Signatures of Moving Magnetic Features in and above the Photosphere

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Abstract. Hinode/SOT observations of NOAA AR 10933 from 2007 Jan 4 16:14 UT - Jan 6 22:20 UT are used to study MMFs (moving magnetic features) in the periphery of the region’s large sunspot and the surrounding moat. The data consist of a nearly continuous set of Fe 6302 Å Stokes $V$ images with sets of G band and Ca $H$ filtergrams at various cadences, FOV’s, and resolutions plus some SpectroPolarimeter (SP) scans. We also used TRACE images in 171 Å to follow any possible signatures at higher temperatures. We applied automatic object recognition and tracking to the MMFs as seen in the Fe 6302 Å Stokes $V$ images. An SP scan was used to determine the line profiles for several paths. Reliable inversions have not yet been done, but we find a few locations of possible supersonic downflows from the Stokes $IQUV$ line profiles. The population of MMFs on the East side of the sunspot is much higher than on the opposite side, mostly involving a large number of mixed polarity MMFs. Consequently, the chromosphere shows strongly enhanced brightenings with a clear pattern: enhanced brightenings in Ca $H$ outline the locations where opposite polarity MMFs meet. This activity does not prevent formation of active low lying ”closed” loops at coronal temperatures seen in the TRACE 171 Å line. The other side, with fewer MMFs, shows a pattern that we found earlier: regions with an MMF deficiency show long living ”open” coronal loops.

This work was supported by NASA contract NNM07AA01C.

1. Introduction

Moving Magnetic Features (MMFs) have been studied for over three decades, first on ground based instruments and later on space based observations. Sheeley, Jr. (1969) was the first to study these small magnetic features with typical diameters of 1 Mm that emerge in the moat region around sunspots and move toward the outer boundary of the moat with speeds of $\approx 1$ km s$^{-1}$. The term moving magnetic feature was introduced by Harvey & Harvey (1973). Brickhouse & Labonte (1988) studied MMFs and mass and energy flow near sunspots, and found that the moat radius is roughly twice the penumbral radius. Shine & Title (2001) describe three types of MMFs: Bipolar; Unipolar with the spot’s polarity; or Unipolar with the opposite polarity.

Hagenaar & Shine (2005) developed a method to automatically recognize unipolar MMFs on SOHO/MDI magnetograms, and find that the tracks of individual MMFs correlate with the direction of local plasma flows and sometimes display a spoke like pattern around the sunspots. Other recent work on MMFs includes Sainz Dalda & Martinez Pillet (2005), Ryutova et al. (2007), and Kubo et al. (2008).

Because of their small size many questions about MMFs remain unanswered. We apply an improved version of the code developed by Hagenaar & Shine (2005) and...
apply it to Hinode/SOT V images. We have matched the MMF tracks to spectra taken with the Spectro-Polarimeter on board SOT and compared with TRACE coronal data in 171Å.

2. Data

2×2 Binned SOT observations of the large spot in AR 10933 were taken in G-band, Ca II H, and Fe 6302 Å. All data are processed and aligned with the G-band. In order to calibrate the Fe 6302 Å filtergrams, a plage area is directly compared with a SOHO/MDI magnetogram, which has a good approximation of the correct field strength.

Slit positions in the SP map are taken at different times. The FGIV magnetogram closest to the time of the central slit position was taken for alignment. SP pixels have x-sizes of 0.149″ and y-sizes of 0.160″. Taking this into account, the scan was aligned with the FGIV magnetogram.

3. Method

We developed an algorithm to automatically recognize and follow unipolar MMFs on the series of FGIV magnetograms. The method is applied to the area around the large sunspot, and has three steps:

Object recognition

We recognize magnetic objects following the method developed by Hagenaar et al. (1999). This method was originally developed for quiet sun, and here it is applied to a sunspot region.

Tracking

Overlapping objects of the same polarity in subsequent frames are assumed to be the same feature. If objects fragment or merge, the object with the largest overlap in flux
Signatures of MMFs

Figure 2. Left: SP scan with paths in blue and green. The field of view shown is 111″ × 111″. Right: line profiles in $IQUV$ at one point in path 6.

is identified with the parent object; the others are given new identities. The properties of each object as a function of time are kept, such as their paths, area, and flux. Object recognitions and tracking are extensively discussed by DeForest et al. (2007) and by Lamb et al. (2008).

Selection

MMFs are selected out of the large population of objects by the following requirements: a) objects have to be recognized for at least 40 frames ≃ 20 min; b) objects inside the umbra may be associated with umbral brightenings; features first need to be recognized outside the umbra but inside the penumbra; and c) in order to filter out stationary objects, an object has to move at least 2 Mm toward the outer boundary of the moat.

4. Results and Discussion

We detect $3 \times 10^3$ objects with the sunspot polarity and $4.5 \times 10^3$ opposite polarity objects. The left hand panel of Figure 1 shows some paths of selected features around the sunspot. The flux distribution function is shown in the right hand panel. Objects near the sunspot are selected that move outward in the penumbra: 154 of these have the sunspot polarity and 98 the opposite polarity. This corresponds to a frequency of 4.7 MMFs hr$^{-1}$, which is on the low side of the findings of 4-24 MMFs hr$^{-1}$ by Hagenaar & Shine (2005), probably due to the lower cadence of the SOT data. The number is very small, resulting in a rather choppy histogram.

Corresponding time slices show that this method successfully finds unipolar MMFs, as shown in the two right panels of Fig. 3. Many time slices suggest bipolar magnetic flux concentrations and a method needs to be developed to find different opposite polarity objects that are somehow coupled. The features are also found in the higher-resolution 1x1 data when available, see Fig. 4.

Line profiles at a point in path 6 in the SP map in Fig. 2 are plotted in the right panel of Fig. 2, suggesting high, possibly supersonic, velocities. Reliable inversion of this scan is not possible; a sequence of fast partial scans might enable reliable inversions.

Locations of very intense MMF formation anti-correlate with the presence of large-scale coronal loops (Ryutova et al. 2007). Figure 5 illustrates this in a TRACE 171Å observation aligned with our map of MMF occurrences. Our method finds more
small scale moving magnetic features in mixed polarity regions. The moat boundary is only clear on one side of the spot; on the opposite side little field is visible.

A better understanding of MMFs can be achieved by studying sunspot simulations or higher resolution observations.

References

Harvey, K., & Harvey, J. 1973, Solar Phys., 28, 61