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The Evolution of Vector Magnetic Field Associated with Major Flares in NOAA AR10656

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Abstract. In this paper, we study the evolution of vector magnetic field of AR 10656 by using the observations of Huairou Solar Observing Station (HSOS, China) and Big Bear Solar Observatory (BBSO, USA). The magnetic flux emergence and cancellation, and thus, magnetic non-potential changes, are associated with the major flares in this active region. Compared with some other super-active regions, the evolution of magnetic morphologies and non-potentialities are relatively gradual, and thus the energy transportation and release are relatively slow. This gradual process may result in the recurrent flares of AR 10656.

Key words. Magnetic field—evolution—flares.

1. Introduction

Flares are believed to be powered by the magnetic energy stored in the nonpotential component of magnetic fields. This nonpotential component can be deduced from the difference between the observed vector magnetic field and the inferred potential field, which is calculated from the observed line-of-sight magnetic field (Rust *et al.* 1994). The causal relations between the non-potentiality and flare occurrence have been discussed by many authors. Wang *et al.* (1996) presented time sequences vector magnetograms obtained at Huairou Solar Observing Station (HSOS) and showed a great enhancement in the non-potential field several hours before an M-class flare. They also found that some decrease in the non-potential field during and after the flare. Vector magnetograms revealed line-of-sight electric currents before the flare. These currents disappeared after the flare. Based on the vector magnetograms observed at HSOS, Bao *et al.* (1999) showed that rapid and substantial changes of distribution of current helicity in an area or in its vicinity are most likely the triggers of flares. Also based on the vector magnetograms observed at HSOS, Deng *et al.* (2001) found that, for the "Bastille Day flare", in the photosphere and before the flare, the distribution of angular shear underwent a dramatic change, and the vertical current system, current helicity and source field were disrupted and weakened. A recurrent solar flare activity

Table 1. Major flares occurred in NOAA AR10656 (from Space Environment Center).

Date	Begin	Max	End	Class	Date	Begin	Max	End	Class
12	0438	0505	0520	M1.2	15	0445	0506	0522	M1.2
13	0636	0729	0738	M1.2	15	0554	0600	0604	M1.2
13	1202	1209	1212	M1.1	15	1123	1132	1148	M2.6
13	1807	1812	1815	X1.0	15	1234	1241	1243	M9.4
13	2314	2343	2346	M3.0	15	1837	1845	1850	M1.2
13	2346	2350	2354	M2.8	16	0331	0347	0415	M1.1
14	0410	0414	0417	M2.4	16	2229	2244	2252	M1.1
14	0536	0544	0552	M7.4	17	1926	1937	1948	M2.4
14	0751	0756	0759	M2.3	17	2112	2121	2139	M1.8
14	0952	1007	1017	M3.2	17	2212	2228	2237	M1.3
14	1331	1343	1350	M5.6	18	1729	1740	1754	X1.8
14	1809	1818	1832	M1.3	19	0635	0701	0718	M3.0
14	2009	2016	2059	M1.3	19	1329	1351	1416	M2.1

including micro to major flares occurred in NOAA active region 10656 (S13 W36) between 08 and 18 August 2004 (Jain *et al.* 2007). An X1.0 flare exploded near the disk center on 13 August 2004, and X1.8 on 18. In addition, there were 24 M-class flares in this region during its disk passage (Table 1). The vector magnetic fields of this region were observed at HSOS and BBSO. Based on these vector magnetograms, and SOHO/MDI observations, we will study the daily evolution of vector magnetic fields and its association to the occurrence of flares in this active region.

2. Observations and data reductions

The vector magnetic field data used in this paper were obtained by the Solar Magnetic Field Telescope (SMFT) (Ai & Hu 1986; Deng *et al.* 1997) at HSOS and the digital magnetograph system (DMG) at BBSO. With the SMFT, photospheric vector magnetic field is measured with a Zeeman line FeI 5324.191Å. The field of view and the spatial resolution of the data are about $5.23' \times 3.63'$ and 2–$3''$ respectively. The noise of longitudinal and transverse fields are about 20G and 200G respectively. The CaI 6103 Å was selected in DMG (Cacciani *et al.* 1990), and in this system the spatial resolution and sensitivity can be markedly improved to $1''$ and 0.5 G (Spirock *et al.* 2001). The registration hardware is 512×512, 12-bit CCD that allows 30 frames per second rate. White light and longitudinal magnetic images of MDI/SOHO (Scherrer *et al.* 1995) are also used in our analyses. The data reductions follow the methods introduced by Wang *et al.* (1996) and Deng *et al.* (2001). Here we only give the summaries in our data reductions. We use the linear force-free approximation to determine the 180° ambiguity. As to the inconsistency between the sensitivities of transverse and longitudinal magnetogram, we will not correct the projection effects. This is reasonable because this active region is quite close to solar disk center during our interested period.

3. The evolution of magnetic morphology

Figure 1 shows the evolution of sunspots and longitudinal magnetic fields in AR 10656, observed by MDI/SOHO. From 07 to 09, the region seems to be a simple bipolar

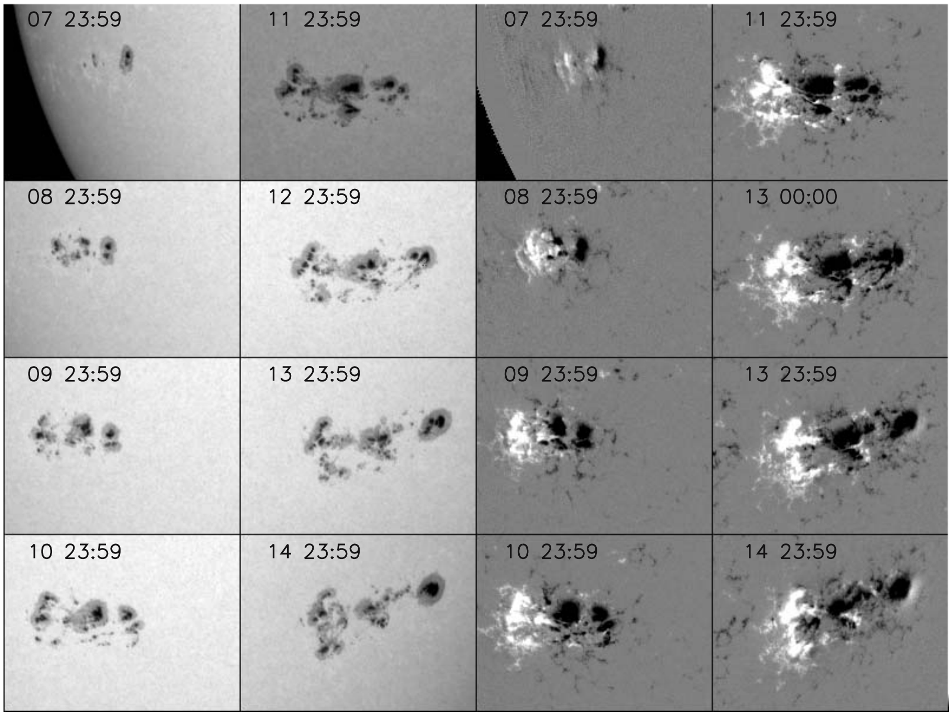

Figure 1. Daily evolution of sunspots (left panel) and longitudinal magnetic field (right panel) in NOAA AR 10656 from 07 to 14 August 2004.

sunspot. After that, new flux emerges between the leading and following sunspot. These emerging fluxes are found to increase in their intensity and area, move towards opposite polarity and finally cancel the flux. This region matches $\beta\tau\delta$ classification. Figure 2 shows the change of tilt angle, which is defined as the angle between magnetic axis of the active region and the local latitude line (Tian *et al.* 1999). There is about 20 degrees of counter clockwise rotation. As this active region is in south hemisphere, it matches Joy's Law. All these phenomena indicate new and rapid flux emergence, and as a result, frequent flare activities (as shown in Table 1).

Guo *et al.* (2006) suggested that the effective magnetic distance could quantify the magnetic configuration of active regions. After studying 43 active regions, they concluded that when the value of effective distance is more than 1, the active region is more complex and active, and when the value is less than 1, the active region is relatively simple and not active. The effective magnetic distance of AR 10656 is 1.03, which means that this region is quite active, but not superactive. Some major flares may happen, but the possibility of massive X-class flares is low.

4. Evolution of the nonpotentiality from 09 to 14 August 2004

Figure 3 gives the daily evolution of longitudinal current distribution. One can see that the current system is a bit stable and changed gradually and slowly during the six days. Some obvious changes occurred in part "A" and "B". Current system "A"

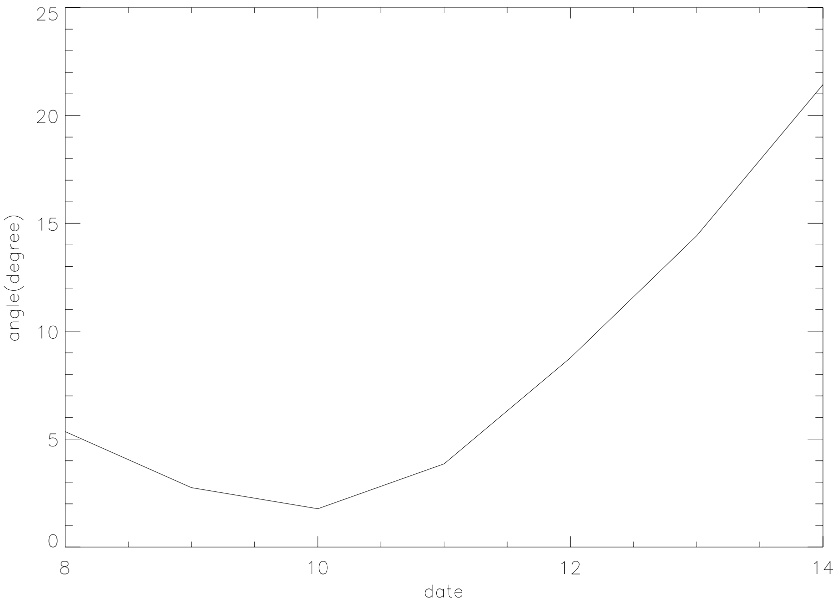

Figure 2. The change of tilt angle deduced from MDI/SOHO magnetogram.

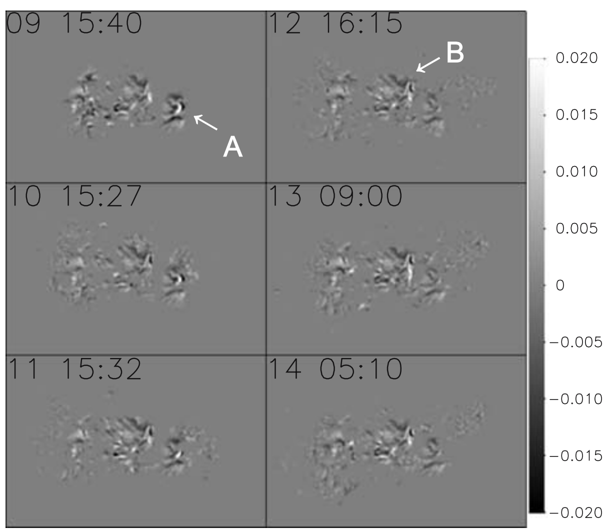

Figure 3. Daily evolution of longitudinal current from 09 to 14 August. The distribution of longitudinal current is scaled between $\pm 0.02 Am^{-2}$. Data from 09 to 12 were collected with DMG/BBSO, the others by SMFT/HSOS.

gradually decreased from 09 to 11, and almost disrupted after 11. System "B" gradually increased, and reached maximum around August 13, and then tended to decrease. The current helicity exhibited a similar evolution pattern. There may be some relationships between these parts and the major flares. This will be discussed in another paper.

We also study the evolution of shear angle and free magnetic energy. Basically, the conclusion is similar with that from daily evolution view – no sudden change happened.

5. Conclusions and discussion

Based on the vector magnetograms observed at HSOS and BBSO, we have studied the evolution of magnetic nonpotentiality of AR 10656. This region has frequent new emerging flux and belongs to $\beta\tau\delta$ classification, and recurrent solar flare activity including micro to major flares occurred. Its effective magnetic distance is about 1.03, which implies that this region is active, but not super active, i.e., low possibility of X-class flares. Deng *et al.* (2001) found that before an X5.7 flare in AR 9077 there were sudden changes of vertical current, helicity, and free magnetic energy in one flare foot point (Box "B" in Deng's reference). Liu *et al.* (2007) studied the nonpotential evolutions of 11 super-active regions, and found that for most super flare activities, obvious changes in nonpotentialities, such as current, helicity, shear, and free magnetic energy, can be found. Compared with these super solar flares, such as "Bastille" (Deng *et al.* 2001) and "Halloween" (Liu *et al.* 2007) events, AR 10656 has a relatively gradual daily evolution of magnetic nonpotentiality. We suggest that the magnetic topological structure is complex, but there is no heavy destruction of the magnetic morphology. Thus, the process of energy transportation and release from lower atmosphere to chromosphere and corona is relatively gradual. These may result in the recurrent flare activity of AR 10656, and low possibility of X-class flares.

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