin^2\theta\frac{\partial^2 \mathrm{B}_r}{\partial\phi^2},$$

where $\hat{U}$ is meridional flow, $\hat{D}$ is diffusion and Ω is differential rotation. We impose a boudary condition on our outer boundary that $\mathrm{B}_\theta = \mathrm{B}_\phi = 0$ at $\mathrm{r} = \mathrm{R}_{ss} = 2.5\mathrm{R}_0$. We then calculate our potential field out to 2.5 solar radii, by splitting up the area between the surface and the outer boundary into 37 distinct layers, and calculating the three components of the field using,

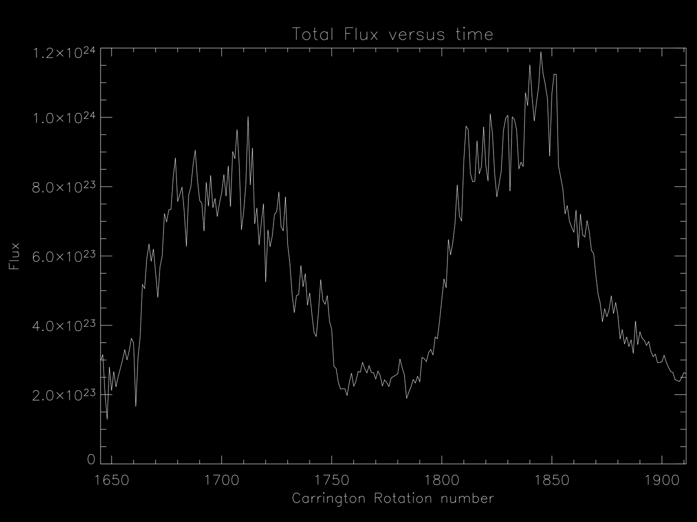
$$\mathrm{B}_r(\mathrm{r},\theta,\phi,\mathrm{t}) = \sum_l \sum_{m=-l}^{l} \mathrm{D}_{lm}\mathrm{Y}_{lm}(\theta,\phi)$$

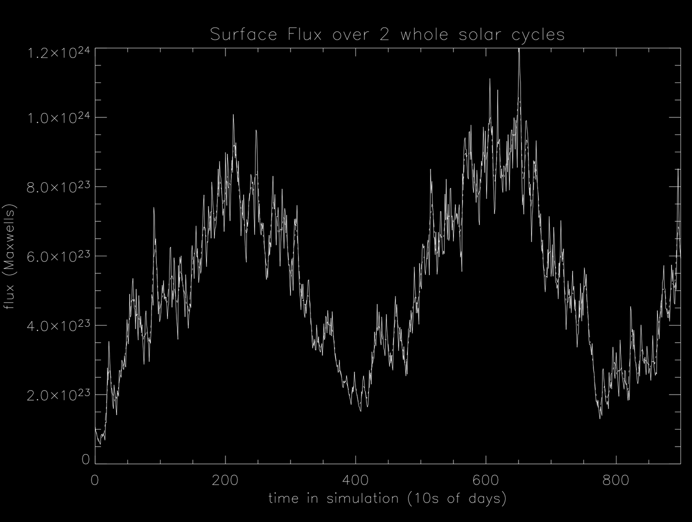
$$\mathrm{B}_\theta(\mathrm{r},\theta,\phi,\mathrm{t}) = \sum_l \sum_{m=-l}^{l} \mathrm{C}_{lm}\frac{\partial \mathrm{Q}}{\partial\theta}e^{im\phi}$$

$$\mathrm{B}_\phi(\mathrm{r},\theta,\phi,\mathrm{t}) = \sum_l \sum_{m=-l}^{l} \frac{im}{\sin\theta}\mathrm{C}_{lm}\mathrm{Y}_{lm}(\theta,\phi),$$

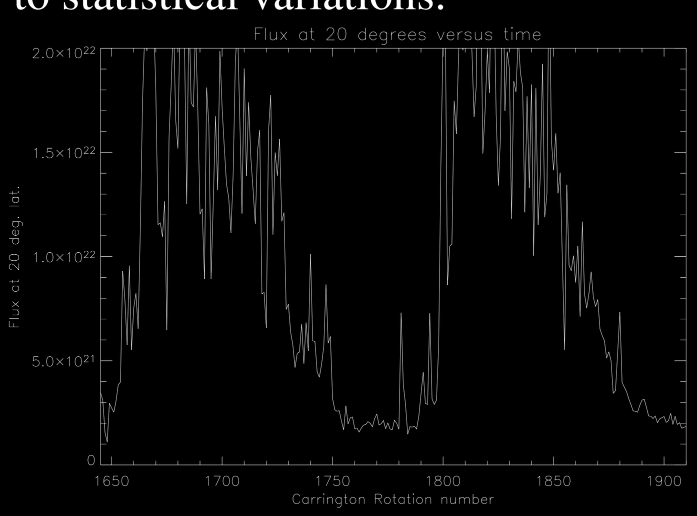
where $\mathrm{D}_{lm} = \mathrm{B}_{lm}(\mathrm{R}_0,\mathrm{t})\left[\frac{(l+1)(\frac{\mathrm{r}}{\mathrm{R}_0})^{-l-2}+l(\frac{\mathrm{R}_{ss}}{\mathrm{R}_0})^{-2l-1}(\frac{\mathrm{r}}{\mathrm{R}_0})^{l-1}}{l+1+l(\frac{\mathrm{R}_{ss}}{\mathrm{R}_0})^{-2l-1}}\right]$, $\mathrm{C}_{lm} = \mathrm{B}_{lm}(\mathrm{R}_0,\mathrm{t})\left[\frac{(\frac{\mathrm{r}}{\mathrm{R}_0})^{-l-2}-(\frac{\mathrm{R}_{ss}}{\mathrm{R}_0})^{-2l-1}(\frac{\mathrm{r}}{\mathrm{R}_0})^{l-1}}{l+1+l(\frac{\mathrm{R}_{ss}}{\mathrm{R}_0})^{-2l-1}}\right]$ and $\mathrm{Y}_{lm}(\theta,\phi)$ are the spherical harmonics.

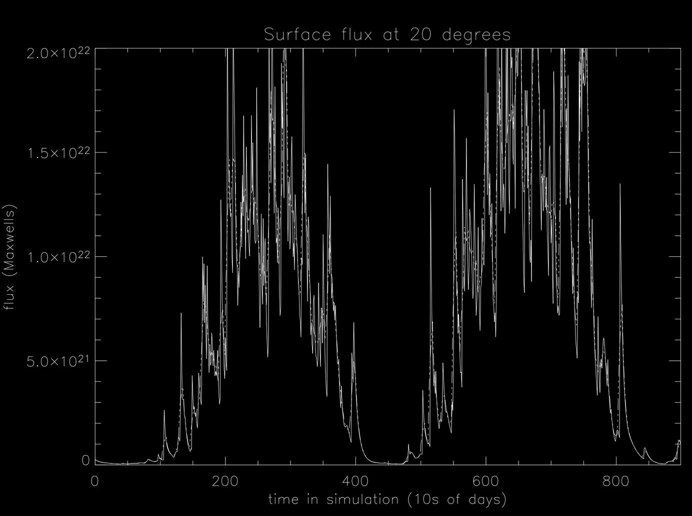
Matching to Observations





In order to get a good simulation, flux strengths between the simulation and Kitt Peak magnetograms were matched. As can be seen from the graphs above, an accurate approximation was found between observations (left) and our simulation (right). The peaks seem to match flux values, as do the minima. The simulation graph is more jagged than our observations, due to statistical variations.





Our approximation can be further refined by checking the flux at various latitudes. The graphs above show the flux at 20° latitude for our observations (left) and simulation (right). We see a fairly decent match between the two graphs. The graphs seem to peak about the same height, with variations above and below, and both show rapid tail offs to minima.

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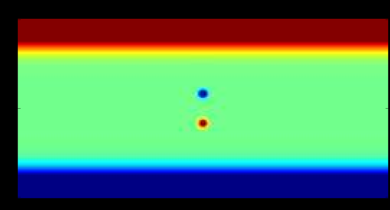
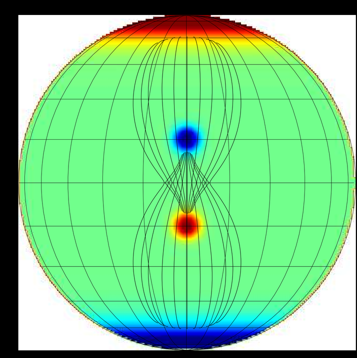
Scanning Code

In order to look for breakout topologies we use the fact that the overlying field lines have different orientation to the underlying field in the center of the model. We compare the horizontal field components B_θ and B_ϕ on succesive pixels using the cosine rule,

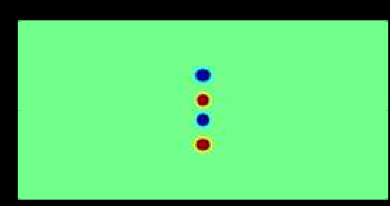
$$\cos\theta = \frac{a.b}{|a||b|},$$

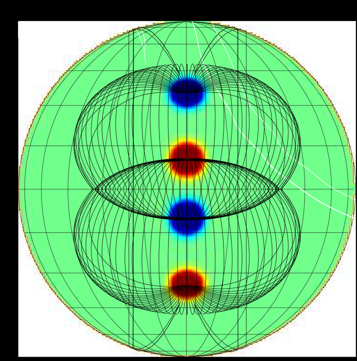
where a=($\mathrm{B}_\theta(\mathrm{r},\theta,\phi)$,$\mathrm{B}_\phi(\mathrm{r},\theta,\phi)$) is the horizontal field vector of the lower pixel and b=($\mathrm{B}_\theta(\mathrm{r}+1,\theta,\phi)$,$\mathrm{B}_\phi(\mathrm{r}+1,\theta,\phi)$) is the horizontal field vector of the succesive pixel. If the two vectors are antiparrallel then the angle between them, $\theta \approx 180^\circ$ (or $\cos\theta \approx -1$). In order to put this to the test, we used two example set ups, the first being similar to the antiochos model, the second being more complex.





The images above show the initial setup for our first test (left) and an orthographic image of the scan results (right), with field lines plotted. We see here that the code picks up the angle changes inside the central area of our region, giving us field lines to plot that show our breakout topology. In the second example below, we see the initial setup for our second test (left), with a bipolar region emerged within another bipolar region and an orthographic image of the field (right) with lines plotted. We see that the code picks out the angle changes within the area focused on within our regions, but also picks up angle changes outwith the area of intrest.





Conclusions and Further Work

- Finish working scanning code through on simulation and calculate frequency and number of breakout topologies.
- Compare with the statistical variations in C.M.E. numbers to draw my final conclusion.
- Convert instant day maps into simulated synoptic magnetograms and run scanning code on this to see if the results are comparable with the previous results.

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