3-D Magnetic Field Modeling with Comparison to TRACE Coronal Images

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Abstract

We present tools that allow for qualitative comparisons between field extrapolation models and observed coronal loops. With these tools it will be possible to find the field model that best fits the data. Our model uses data from the Michelson Doppler Imager (MDI), Global Oscillation Network Group (GONG), and the Transition Region and Coronal Explorer (TRACE). We have developed a 3-D magnetic potential field model from line-of-sight MDI and GONG magnetograms. These potential fields are aligned with TRACE 171 Å coronal loop images to find potential field deviations in the active region. This model has imaging and loop-fitting capabilities to compare and analyze such deviations. Our work has focused on the study of NOAA 0130 on September 26th, 2002; NOAA 0372 on June 7th, 2003; and NOAA 9575 on August 18th, 2001. We have studied the field configurations in these regions and focused on the deviations from the potential field model.

Introduction

Energetic and complex solar magnetic fields are responsible for high-energy phenomena such as flares and coronal mass ejections. While the magnetic field constrains and energizes the coronal plasma, direct measurements of the field in the corona are difficult. We have developed an IDL program to test the strength of magnetic field models by comparing them to coronal loop images.

The program extrapolates the 3-D magnetic field configuration from solar magnetograms and creates a potential field model with periodic boundary conditions. The program also analyzes the model with comparisons to observations.

Program Features

The program, developed by Aad VanBallegooijen, has many tools and features to facilitate the systematic study of fit between loop models and observations. These features include:

- Manual selection of active region location, size, and resolution (with some restrictions on AR size).
- Adjustment made for projection effects and viewing angles.
- Ability to select and trace certain magnetic field lines and project them onto a 2-D Cartesian plane.
- Ability to select multiple field lines that intersect any given line of sight. This option allows these selections to be made with an underlying TRACE EUV image as a reference. The user can manipulate the variety of configurations by editing the starting points of these field lines.
- Viewing of the field lines either superimposed on the TRACE image or from any angle in 3-D.
- Quantitative comparison of the field lines with the user's selection of the visual loop. Thus, the potential field lines with the best fit to observations can be saved and further analyzed by height and length.

Table 1. Table of TRACE and MDI Observations

Date	Instrument	Image Type	Time Range (UT)	Fig. #
Aug. 18, 2001	TRACE	171 Å	10:00-12:59	···
Aug. 18, 2001	TRACE	WL	12:00-12:59	···
Aug. 18, 2001	MDI	HR Mag	14, 16:47-16:50	···
Aug. 18, 2001	MDI	HR Cont	14, 16:51	···
Jun. 7, 2003	TRACE	171 Å	18:34-23:59	···
Jun. 7, 2003	TRACE	WL	18:30-22:12	···
Jun. 7, 2003	TRACE	1600 Å	18:30-22:12	···
Jun. 7, 2003	MDI	HR Mag	17:59-23:58	···
Jun. 7, 2003	MDI	HR Cont	17:59-19:51	···
Sept. 26, 2002	TRACE	171 Å	15:00-17:59	1, 3-6
Sept. 26, 2002	TRACE	WL	15:02-16:00	2
Sept. 26, 2002	MDI	HR Mag	15:00-17:59	1,4, 7-8
Sept. 26, 2002	MDI	FD Mag	14:34, 19:12	···
Sept. 26, 2002	MDI	FD Cont	14:30, 19:11	···

Table 1. List of Observations. 'HR Mag' = High-Resolution Magnetogram. 'Cont' = Continuum. ' WL' = TRACE white light images. 'FD' = Full-Disk images.

Observations

This program requires closely coordinated TRACE and MDI images. We chose high-resolution data of active regions with clearly defined, potential field loops and appropriate photospheric images for co-alignment. With spatial resolution of 1 second and temporal resolution of 30 seconds, TRACE 171Å images clearly show the coronal loop structure. TRACE White Light images were aligned with MDI High-Resolution Continuum images. Regions with large-scale flaring events were avoided due to their sheared, non-potential magnetic field configurations.

Other Regions Studied

NOAA 9575, August 18, 2001

This region consists of a small magnetically positive sunspot close to disk center (N11 W11). The magnetogram shows a strong, compact region of positive magnetic flux followed by more diffuse negative flux. The configuration of loops in the TRACE image appear to be quite potential. However further study of one clear loop shows that locally perturbed magnetic fields, close to the photosphere, can strongly influence loop structures.

NOAA 0372, June 7th, 2003

More complex than the preceding regions, NOAA 0375 (at N12 E10) consists of a cluster of small sunspots that mix the positive and negative fluxes. This NOAA has a number of loops that seem to cross each other. In general, the loops are fairly steady with time. The higher loops are fainter and more difficult to fit.

Conclusion

This work has demonstrated the complexity of loop configurations. Even loops that appear potential can often have strong perturbations that strongly constrain the field lines into a non-potential state. However, the program provides a better understanding of loops with strong fits to the potential field, with the estimated height and length of the loop.

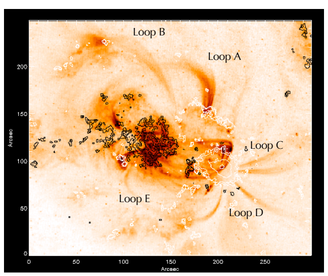
Further work will create a force-free model that can be compared to coronal observations as well as develop the program to compare vector magnetograms to the force-free model. This work has been supported by the XQT #NAS8-01003 and AIA #SP02D4301R contracts.

References:

http://soi.stanford.edu/science/obs_prog.html

http://vestige.lmsal.com/TRACE

http://chippewa.nascom.nasa.gov/~dcm/table/table.html



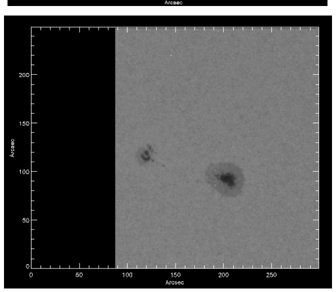


Fig 1. 26 Sept 2002. (*upper left*) TRACE 171 Å image [UT 15:33:26] overlaid with MDI HR magnetogram [UT 15:33:01]. The various studied loops are labeled.

Fig 2. 26 Sept 2002. (*left*) TRACE WL image [UT 15:34:06]. Examines same region as Fig 1 with the same scaling and positioning.

NOAA 0130, September 26, 2002

NOAA 0130 is an isolated active region consisting of two small sunspots (Fig. 2) close to disk center (N06, W04). The leading sunspot emits concentrated positive magnetic flux, while the following sunspot is surrounded by diffuse negative flux regions. This region has no high-energy flaring events.

The analysis of this region focused on five different loops (Fig. 1). Loops A,D, and E had varying potential field fits (documented in Table 2) and will be used to demonstrate the fitting procedures (Fig. 3, 4, 5). Loop C has a clearly non-potential curvature and Loop B was too high-lying to fit.

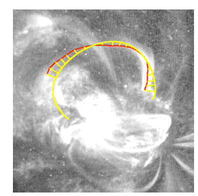
At first glance, Loops D and E (Figures 5-8) appear to be legs of the same coronal loop. However the TRACE 171 Å observations reveal that D and E seem to be heated independently. E displays much more activity and fades almost an hour before D begins to cool. The actual joint between the two regions is obscured by heated plasma over a small region of positive flux . Thus we chose to examine D and E separately and found very good fits to each segment. However none of the results resulted in good overall fits to the entire loop.

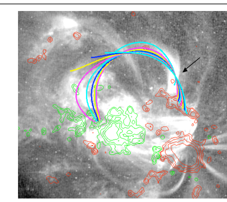
Table 2. Overview of fits and qualities of Loops A, D, E

Table 2. Sept. 26, 2002 Potential Field Line Fits to Observed Loops

Loop	Fit(arcsec)	Height(Mm)	Length(Mm)	Notes	Fig. #
A	4.9	58.74	205.3	Good fit to apex	3, 4
D	0.5	131.2	138.1	Open field line	5
E	0.7	37.25	135.1	Good fit to curvature	6-8

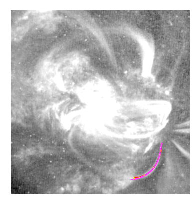
Field lines for Loop A.
Fig 3.(*right*) Best fitting field line to Loop A. The yellow line is the field line while the red line is the manually-drawn representation of Loop A. The yellow notches between the two represent the closest distance and is used to quantify the quality of fit.
Fig 4.(*far right*) several field lines selected with the multiple line plotting routine.





This multiple field line selection routine (seen in Fig. 4) facilitated the comparison of the loop with the field lines at multiple heights. All of the field lines pass through the line of sight (indicated with an arrow). The quality of fit is determined by the averaged distances between the traced loop points and field lines (Fig 3).

Field lines for Loop D
Fig 5.(*right*) Best fitting field line to Loop D despite being an open field line.



The ability to visualize the magnetic field lines in 3-D helps immensely in the understanding of loop structure. As seen below in Figs. 7 and 8, the ability to rotate the viewing angle clarifies the loop curvature and height. Figure 7 shows the loop as would been seen from Earth, with a slight rotation in azimuth angle. Figure 8 rotates the altitude angle to show the same configuration of loops from a side view. This tool is also useful in understanding how loop shapes change at greater heights.

Field Lines fr Loop E.
Fig 6. (*right*) Best fitting field line.
Fig 7. (*far right*) Several field lines seen from line of sight. [azim ang=30 deg.]
Fig 8. (*even further right*) Several field lines viewed from a non-Earth based point of view. [altitude ang=15 deg.]