A SEARCH FOR THE RELATIONSHIP BETWEEN FLARING ACTIVITY AND SUBPHOTOSPHERIC FLOWS

E. Dzifčáková¹, A. Kulinová¹ and A. G. Kosovichev²

¹Astronomical Institute, FMPh Comenius University, Mlynská dolina, 842 48 Bratislava, Slovak Republic, E-mail: dzifcakova@fmph.uniba.sk, kulinova@fmph.uniba.sk
²Stanford University, 455 Via Palou, Stanford, CA 94305-4055, USA, E-mail: sasha@quake.stanford.edu

ABSTRACT

It is believed that subphotospheric shearing flows play important role in creating unstable magnetic topology that leads to initiation of flares and CME. However, the relationship between the flows and flaring activity is not well understood. Using the flow maps obtained by local helioseismology and magnetic and coronal data we attempt to search for this relationship. In particular, we study the evolution of active region NOAA 9393 in the context of changes in magnetic topology and flaring activity. 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.

Key words: flares; magnetic reconnection; subphotospheric velocity field.

1. INTRODUCTION

The mechanism of flaring activity is not well understood. It is widely believed that it is associated with deformations of coronal magnetic structures caused by various kind of foot-point motions (shearing, braiding or random walk), which lead to formation of current sheets. The current sheets tend to diffuse or become unstable, and via a reconnection process produce an energy release, we usually observe as flares. Theories and numerical simulations of 3-D magnetic reconnection are developing rather fast nowadays (e.g. Priest & Forbes 2000, Milano et al 1999, Galsgaard and Nordlund, 1996), and there is a demand to confront models with observations. The purpose for our study is to look for the relationship between subphotospheric velocity fields and motions of foot-points of magnetic structures producing flares. For the initial study, we have chosen one of the flares observed in active region (AR) NOAA 9393. We believe that this flare may be explained by the theory of magnetic flipping suggested by Priest & DEMOUIN (1995). This kind of 3-D reconnection requires the foot-points to move across quasi-separatrices (QSs), producing electric field parallel to the magnetic field lines. Then, the field lines may become disconnected from the plasma and rapidly flip through it in the quasi-separatrix layers. We hope that local helioseismology data help to reveal this kind of foot-point motions. For this study we use the subphotospheric velocity maps inferred by time-distance (T-D) helioseismology (Duvall et al, 1993; Kosovichev & Duvall, 2002). Each of the flow maps was 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 was approximately 2.9 Mm. For our analysis we used only the horizontal components of the flow field in the upper 10 Mm layers, which are determined most reliably (Kosovichev & Duvall, 1997).

2. ANALYSIS OF OBSERVATIONAL DATA

On March 28, 2001, NOAA AR 9393 was located near the center of the solar disk and about 8 flares occurred there. We have chosen a M4.3/SF flare for analysis, which started at 11:21 UT, reached the maximum of X-ray intensity at 12:40 UT and ended at 13:06 UT. The flare was observed in detail by TRACE in 1600 Å UV continuum and EUV line 171 Å (Fig. 1,2). The spatial resolution of TRACE images is 0.5 arcsec (0.36 Mm) per pixel. Also, MDI magnetograms were used to analyze the magnetic structure of the AR and for constructing the potential model (Fig.3). Basically, we used 3 magnetograms taken before the flare, at 4:00 UT, during the flare, at 12:00 UT, and after the flare, at 20:00 UT. Their spatial resolution is about 2 arcsec (1.5 Mm) per pixel. The subphotospheric velocity fields were obtained for 8-hour intervals centered at the same moments as the magnetograms. The observations show that during this period the magnetic field (MF) rapidly evolved in the lower part of AR (rectangle in Fig. 4a). In this part, the averages horizontal velocity vector was directed to the south-west (Fig. 4). The MF structures moved simultaneously with the plasma, so that the field lines became stretched. This kind of motion was observed just in few depths close to the surface, 3-12 Mm. In general, the velocity pattern seems to vary significantly with depth and not all flow patterns are connected with the MF movements.
2.1. Flare Structures in the Corona

The first flare brightenings appeared in UV continuum: one in a big positive polarity (BPP) spot and another one close to a smaller positive polarity feature (SPP, Fig. 1a). Similar behavior was observed in the EUV 171 Å line (Fig. 2a). At about 12:00 UT, the third brightening in the UV continuum appeared in the big negative polarity (BNP) spot (Fig. 1b). Simultaneously, a coronal loop system connecting the BPP and BNP spots became visible in the 171 Å line emission having a diffusive character (Fig. 2b). In addition, below this loop system two smaller and more clearly visible loop structures appeared in the EUV emission. However, they were short-living and disappeared about 30 minutes later. Near the maximum of the flare (12:40 UT), an additional loop system connecting BNP with SPP started to be visible. In the gradual phase of the flare, the evolution continued with the fragmentation of the diffusive loop systems to individual loops (Fig. 2c).

2.2. Magnetic Field Model and Flare Scenario

In order to compare the flare evolution with models we need to know field line connectivity in the observed AR. That is why we constructed a potential filed model from MDI magnetograms (Fig. 3) using magnetic charge method (Démoulin et al., 1993; Longcope, 1996). This model provides the coronal field structure in the absence of significant electric currents. It seems that during the flare evolution the global field structure remained largely unchanged. However, the detailed analysis of the sequence of model field revealed changes in connectivity of some field lines in the vicinity of quasi-separatrices (QSs) shown by the thick curves in Fig. 3a-c. We propose the following scenario for the M4.3/SF flare of March, 28, 2001. The first brightening appeared close to the QSs numbered 1 and 3 (Fig. 3). At this time, several field lines connecting the big and smaller positive magnetic polarities to the weak negative polarity at the right top corner of the image (see e.g. Fig. 3, 4) then changed their connection to the BNP spot in the center of AR NOAA 9393, where the QS number 2 is situated. In our opinion, this flare evolution resembles the 3-D reconnection without null points via magnetic flipping (Priest & Démoulin, 1995). This theory requires plasma motions across the QSs. To search for the suitable plasma motions we used the local helioseismology results for the horizontal velocity fields obtained by the T-D technique. We analyzed the flow patterns in the center of the active region for the different depths below the surface (photosphere). According to the theory and TRACE observations we looked for flows crossing the QSs 1 and 3 depicted on Fig. 3 for modeled field configurations.

2.3. Analysis of Subphotospheric Flows

Generally, the most shallow depths have very similar flow pattern. This may be explained by the small depth difference among the depth levels so they represent flows in the same subphotospheric shell. As the depth increases, the flow pattern changes noticeably. Totally opposite plasma flows can be find in the same part of AR for deeper levels. The plasma flows suitable for our flare scenario have to be directed nearly to the center of AR. We have found this kind of flows at four depths: 3.0 Mm, 4.5 Mm, 6.4 Mm and 11.8 Mm below the surface. For these four depths the same flow pattern in the BPP spot prevails but the sought flow is not so evident for the region near the SPP. For instance, in 6.4 Mm there is just very weak sign of plasma motion across the QS number 3.

3. CONCLUSION

The NOAA AR 9393 was very complicated and rapidly evolving during the disk passage. It produced several flares. The initial analysis of M4.3/SF flare of March,
Figure 2. The flare evolution in 171 Å EUV line: a) pre-flare EUV image, b) EUV image with corresponding contours showing sunspot location, c) gradual phase of the flare. Solar north is up and west is to the right. Field of view is 300'' × 300''.

Figure 3. The potential magnetic field model of NOAA AR 9393: a) pre-flare configuration 4:00 UT, b) close to the maximum (12:40 UT) configuration 12:00 UT and c) post-flare configuration. The active quasi-separatrices are presented by heavy lines and are numbered 1,2,3, see text. Solar north is up and west is to the right. Field of view is 300'' × 300''.

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28, 2001, have shown significant motions of the photospheric footpoints of the magnetic field structures associated with this flare. It seems that in this case the plasma flows that led to the global evolution of the lower part of the AR just deformed (stretched) the field lines, and the trigger of this flare should be plasma flows across the quasi-separatrices. A possible scenario of this flare, magnetic reconnection via magnetic flipping without null points, requires subphotospheric flows directed toward the center of the AR across the quasi-separatrices. We have searched for such flows using the flow maps obtained by the time-distance helioseismology and found these flows might be located at the depth of 0-3 Mm. However, the flows in the upper layers were in the opposite direction. Therefore, the precise relation between the subphotospheric flows and the reconnection scenario is not yet clear. This kind of study needs to be expanded to other suitable flares. Further analysis should be able to provide answers for the following questions: Should all plasma flows across the quasi-separatrices leading to flaring activity be observed in the same depth (below the photosphere)? What is the connection between the subphotospheric plasma flows and large-scale magnetic evolution of active regions?

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REFERENCES