Evolution of Magnetic Field and Flow in NOAA 10930 Obtained by Hinode Observations

T. Magara, Y. Katsukawa, K. Ichimoto, and S. Tsuneta
National Astronomical Observatory of Japan, 2-21-1, Osawa, Mitaka, Tokyo, 181-8588 Japan

T. Yokoyama
Tokyo University, Hongo, Bunkyo-ku, Tokyo, 113-0033 Japan

S. Nagata
Kyoto University, Kurabashira, Kamitakara-cho, City of Takayama, Gifu, 506-1314 Japan

S. Inoue
Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601 Japan

Abstract. We here present an initial result of investigations into the evolution of NOAA 10930 obtained by the Solar Optical Telescope on board Hinode. The fine-scale G-band images associated with three components of the magnetic field provide useful information on the characteristics of this active region. We derived three phases characterizing the evolution of magnetic field toward producing an X-class flare. We also study the nature of a rapid flow found in this active region by investigating the configuration of the magnetic field and flow.

1. Introduction

Recent developments in observations and theoretical modeling enables us to provide useful information to predict the possible behaviour of solar plasma by combining these two techniques. This is important for space weather research investigating the effect of solar phenomena on the Earth. In order to develop a model for space weather we need to incorporate the observed properties of solar phenomena into the model. As an important step toward this goal, we have derived key features of an active region from observations. In this short paper we report a result of using Hinode observations of NOAA 10930 to investigate the evolution of magnetic field and flow in this region.

2. Results

Figure 1 shows a G-band image of NOAA 10930 obtained by the Solar Optical Telescope (SOT) on board Hinode (Ichimoto et al. 2007; Katsukawa et al. 2007; Lites et al. 2007; Okamoto et al. 2007; Shimizu et al. 2007). The image is transformed into disk-centre coordinates, and it is overlaid with the contours of the normal component of magnetic field ($B_z$) and with arrows representing...
the transverse component of magnetic field \((B_x, B_y)\). These components were obtained at the photospheric level by using a Milne-Eddington model. The (light blue and red: see online version) contours show the positive and negative values of \(B_z\), and the arrows indicate the strength of transverse magnetic field (in colour online). There is a region of strong transverse magnetic field around \((x, y) = (0, -10)\), where a couple of penumbrae are sticking into the umbra. These penumbrae are outlined by the contour of \(B_z\), meaning that the vertical field is weak in this region. This naturally explains that the penumbrae basically have horizontal structure with strong horizontal field but weak vertical field.

![Figure 1.](image)

**Figure 1.** G-band image of NOAA 10930 observed by the SOT on board *Hinode*. The (light blue and red: online version) contours represent positive and negative values of vertical magnetic flux, while the arrows show the transverse component of magnetic field.

The left panel of Figure 2 shows the temporal development of the positive and negative polarity regions (sunspots) in fixed coordinates at the peak flux location of the negative spot. In this panel the solid and broken contours show the level of \(B_z = 1500\) G and \(-1200\) G, and their shading indicates the observing times. From this panel, it is found that the negative spot almost maintained its shape throughout this observing period, while the positive spot moved from right to left with some additional motions such as rotation, elongation, and distortion. We can also notice that another small spot with positive polarity
moved downward at the top right corner, indicating that the positive polarity regions globally rotated around the negative polarity region in the clockwise direction. This matches the left-handedness of the transverse field observed near the centre of the negative spot (see Figure 1). The characteristics of sunspot evolution are further explained in an evolution diagram shown in the right panel of Figure 2. During the early phase, the positive spot is transported at about 50 m/s, and then it rapidly changed shape by elongation and rotation. Finally the positive spot almost stopped, but was subject to strong distortion. An X-class flare occurred during this late phase.

Figure 2. The left panel shows the evolution of the positive (solid contours) and negative (broken contours) spots in fixed coordinates at the peak flux location of the negative spot. Each observing time is shown by a different shade. The right panel displays the temporal development of signed magnetic flux, associated with the three phases characterizing the motion of the positive spot. These three phases are represented by horizontal bars with different shades (online: blue is early, green and red are intermediate and late phases). The time when an X-class flare occurred is also indicated in this panel.

Figure 3 shows the close-up of a rapid flow region presented in Figure 1. In the top-left panel the arrows and contours overlying the G-band image represent transverse and vertical components of magnetic field. The top-right panel shows the same G-band image overlaid with the arrows representing the velocity field obtained from a local correlation tracking method (Magara & Kitai 1999). A negative polarity is found to be sited at the root of the flow (top-left panel). The bottom panel illustrates a possible configuration of magnetic field and flow, in which the flow originates from the region of weak magnetic field by means of siphon mechanism.

3. Discussion

The characteristics of magnetic field and flow presented above are important when we try to make a model to study mechanisms for activity in NOAA 10930. It is now widely recognized that magnetic configuration is an important factor controlling activity observed on the Sun, and the transverse component of magnetic field plays a key role in determining magnetic configuration. In this re-
Figure 3. The top-left panel shows the distribution of vertical magnetic flux (online: contours: blue is positive and red is negative) and transverse magnetic field (arrows) in a local region of NOAA 10930 presented in Figure 1. The top-right panel shows a velocity map while in the bottom panel is presented a possible configuration of magnetic field and flow.

spect, the so-called 180° ambiguity problem makes it difficult to obtain the right configuration of magnetic field, so careful investigations are needed. Following the evolution of magnetic field is one of the ways to find the right configuration, while using the information on flow is also helpful in finding a possible magnetic configuration, as demonstrated above. We will continue to focus on this topic and try to understand how solar phenomena proceed in real circumstances, which is important for space weather.

References