INTERPRETATION OF MAGNETIC FIELD
STRUCTURES OF AR 6659 IN JUNE 7-10, 1991

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Abstract. We examine the magnetic structures in AR 6659 by using the observation
of vector magnetic fields obtained at Marshall Space Flight Center/National Aeronautics
and Space Administration (MSFC/NASA). Using these vector magnetic field
data as the input for the non-linear force-free model developed by Wu et al. (1990),
the structure of coronal loops is revealed. The results obtained include: (i) loop sys-
tem configurations and (ii) current distributions for AR 6659 during the period 1991
June 7-11. In addition, we also computed the total magnetic energy vs time of this
region. It shows that there is indeed enough energy to propel the numerous, energetic
flares that were observed in this region. It also revealed that the flare loop system
corresponds to the two-ribbon flare on 1991 June 9.

Key words: Force-Free Magnetic Field – Photosphere – Corona

1. Introduction

AR 6659 produced thirty flares during its passage across the solar disk in the pe-
riod of the international campaign of June 1991, among them, six were very large,
long-duration flares (X10/12). Recently, Schmieder et al. (1993) investigated the mor-
phology of the magnetic field evolution in relation to flaring sites in AR 6659. However,
the three-dimensional magnetic field structures were not analyzed in their study. We
recognize that in order to understand the fundamental physics of flares, we must
understand both the magnetic field evolution and structures in the active region.
Therefore, we employed a nonlinear force-free (NLFF) model (Wu et al., 1990) to
analyze the magnetic structures of AR 6659. This NLFF model enables us to reveal
the loop configuration, current density distribution, and available magnetic energy for
AR 6659. The procedures for obtaining the three-dimensional magnetic field configuration on the basis of observed vector magnetograms are briefly described in Section 2. The results and physical interpretations are presented in Section 3 and concluding remarks are in Section 4.

2. Procedures for the Extrapolation of Three-Dimensional Magnetic Field Configuration

To examine the evolution of the magnetic structures in relation to the flaring region of AR 6659, we have employed vector magnetograms from the George C. Marshall Space Flight Center (MSFC) Solar Observatory (Hagyard et al., 1982, 1985). MSFC’s magnetograms have a pixel size of 2.8” in a field of view of 6’ × 6’ with a cadence of one vector magnetogram every six minutes. These magnetograms are the input for the NLFF model (Wu et al., 1990) to reveal the magnetic structures in three dimensions. The procedures for construction of the three-dimensional magnetic structures are:

1. Use the vector magnetograms of AR 6659 from MSFC during the period 1991 June 7 - 10 as the boundary conditions for the NLFF model.

2. Use line-of-site component of the vector magnetograms to compute the potential field in a comparison with Schmidt’s model to verify the NLFF model in the lowest order of approximation.

3. Reduce the 128 × 128 pixel array of the MSFC vector magnetograms to 64 × 64 through a four-point average procedure for the input of the NLFF model.

4. Use the NLFF model to calculate the three-dimensional magnetic field configuration and other physical parameters

3. Numerical Results

The detailed computational method and accuracy of the NLFF model are given by Wu et al. (1990). First, we used the vector magnetograms together with the NLFF model to obtain the three-dimensional force-free magnetic field configuration at 1991 June 7 - 10. On the basis of these computed data, it is possible to deduce the total magnetic energy available to propel the flares. This was done by computing

\[ E_{ava} = \frac{1}{8\pi} \int_V (B_{NLFF}^2 - B_{pot}^2) dV \]  

(1)

where \( V \) is the volume of the computation domain: horizontal dimension = 250,000 × 250,000 km and vertical height = 30,000 km. The computed total available magnetic energy on the basis of observed magnetograms during the period 1991 June 7 - 10 is
Figure 1. Computed differences of the total force-free magnetic energy and potential magnetic energy from observed vector magnetograms (MSFC/Solar Observatory).

plotted in Fig. 1. From these results we notice that there is enough magnetic energy stored (> \(10^{33}\) ergs) in AR 6659 to propel the flares (X10/12). Fig. 2 presents the current density distribution at various heights (i.e., 0 km, 5,000 km, 15,000 km and 25,000 km) for 1991 June 9 at 1255 UT. We notice the following: (i) the patterns of the current density distribution become less structured with increasing height and (ii) the larger gradients of current density are located near the neutral line where the observed flares occurred.

We selected the two ribbon flare observed on 1991 June 9 01:51:42 UT in \(H_\alpha\) to compare the magnetic field structures extrapolated from MSFC's magnetograms (1991, June 9, 1225 UT) using the NLFF model. We notice that the foot points of the computed magnetic loops (Figs. 3a,b) coincide with the two main ribbons observed (Figs. 3c,d). It should be noted that the computed magnetic loops are based on MSFC's magnetogram in the heliographic coordinate system and Fig. 3d is based on local coordinate systems.

4. Concluding Remarks

In this study, we have briefly presented the three-dimensional magnetic structures for AR 6659 using NLFF model (Wu et al., 1990) on the basis of the MSFC vector magnetograms. We suggest that the NLFF model can aid us to understand the physics of the magnetic structures in an active region quantitatively. From these results we demonstrated (i) there is enough magnetic energy to propel the flare; (ii) the locations
Figure 2. Computed current density contours at different height (i.e., 0 km, 5,000 km, 15,000 km and 25,000 km) in 1991 June 9 1225 UT using the NLFF model. At z = 0, the positive and negative high current density regions correspond to flare ribbons (a and b) shown in Fig. 3d.

of the flare corresponds where the current density is high and (iii) the magnetic loops revealed by the NLFF model can be related to the observed two-ribbon flare.

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References

Figure 3. The comparison between Hα and computed magnetic field configuration in 1991 June 9 two ribbon flare; (a) the computed three-dimensional magnetic loops on the basis of MSFC/solar observatory magnetograms, (b) top view of the computed magnetic loops of (a), (c) Hα two-ribbon flare 1991 June 9, 01:36:22 UT (courtesy of Li Zhi Kai, Yunnan Observatory, Kunming, PRC), (d) Longitudinal magnetic field map 1991 June 9, 12:55 UT obtained by MSFC magnetograms (a and b indicate the flare ribbon). See Schmieder et al. (1993) for detailed explanation of this figure.