Nonlinear Force-Free Modeling of Aug 4 & 10, 2010 Sigmoids via Flux Rope Insertion Method

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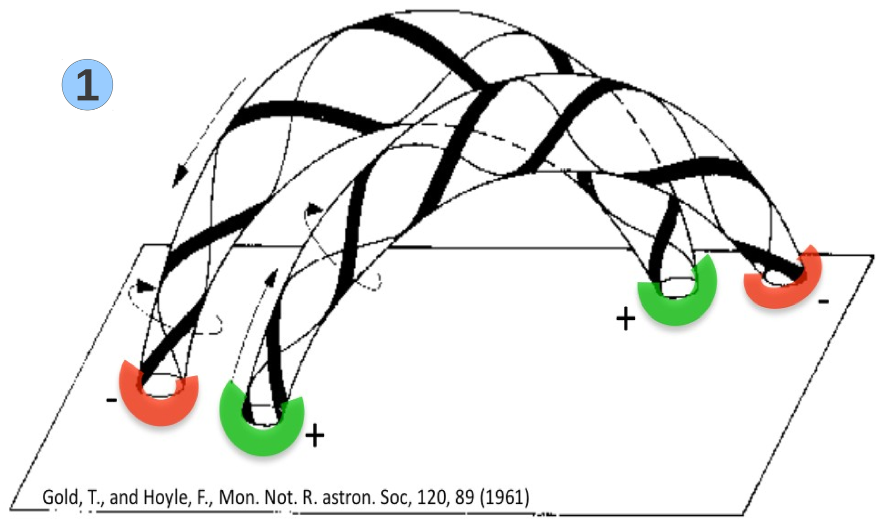

Fig. 1) Two flux ropes' field lines arc from the positive footpoints to the negative footpoints carrying plasma along the field lines up into the corona. Each flux rope has a field line component that travels along the rope's axis (axial) and another that curls around its axis (poloidal).

Introduction

Sigmoids are anchored to the photosphere by what are called "footpoints" The twisting of the sigmoid between footpoints stores energy in the magnetic field given by the equations below. More curl will store more energy, but there is a critical angle (less than 3.5Pi) at which the sigmoid will develop a kink instability[3].

2a
2b

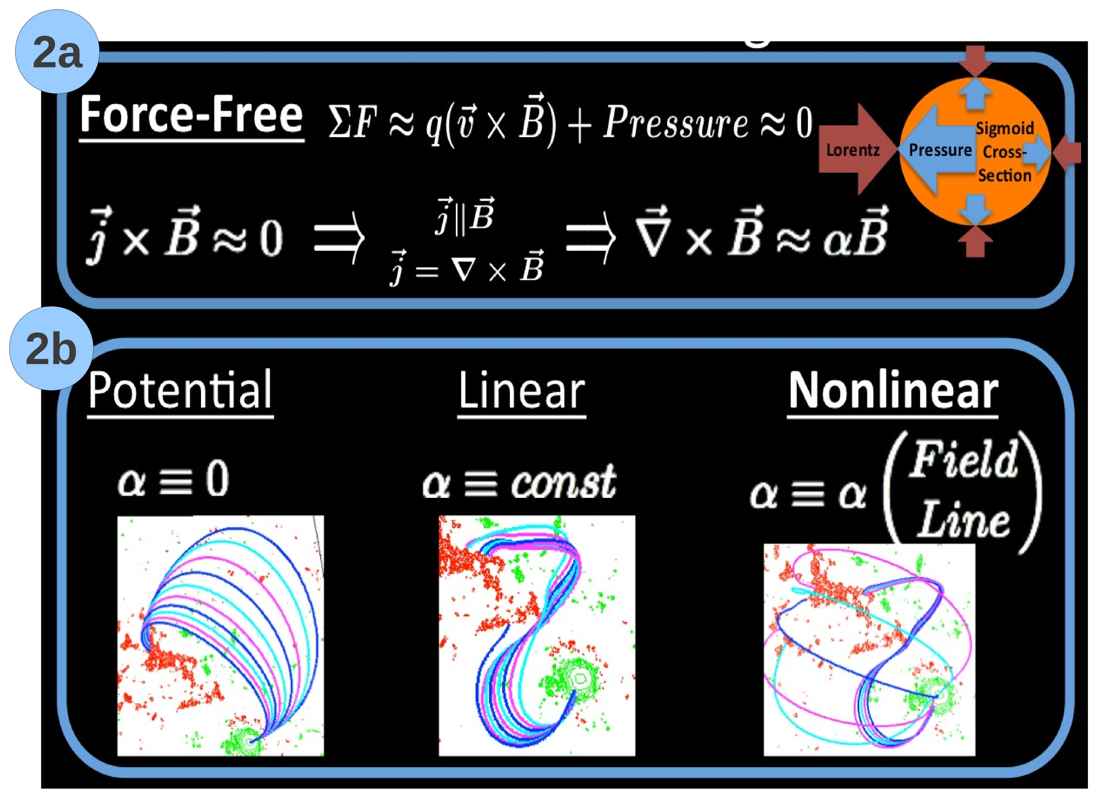

Fig. 2a) The force-free condition equates to the balance between the Lorentz Force of moving charge in the rope and the (negligible) gas pressure on the rope. This implies the torsion parameter which is a characterization of the curl in the field. High torsion means more curl. 2b) Three modeling methods ordered by increasing sophistication.

Method

We shall explain that nonlinear force-free modeling[4] has two criterion for modeling: the flux rope is in equilibrium and the torsion parameter is constant along a field line but varies from field line to field line. This allows the model to capture the two essential components of the sigmoid: the low altitude S-shape that forms the body of the sigmoid and the high altitude envelope that holds the S-shape down and keeps it from erupting[5].

The flux rope insertion method[6] evokes NLFFF's two criterion to generate the sigmoid's B-field model. First, an initial "guess" of the axial and poloidal flux parameters are made for the initial flux rope. Next, the flux rope is allowed to evolve over many time steps. (Note that all sigmoid empirical data is taken at one time, though.) Finally, the model is evaluated to see if it reached equilibrium or resulted in an instability. This process is repeated for many values of axial and poloidal flux thus spanning the parameter space.

Abstract

Fine S-shaped structures in active regions can be studied in more detail than before thanks to the high spatial resolution of space-based solar telescopes like Yohkoh/SXT, Hinode/XRT, and SDO/AIA. The collection of such S-shaped loops is known as a sigmoid[1] and is of great interest to solar physics since 68% of coronal mass ejections appear in such a region[2]. In our research, we detail methods of studying sigmoids by using photospheric magnetograms to make nonlinear force-free field models and by comparing these models to the observed loops in X-ray and EUV images. We use the flux rope insertion method to set the initial parameters for these models and to evolve the configurations to force-free states. From our models, we estimate the helicity and free energy stored in the sigmoids.

Results

In figure 3 are the two different sigmoids that were modeled. For each sigmoid, 32 different combinations of axial and poloidal flux were tried. Of those, only 16 resulted in stable and thus viable models for each sigmoid. These results can be seen on figure 5. Additionally, we estimated the sigmoids' free energy and helicity from the models; the results of which are in figure 4.

3a
3b
3c
3d

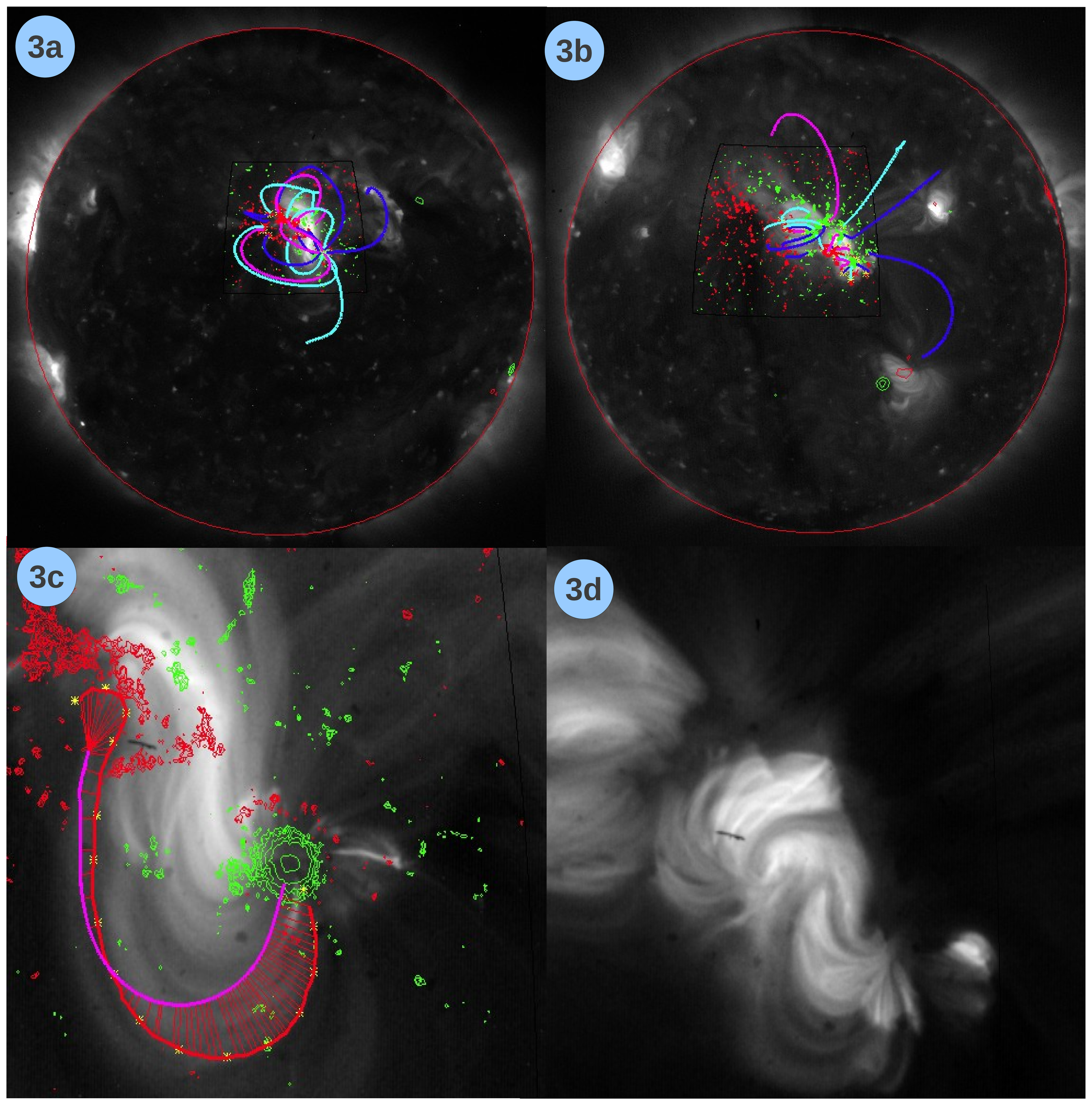

Fig. 3a) The full disk image with LOS magnetogram and selected field lines of Aug 4th sigmoid. 3b) Same as 3a for Aug 10th sigmoid. 3c) Chi-squared fitting between one field line and one coronal loop for Aug 4th sigmoid. 3d) Zoomed Aug 10th sigmoid image.

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Sigmoid	Free Energy (in 10^{31} ergs)	Helicity (in 10^{42} Mx)
August 4, 2010	6.0	-5.2
August 10, 2010	3.4	-2.3

Fig. 4) Using the best fit models for each of the sigmoids, we found lower bounds for the free energy stored in the field and the helicity of the field.

5a
5b

Figure 5a) Deeper green represents a better chi-squared fit between coronal loops and field lines for that parameter combination. For reference, figure 3c illustrates the light green combination (Axial, Poloidal)=(1,10). The Aug 4th best fit combination is given by (7,100) 5b) The Aug 10th best fit combination is given by (7,50).

Discussion

There are many aspects of this research that warrant further work. For example, the best fit flux parameter combinations occur on the edge of the unstable region of the parameter space for both sigmoids. Also, we have only evaluated the sigmoids at one point in time. It would be both interesting and insightful to see how the free energy and helicity of a sigmoid evolves as that sigmoid draws closer to eruption.

Acknowledgements

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