Preliminary Results for Coronal Magnetic Fields as Suggested by MDI Magnetograms


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**Abstract.** In this paper, the authors present preliminary results for force-free and potential models of a small, emerging active region present on 14th November 1996. The active region was the subject of an activity study using the Coronal Diagnostic Spectrometer (CDS) onboard the Solar and Heliospheric Observatory (SoHO). The three-dimensional coronal magnetic field is constructed from a magnetogram taken by the Michelson Doppler Imager (MDI) using a multi-grid numerical scheme. The results for different model parameter values are displayed as anaglyphs.

1. **Introduction**

The solar corona is not a homogeneous and uniform environment but rather is a very complex and dynamic system consisting of a large variety of loop-like structures that are thought to outline the Sun's magnetic field. Observations from both the Soft X-ray Telescope on Yohkoh (Strong 1994) and the Extreme-Ultraviolet Imaging Telescope (EIT) (Delaboudinèrè et al. 1995) onboard the Solar and Heliospheric Observatory (SoHO) (Domingo, Fleck & Poland 1995) show active regions as bright tangles of magnetic fieldlines surrounded by a network of larger scale loops.

In this paper, the authors describe the initial test results for the construction of the possible three-dimensional nature of an emerging active region observed on the solar disc on 14th November 1996 by the Michelson Doppler Imager (MDI) (Scherrer et al. 1995). The main motivation behind this study was that this particular region was the target for several long duration observations made by the Coronal Diagnostic Spectrometer (CDS) (Harrison et al. 1995) as part of the St. Andrews/RAL Loops Campaign. Figure 1 displays the MDI magnetogram and an initial CDS snapshot in the Mg ix line \( \log T_e = 6.0 \) of the active region.

After providing a large image of the region, a much narrower CDS slit was used to investigate fast variations within the region. In this case, the slit was placed over the area of strong positive flux and is indicated by a black (white) rectangle in the MDI (CDS) image in Figure 1. A detailed analysis of the time series results for periodicities present can be found elsewhere (Ireland et al. 1997).
Figure 1. MDI magnetogram and CDS Mg IX image of the emerging active region (with units in arcsecs from Sun centre). The black/white rectangle on the MDI/CDS image represents the slit position for the activity studies.

2. Three-Dimensional Force-Free Equilibria

For a dominant magnetic field in equilibrium we have,

$$\mathbf{j} \times \mathbf{B} = 0,$$

where $\mathbf{j}$ is the current density and $\mathbf{B}$ is the magnetic field. Equation (1) can be written as

$$\nabla \times \mathbf{B} = \alpha \mathbf{B},$$

where $\alpha$ is a function of position within a force-free magnetic field. Consider the special case of equilibria where $\alpha=$constant everywhere. If we introduce the vector potential $\mathbf{A}$ such that $\mathbf{A} = \nabla \times \mathbf{B}$, then the force free equation reduces to

$$\nabla \mathbf{A} + \alpha \nabla \times \mathbf{A} = 0.$$

The equation is solved in a cube $(-1 < x, y, z < 1)$ subject to the boundary conditions,

1. the tangential components of $\mathbf{A}$ on each face are consistent with the normal component of $\mathbf{B}$,

2. the normal component of $\mathbf{A}$ satisfies $\nabla \cdot \mathbf{A} = 0$ on the boundary. In fact with convergence of the solution to (3), $\nabla \cdot \mathbf{A} = 0$ everywhere.

The cube is taken to be an isolated region of the solar surface and flux can only leave and enter through the bottom surface ($z = -1$). The base flux is specified as the normal component of the magnetic field at $z = -1$ which is derived from the MDI magnetogram. The numerical model used to solve this equation to obtain a three-dimensional magnetohydrodynamic equilibrium involves multi-grid methods (see Longbottom, Fielder & Rickard 1997).
3. Results

3.1. Setting up the Model

Consider the active region shown in Figure 1. Our aim is to achieve a rough idea of the magnetic topology within the active region sampled by the CDS instrument. Thus, the manipulation of the magnetogram data to produce the numerical model is as follows.

Figure 2. Calculating the total flux through a series of patches on a contoured image of the magnetogram.

Figure 3. Contour plot of the geometrical shapes used to represent the flux patches. Notice flux region 9, used to include the influence of the active region to the north-west of the target region.

An area around the active region is extracted and the total flux density of each "patch" (1 to 8) on the magnetogram is calculated (Figure 2). It is found that there is a slight imbalance towards the negative flux. A full disc
Figure 4. Extrapolation of the coronal field for $\alpha = 0$. The narrow CDS slit used for the activity study of the active region is shown by the dashed line.

magnetogram shows that there is a second active region to the north-west of the region of interest. The numerical scheme requires perfect flux balance through the base of the numerical box and therefore, this is corrected for by having a “long” range connection to the positive flux of the adjacent active region. The area is scaled into a $[-1, 1] \times [-1, 1]$ box and the flux regions are replaced by simple geometrical shapes which contain the same amount of flux (see Figure 3). The small deficit (about 10%) is made up by the additional region 9 as the influence of the other active region.

3.2. Coronal Field Extrapolation

The results for the extrapolation of the coronal magnetic field are shown in Figures 4 and 5 for $\alpha = 0$ and 2. The CDS slit position crossing the positive flux is shown by the dashed rectangle. The reconstructed fieldlines for the potential and force-free cases indicate that the CDS slit is sampling fieldlines that connect patch 4 to patch 2. One advantage of the CDS instrument is that the observer is allowed to examine the same portion of the Sun, at the same time over a wide range of temperature. By considering simply the brightest portion of the active region incident on the CDS narrow slit, a wavelet analysis on the intensity changes in the He i 584 line ($\log T_e=4.3$) yield distinct peaks in the power for oscillations with periods around 140 to 200s.

Unfortunately, the corresponding EIT images are confusing and no distinct loop structures are visible. Hence, no comparison with the model results has been undertaken.

3.3. Three Dimensional Visualisation

Anaglyphs (Ireland, Walsh & Galsgaard 1997) are a way of creating an impression of three dimensions from two dimensional images that are at slightly
Figure 5. Extrapolation of the coronal field for $\alpha = 2$.

different angles. Three dimensional movies of the above results along with instructions on how to view them can be found at http://www-solar.dcs.st-and.ac.uk/image_player/aspe97.html.

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