Estimating changes in connection fluxes due to emergence or submergence

Lucas Tarr & Dana Longcope
Department of Physics, Montana State University

Overview

The Minimum Current Corona (MCC) model provides a way to estimate stored corona energy using the number of field lines connecting regions of positive and negative photospheric flux. This information is quantified by the net flux connecting pairs of opposing regions in a connectivity matrix. Changes in the coronal magnetic field, due processes such as magnetic reconnection, manifest themselves as changes in the connectivity matrix. However, the connectivity matrix will also change when sources emerge or submerge through the photosphere, as often happens in active regions. We have developed an algorithm to estimate the changes in flux due to emergence and submergence of magnetic flux sources. The differences between the invariants of the vector potential

\[ A = \rho \left( \frac{\partial \phi}{\partial z} \right) \]

and \[ \phi = \int B_z dx dy \]

represent an example run of this algorithm. An example run of this algorithm is depicted in Figure 4. The change–in–connectivity–matrix submerging or emerging through the photosphere together by creating a connectivity matrix for each maximum and every pixel strictly downhill with respect to \[ B_z \] from each maximum.

Figure 3 shows the positive, negative and total flux for AR 10273 over the course of one day. The change–in–connectivity–matrix is not unique and will depend on the algorithm used to pair up submerging and emerging regions. Our algorithm avoids egregious unphysical connections, such as those in Figure 5, where single poles have simultaneous submerging and emerging flux.

Removing submerging/emerging flux

Figure 3 shows the positive, negative and total flux for AR 10273 over the course of one day. Note that there is a net amount of positive flux, both the positive and negative flux regions are emerging, and that the positive flux is emerging faster. In order to use the FCC model to estimate the amount of magnetic energy stored in coronal ribbons, we need to remove the effects of submerging and emerging flux. To do so, we identify pairs of subregions (poles) that are submerging or emerging through the photosphere together by creating a connectivity matrix for changes over flux exchange over time.

Partitioning[1, 3]

Partionting the magnetogram occurs in three steps, via the gradient-based relaxation scheme:

1. Convolve the magnetic field, \( B_z \), with the Green's function for a potential extrapolation up to a height \( h \) from an unbound plane, where

\[ B_h(x,y) = \frac{B_z(x,y)}{\sqrt{x^2+y^2+h^2}} \]

2. Assign a unique label for all local maxima and every pixel strictly downhill with respect to \( B_h \) from each maximum.

3. Eliminate internal boundaries in unipolar regions when the saddle point \( |B_n| > \min(|B_{all}) = B_{scale} \), where \( B_{scale} \) is a threshold.

Figure 1 shows an example magnetogram before and after Partitioning. Each region is then characterized by its net signed flux and centroid location, which we call the centroids, together with their associated net flux, sources or poles. Figure 1 depicts AR 10273 before and after partitioning, with each region labeled by it's pole.

The Algorithm

The change–in–connectivity–matrix is not unique and will depend on the algorithm used to pair up submerging and emerging regions. Our algorithm avoids egregious unphysical connections, such as those in Figure 5, where single poles have simultaneous submerging and emerging flux.

For a set of poles at different times, \( \{P_n\} \), \( \{P'_m\} \), as in Figure 2, we do the following:

1. Create a symmetric change–in–connectivity–matrix, \( M_{ij} \).
2. Calculate the change in flux for each pole, \( \Delta \phi = \phi_i' - \phi_i \).
3. Find pole with smallest (but non–zero) changing flux, \( \phi_i \), as in Figure 2, we do the following:

\[ x = \Delta^{-1} \int B_h(x,y) \right] dx \]

4. Find \( P_n \)’s closest neighbor of opposite polarity and same sense in \( \Delta \phi_{ij} \).
5. For \( P_n \)’s, cancel the minimum change in flux, \( \min(|\Delta \phi_{ij}|, |\Delta \phi_{nii}|) \), from both \( \Delta \phi_{ens} \) and \( \Delta \phi_{en} \) and encode that in the change–in–connectivity–matrix at \( M_{ens} \) and \( M_{en} \).
6. Repeat steps 3–5 until no more submerging or emerging flux can be removed.

An example run of this algorithm is depicted in Figure 4. The change–in–connectivity–matrix \( M \) represents an expected term of submerging and emerging flux between pairs of poles. This matrix of flux change can then be removed from the difference between the potential field’s connectivity matrix at two times; for example, as in Figure 2. The remaining differences should then be due only to changes in the coronal magnetic field itself. Figure 6 depicts the algorithm’s output for the magnetograms in Figure 2. Because the algorithm operates on differences between sets of poles at different times, the same set of connections has been plotted at both times.

The present work uses magnetograms from the Michelson Doppler Interferometer on the SOHO spacecraft, as in Figure 1. Lighter and darker pixels show vertical field, \( B_z(x,y) \), out of and into the page respectively. For this particular magnetogram of AR 10273 (N09\(^\circ\), W22\(^\circ\)), the vertical field varies from 202 G to –162 G.

Minimum Current Corona[2][5]

The MCC model is a self–consistent, analytic model of quasi–static 3–D field evolution, which relies on two assumptions:

1. Photospheric field is composed of discrete, unipolar regions surrounded by a contiguous region of zero vertical flux.
2. Corona evolves quasi–statically through a series of flux–constrained equilibria (FCE), fields with the lowest magnetic energy that still match the photospheric boundary and contain the prescribed distribution of domain fluxes.

The coronal field resulting from assumption 2 is current–free except along separatrices of the field. These ribbons of current store energy as stress in the internal field. The FCE fields have the same domains as a potential field, but with different domain fluxes. The FCE field is defined to minimize the magnetic energy, constraining each domain flux to remain constant under variation of the vector potential \( A \),

\[ \bar{\Phi} = \int B_h(x,y) \right] dx \]

\[ \int B_h(x,y) \right] dx \]

\[ \int B_h(x,y) \right] dx \]

References