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INVESTIGATION INTO THE SUBSURFACE MAGNETIC STRUCTURE IN AN EMERGING FLUX REGION ON THE SUN BASED ON A COMPARISON BETWEEN *HINODE*'S OBSERVATIONS AND NUMERICAL SIMULATIONS

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ABSTRACT

In this Letter we report a result of investigating the structure of subsurface magnetic field in an emerging flux region on the Sun, which was observed by *Hinode*. The data obtained by *Hinode* captured well the structure end evolution of the emerging flux region, showing the appearance of small magnetic features that lead to a well-developed bipolar structure. We derived several statistical quantities characterizing the spatial distribution of surface magnetic field. These quantities were then used to investigate the structure of invisible subsurface magnetic field, such as the twist of subsurface field lines, when we compared the observations with numerical simulations performed for the emergence of subsurface magnetic field into the solar atmosphere. The result suggests a possible way of investigating the structure of solar-interior magnetic field by using observational information on solar-surface magnetic field.

Subject headings: MHD — Sun: magnetic fields — Sun: photosphere

1. INTRODUCTION

The solar photosphere is a special region in that it gives a plentiful amount of information on active phenomena on the Sun via radiation. By observing this region, we know the behavior of solar plasma on the surface, which is driven by invisible subsurface processes. It is believed that the subsurface region is dominated by the convective motions of plasma that accompanies magnetic field, which have been known as magnetoconvections. Using good observations of surface phenomena is a key to understanding those invisible subsurface processes that play an important role in producing the activity observed on the Sun.

Here we mentioned "good observations," meaning that the observations satisfy the following requirements: to obtain clear images of dynamic phenomena and to provide these images as a continuous time series of data, keeping the quality of individual images. These two requirements are important for understanding the structure and evolution of the dynamic phenomena. Recently, an international collaboration successfully launched the solar observational satellite *Hinode* to achieve these important but difficult requirements (Kosugi et al. 2007). The satellite has so far provided fruitful information on various solar phenomena, using its onboard advanced telescopes (De Pontieu et al. 2007; Ichimoto et al. 2007; Imada et al. 2007; Kamio et al. 2007; Katsukawa et al. 2007; Kotoku et al. 2007; Kubo et al. 2007; Lites et al. 2007; Okamoto et al. 2007, 2008; Nagashima et al. 2007; Shibata et al. 2007; Sakao et al. 2007; Nagata et al. 2008; Berger et al. 2008; Brown et al. 2008; Hara et al. 2008; Ishikawa et al. 2008; Kano et al. 2008; Morinaga et al. 2008). One of the pieces of data obtained by this satellite revealed the development of an emerging flux region with high spatial and temporal resolutions, showing the appearance of small magnetic features on the surface that lead to a well-developed bipolar structure. Since emerging flux regions are the place where prominent activity comes out, the nature of emerging flux regions has been an important research target in solar physics (Zwaan 1985; Kurokawa 1987; Tanaka 1991; Lites et al. 1995; Leka et al. 1996; Schmieder et al. 1996; Ishii et al. 1998; Wang et al. 2004; Zhang et al. 2007; Su et al. 2007; Magara & Tsuneta 2008).

In this Letter we report a result of investigating the structure of invisible subsurface magnetic field in the emerging flux region observed by *Hinode*. We found that fragmented magnetic features appeared in the emerging flux region, which were formed by the emergence of the subsurface field that has been subjected to magnetoconvections. These processes cannot be detected directly via radiation (local seismology can provide useful information on subsurface processes; see Sekii et al. 2007). Our strategy is to derive several statistical quantities characterizing the spatial distribution of the surface field, and use them to find a relationship between invisible subsurface magnetic structure and visible surface magnetic structure. For this purpose, we compared the observations with the magnetohydrodynamic (MHD) simulations reported in Magara (2006), which have reproduced the emergence of the subsurface field into the solar atmosphere. The result suggests a possible way of investigating the structure of solar-interior magnetic field by using observational information on solar-surface magnetic field.

2. OBSERVATIONS

We used a data set obtained by *Hinode*'s Solar Optical Telescope (SOT; Tsuneta et al. 2008; Ichimoto et al. 2008; T. D. Tarbell et al. 2008, in preparation; Suematsu et al. 2008; Shimizu et al. 2008), which displayed the structure and evolution of an emerging flux region during 2006 December 1–2. The Fe I (6302 Å) Stokes *V* images were taken during that period by the Narrowband Filter Imager (NFI) of the SOT. Figure 1 shows the observing time and area of these images. The images cover the area of the emerging flux region, which is about $150'' \times 150''$ with the spatial resolution of $0.16''$ in both horizontal (east to west) and vertical (north to south) directions.

The emerging flux region appeared in the southern hemisphere around 16:00 UT, 2006 December 1, and its location was about $50''$ east and $170''$ south from the disk center (DC). It then moved westward, reaching the position of about $230''$ west and $170''$ south from the DC at 20:58 UT, 2006 December 2. At this time, the emerging flux region showed bipolar structure, while a lot of fragmented magnetic features appeared and disappeared during the evolution, characterizing the property of this emerging flux region. We particularly focused on a transient phase in which the main bipole and many fragmented