ANALYSIS OF RELATIONSHIP BETWEEN FLARING ACTIVITY AND SUBPHOTOSPHERIC FLOWS IN NOAA 9393

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ABSTRACT

The relationship between the subphotospheric flows and flaring activity is not well understood. It is believed that subphotospheric shearing flows play important role in creating unstable magnetic topology that leads to initiation of flares and CMEs. In this paper, we study subphotospheric flows and their relationship with two flares observed in active region NOAA 9393. One of the flares is connected with halo CME. SOHO/MDI and helioseismology data are used for determining the changes in morphology and are compared with changes of the topology as observed by TRACE. We find evidence of some connections between subphotospheric flows within 12 Mm below the photosphere and changes of photospheric magnetic fields and also the flaring activity.

Key words: subphotospheric flows; solar flares; CME; magnetic reconnection.

1. INTRODUCTION

It is widely believed that the Sun's flaring activity is associated with deformations of coronal magnetic structures caused by various kind of foot-point motions. These motions produce electric currents that may dissipate very quickly through the process of magnetic reconnection. The theory of magnetic reconnection is well developed for 2-D geometries, and nowadays it is being developed for 3-D cases (for a review, see Priest & Forbes, 2000). For understanding the solar flares and associated with them coronal mass ejections (CME), it is important to develop various approaches for comparing the theories with real observations.

The purpose for our study is to look for the relationship between subphotospheric velocity fields and foot-point motions of magnetic structures producing flares or possibly CMEs. We hope that local helioseismology data may help to reveal this kind of foot-point motions. Recently, we studied M4.3/SF flare that occurred on March, 28, 2001 in active region (AR) NOAA 9393 (Dzifčáková et al., 2005) in this context. We have suggested that this flare can be explained by the theory of magnetic flipping (Priest & Démoulin, 1995). In this paper, we have studied another flare in this AR, and argue that the flare also may be explained by magnetic flipping. This flare was clearly associated with halo CME.

2. DATA

The X1.7/SF flare occurred in AR NOAA 9393, on March 29, 2001, and was the strongest flare of that day. According to the SXR classification it started at 09:58 UT, reached its maximum at 10:15 UT and ended at 10:26 UT. At 10:26 UT, a narrow bright front developing into a full halo CME by 10:56 UT was observed by SoHO/LASCO coronographs.

For analysis of this flare, we have used TRACE and SoHO/EIT images, and also sequences of line-of-sight magnetograms and 3D velocity fields obtained by time-distance (T-D) helioseismology technique (Duvall et al. 1993; Kosovichev & Duvall, 2002) from SoHO/MDI data. The flare evolution has been analyzed using TRACE images in UV 1600 ÅContinuum , 171 Å EUV line and white light, and also EIT 195 Å images. The TRACE and EIT data, the spatial resolution of which is 0.5 arcsec/0.36 Mm per pixel and 5.2 arcsec/3.8 Mm per pixel, respectively, have been processed using the standard SolarSoft procedures. The flow maps have been obtained by the T-D analysis of 8-hour series of MDI full-disk Dopplergrams, at 14 depths below the photosphere in the range 0-80 Mm. The horizontal resolution of these maps is approximately 5.51 Mm. For our analysis, we used only the horizontal components of the flow field in 6 layers, down to the depth of 12 Mm, which are determined most reliably (Kosovichev & Duvall, 1997). A part of SoHO MDI magnetogram of 12:00


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UT was used to analyze the magnetic structure of the flaring region, and for computing the potential field model. The potential field model have been computed using magnetic charge method (Démoülin et al., 1993), and also quasi-separatrices (QSs) have been determined following Démoülin et al. (1996).

3. RESULTS

- The inspection of the subphotospheric horizontal flows revealed that flows suitable for producing the foot-point motion across the quasi-separatrices might be observed somewhere within 12 Mm below the photosphere.
- The flows beneath AR 9393 are characterized by fast streams, visible at depths of 4.5 and 6.4 Mm; at these two depths the background horizontal velocities are small, showing nearly no structure (Figure 1b, c).
- The streams are modulated by background horizontal fields: supergranular outflows in the upper layers and turbulent network-like flows in the deeper layers (Figure 1a, d).
- In the previous paper (Dziščaková et al., 2003), we found few depths in the range from 3 to 12 Mm, where strong flows close to the QSs were observed for the March, 28, 2001, M4.3 flare. For the March, 29, 2001, X1.7 flare, we consider the depths of 2 and 6.4 Mm as the location of the appropriate horizontal flows near QSs.
- Both flares occurred during the growth of the AR NOAA 9393. Especially, the Southern part of AR underwent quick development: flux emergence and strong sunspot motions. The flows in the upper layers, 2 - 4.5 Mm deep, (Figure 1a) seemed to fit the proper motions of magnetic
Figure 2. The structure of magnetic field and computed quasi-separatrices. Top panel shows magnetic field contours ±300 G (grey, black) at 04:00 UT (full line) and at 12:00 UT (dotted line). The arrow marks the greatest changes during 8 hour evolution. Bottom panel shows QSs computed from the potential field model (thick lines - QSs, thin lines - field lines).

- Both flares could be explained by magnetic flipping: they are characterized by intensive emission at 1600 Å at locations of computed QSs (Figure 2, bottom and Figure 3, top); they showed quite large areas of diffusive emission in EUV 171 Å line, in which a loop system had condensed later (Figure 3, bottom). For the X1.7 flare of March 29, a possible scenario could be that the loop ends anchored in the QS visible across the big positive spot P (see Figure 3, top) flipped and connected to the positive polarities at the Southern part of AR.
- The March, 29, flare was much shorter in duration and was associated with halo CME; this flare caused destabilization of large-scale coronal loops rooted in and close to the magnetic flux concentrations involved in the flare (Figure 4).

4. CONCLUSION

The active region, NOAA 9393, has been already studied within the frame of subphotospheric dynamics of sunspots and developing active regions. Kosovichev et al. (2002) found that there was no evidence of emergence of a large magnetic Ω-loop from the solar interior in this active region. In agreement with this, we did not find any (larger) concentration of downflows (in the vertical velocity component) deeper than 12 Mm below the photosphere, at places of the sunspots. Therefore, we think that only
flows down to this depth may influence coronal magnetic structures. Haber et al. (2003) have studied the interaction of large-scale subsurface flows with major active regions using ring diagram analysis. They also concluded that NOAA 9393 was formed most likely by fragmented flux tubes that emerged over an extended period of time. From March, 28, to March, 30, 2001, they observed asymmetric convergence of flows toward the main axis of the active region at depths 2 Mm and 7 Mm. We have found fast streams flowing at the central part of the active region on March, 29, in the depth range from 3 to 9 Mm, clearly visible at depths 4.5 and 6.4 Mm. The streams mainly appeared between the sunspots, in areas with weak magnetic field or no magnetic field, but sometimes such a stream was observed also in the area of a sunspot. We consider that the horizontal flows between depths 2 and 6.4 Mm may be responsible for the foot-point motions that may lead to flaring activity. We suggest that X1.7/SF flare can be explained by magnetic flipping. This kind of 3-D reconnection can occur without null points in quasi-separatrix layers when there is a breakdown of ideal MHD. It requires the foot-point motion across the quasi-separatrices (Priest & Démoulin, 1995). In these places, the continuous flows across one quasi-separatrix may produce flipping of magnetic field lines in another quasi-separatrix layer. The flows suitable for this kind of reconnection were partially found, e.g. at depth of 4.5 Mm at 12:00 UT. This result is not quite conclusive as the time span between two flow maps is 8 hours and covers 4 layers which could also affect the flow patterns; however, the X1.7 flare was the strongest during the observing period. Obviously, there is a need for more statistical evidence to provide more insight into the relationship between subphotospheric flows and flaring activity. In addition, the X1.7 flare was associated with halo CME. We have noticed that during the CME the large scale loop system has disappeared. This loop system was connected from one side with the Southern part of the AR NOAA 9393, which underwent a rapid evolution before the flare.

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