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Vertical current and flare sites in an active region in 1989 October

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Abstract. We study the configuration of the vector magnetic field in a δ-active region in October 1989. The distribution of the foot points of the electric current loops can be confirmed by the photospheric vertical current, which is inferred by the observational photospheric vector magnetograms resolved 180°-ambiguity of the transverse components. The distribution of the photospheric electric current can be separated by several kinds of simple structures in the active region. The formation of new electric current in the photosphere is caused by the emergence of a magnetic flux or is related with the magnetic shear and squeeze. In the electric current picture, the flares are probably caused by the interaction of different electric current loops.

Key words: Sun: flares – Sun: magnetic fields

1. Introduction

The study of the vector magnetic field and vertical current in solar active regions is a major topic in solar physics. Measurements of the vector magnetic field configurations in active regions have been made for a long time. Early work on the electrical current of active regions inferred by the observational transverse magnetic field was made at the Crimean Astrophysical Observatory (Moreton and Severny, 1968). In recent years, some authors have investigated in detail the photospheric vector magnetic field and calculated the vertical currents in active regions (Krall et al., 1982; Hagyard et al., 1984; Ding et al., 1983; Lin and Gaizauskas, 1987; Abramenko et al., 1991; Canfield et al., 1991; Chen and Zhang, 1991; Zhang et al., 1993; Demoulin et al., 1994; van Driel-Gesztelyi et al., 1994). The relationship between the flare kernels and electrical currents has been analyzed by authors who obtained various results. The formation of the electrical current is related with the emergence of magnetic fluxes of opposite polarity (Zhang, 1995). The questions are: how is the basic configuration of the electric current and what is the relationship with solar flares in active regions?

In this paper, we discuss the relationship between the evolution of the sites of the Hβ flares and the peaks of the vertical current, and also pay attention to the possible configuration of the electric current in active regions.

2. Magnetic shear

The magnetic shear is an important parameter to the non-potential magnetic field. The shear angle normally is defined by the inclination of the transverse component of the photospheric magnetic field relative to the magnetic neutral line of the longitudinal magnetic field. The powerful flares often occur near the strongly magnetic sheared regions. Active Region 5747 (S26, L213) was a flare-producing region which appeared at the solar surface in October, 1989. Fig. 1 shows an ambiguity-resolved vector magnetogram in the image plane (S26, E05) at 02:15 UT on October 21, 1989, which was observed at Huairou Solar Observing Station of Beijing Astronomical Observatory. The evolution of the magnetic field in this active region was discussed by Zhang (1993) and Wang et al. (1994). The magnetic main poles (N_2 and S_2) of opposite polarity are close to each other. The transverse components of the magnetic field between the main poles were almost parallel to the magnetic neutral line. If we compare with the connection of the photospheric transverse magnetic field, we can infer that the magnetic lines of force probably did not connect the two poles of opposite polarity near the magnetic neutral line in the lower atmosphere. The transverse components of the photospheric vector magnetic field connected the main poles N_1 and S_1. This means that some magnetic lines of force linked the two main poles. Accompanying the motion of the main pole S_1 of positive polarity toward the north direction at the average speed of about 0.2 km/s and the continuous emergence of new magnetic flux from Oct. 17 to 21, 1989, the transverse components of the magnetic field at the main pole S_1 showed a clockwise twisting pattern. From a series of daily vector magnetograms, we find that the transverse component of the field tended gradually to be parallel to the curved $B_{\|}$=0 line between the magnetic main poles N_1 and S_1, N_2 and S_2 in the active region.

3. Electrical current and flares

3.1. Photospheric vertical electrical current

As the distribution of the vertical electrical current density in active region 5747 is overlapped on the vector magnetogram (Fig. 1), we find that the electrical current basically flows out from the main poles of negative polarity and returns to the mag-

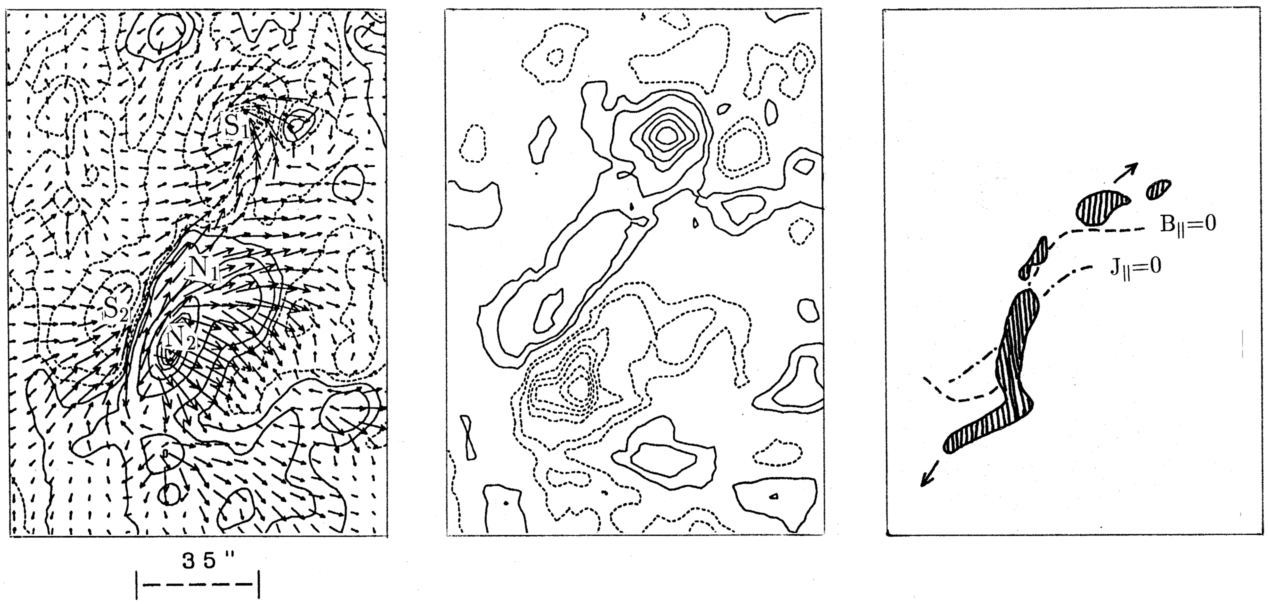

Fig. 1. Ambiguity-resolved vector magnetogram (left) in the image plane at 02:15 UT on October 21, 1989 in active region (NOAA 5747). The contour indicates the longitudinal magnetic field distribution, ±20, 160, 640, 1280, 1920, 2240, 2560, 2880 Gauss. Corresponding vertical current density map (middle), ±0.2, 0.4, 0.8, 1.0, 1.4 1.6, 2.0 ($\times 10^{-2}$)A m^{-2}. The contour indicates the vertical electric current distribution. The relationship between the magnetic neutral line and the inversion line of vertical electric current (right). The shadow areas make a flare at 0152 UT and the arrows indicate their extending directions.

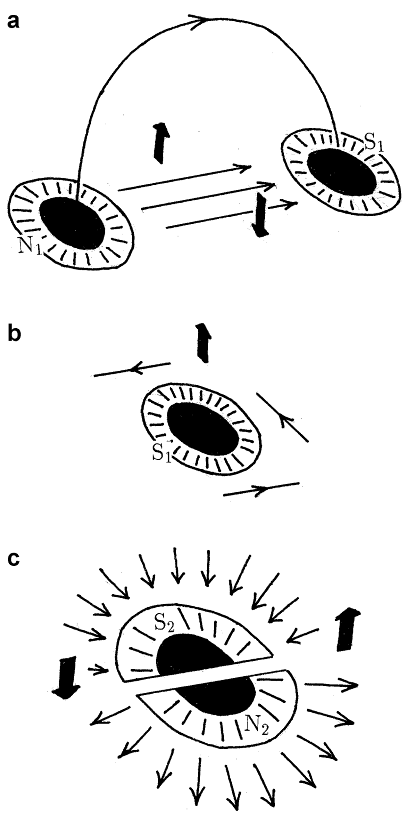

Fig. 2. a A sketch of the relationship between the photospheric vertical electric current and bipolar magnetic region (top). **b** The enhancement of the photospheric electric current of the magnetic main pole is caused by the emergence of the surrounding new magnetic flux (middle). **c** The configuration of the photospheric electric current in the compact bipolar magnetic structure (bottom). The thick arrows mark the directions of the vertical currents and the thin arrows mark that of the magnetic field.

netic main poles of positive polarity, even if the magnetic neutral line does not coincide with the inversion line of the vertical current completely in the active region. If we compare daily magnetograms with the corresponding vertical currents in this active region, we find that the magnetic pole S_1 moves toward the North and the peak of the vertical current moves also in the same way as the magnetic pole (Wang, Xu and Zhang, 1994). This means that the new magnetic flux emerges near the magnetic neutral line with the development of the magnetic shear.

The sites of the Hβ flare at 0152UT on October 21, 1989 occurred near the magnetic neutral line and extended along the transverse magnetic field in Fig. 1c. If we compare with the distribution of the vertical current, we find that some sites of the flare are not located at the peaks of the vertical current (Chan and Zhang, 1992; Zhang and Wang, 1994; Zhang, 1995).

3.2. Basic form of electric current

The observational magnetic field in solar active regions can be separated into two parts $\mathbf{B} = \mathbf{B}_p + \mathbf{B}_n$, where $\mathbf{B}_p$ is the potential magnetic field and $\mathbf{B}_n$ is the non-potential magnetic field. The latter connects with the electric current in the solar atmosphere. If we consider the electric current from the photospheric transverse magnetic field by

$$\mathbf{J}_z = \frac{1}{\mu_0}(\nabla \times \mathbf{B})_z, \tag{1}$$

this only gives us information on the vertical components of the photospheric electric current. The electric current probably includes two characteristic components. One is parallel to the magnetic field and the other is encircled by the magnetic field.

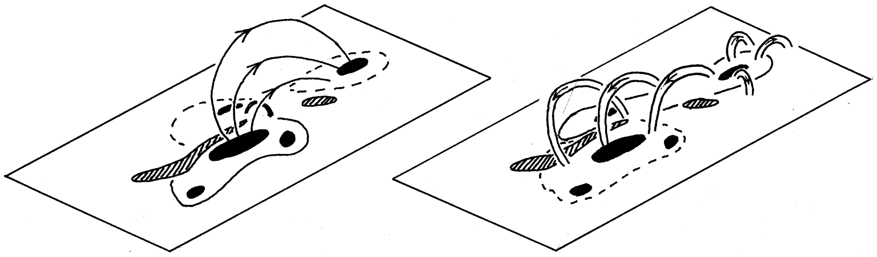

Fig. 3. A possible configuration of the magnetic field and electric current in the active region 5747. The arrows in the left map mark the magnetic lines of force and the arrows in the right map mark the electric current loops in the active region. The shadow areas mark the Hβ flare.

The transverse magnetic field, reflected the photospheric vertical current, normally shows the character of the curvature or gradient in the solar surface. In the special case of the force free magnetic field, the magnetic lines of force are almost parallel to the electrical current, e.g. the magnetic inversion line coincides with the inversion line of the electric current in the solar surface. In some areas of the active regions, the magnetic fields deviated from the force free can be detected by comparing the photospheric magnetograms and the vertical current maps. As the magnetic lines of force do not connect the closed photospheric magnetic poles of opposite polarity at the lower atmosphere, then the electrical currents are not completely parallel to the magnetic lines of force. The electrical current probably flows near the interface of the magnetic poles of opposite polarity. This is probably the reason why the magnetic inversion line crosses the inversion line of the vertical current between the magnetic main poles N_2 and S_2 of opposite polarity in active region 5747 in Fig. 1.

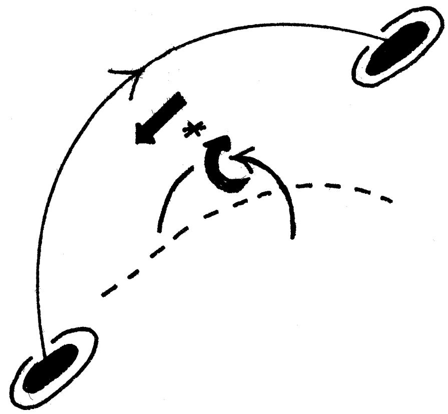

Fig. 4. A sketch of the possible configuration of the electric current near the newly emerging flux region of opposite polarity. The thick arrows mark the electric current and the thin arrows mark the magnetic lines of force. The dash line marks the magnetic neutral line and the star marks the triggering place of the flare.

3.3. Combination of electric current

In the discription of electrical currents, the formation of the new electrical current at the solar surface accompanies the development of the shear of the magnetic field (Zhang, 1995). We find that the photospheric vertical electrical current in active region 5747 consists of three major configurations. The first kind of electrical current accompanies the emergence of the new magnetic flux between the magnetic main poles N_1 and S_1 of opposite polarity in Fig. 2a, where the inversion line of the electric current is almost parallel to the connected line of the magnetic main poles of opposite polarity in the photosphere. The electrical current loop probably bridges over the sheared transverse components of the magnetic field in the active region in the lower solar atmosphere. The second kind of electrical current forms near the magnetic main pole S_1. The electric current loop is related with the emergence of small-scale magnetic bipoles around the magnetic main pole S_1, where the transverse component of the field rotates clockwise around the magnetic main pole in Fig. 2b. In the case of this active region, the peak of the electric current is almost located near that of the magnetic main pole. The electrical current flows upward from the magnetic main pole and returns to the surrounding areas. The emergence of small-scale new magnetic fluxes of opposite polarity around the magnetic main poles causes the twist of the photospheric transverse magnetic field and also the increase of the vertical current in the active regions. This electric current is almost parallel to the photospheric longitudinal magnetic field of the main pole. The third kind of electric current loop is connected with the compact magnetic bipole (N_2 and S_2) of opposite polarity. The electrical current mainly flows up and down near the magnetic neutral line between the magnetic main poles N_2 and S_2 as demonstrated in Fig. 2c, where it is shown that the inversion line of the vertical current crosses the magnetic inversion line. The first and second cases obviously occur with the emergence of the new magnetic flux as demonstrated by Zhang (1995). The third case reflects the local electric current formed in or near the interface between the oppositely directed magnetic fields.

3.4. Electrical current and flares

The relationship between the configuration of the magnetic field and flare sites was analysed by several authors. In the picture of the magnetic field, the flare is caused by the interaction of different systems of the magnetic lines of force. According to the formula, the electrical current $\mathbf{J} = \frac{1}{\mu_0} \nabla \times \mathbf{B}$, the sheared and curved magnetic field is related with the electric current. A possible distribution of the electrical current loops in this active region is shown in Fig. 3. The Hα, Hβ flares usually occur near the magnetic structures of opposite polarity in active regions. The sites of flares occur near the magnetic inversion line and extend in the same direction as the transverse magnetic field in Fig. 1.

In the upper solar atmosphere, the approximation of the force free field probably is correct, where the electrical current vector is almost parallel to the magnetic field. The Hβ flare sites extend along the photospheric magnetic field during the flares, which means that the accelerated charged particles move along the magnetic lines of force. These accelerated charged particles should also move along the electric current. As a conclusion we propose the following scheme in Fig. 4. The direction of newly emerging electric current is not parallel to the large-scale electric current loops. The large-scale electric current almost connects both the magnetic main poles N_1 and S_1 of opposite polarity in the higher atmosphere. The flare probably would be caused by the interaction of the different electric current loops of opposite directions. Some sites of flares are located near the boundaries of the electrical current. This indicates that the sites of flares in general have no immediate relationship with the maxima of electrical current, even if some sites of powerful flares occur near the maximum areas.

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