THE SIGNATURE OF MOVING MAGNETIC FEATURE IN THE SOLAR ATMOSPHERE

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ABSTRACT

Moving Magnetic Features (MMFs) are small magnetic features moving in a moat, which is a ring of weak line-of-sight magnetic fields surrounding a sunspot. Despite the extensive study on the characteristics of MMFs since their discovery more than 35 years ago, their effect on the high atmosphere has never been investigated. In this paper, we would like to show for the first time the detected upper-atmospheric oscillations and flows associated with a MMF. The oscillations may be excited inside the MMF and propagated to the atmosphere along the magnetic field tubes of the MMF. The results indicate that MMF, despite being small, is capable of influencing the dynamic behaviors in the atmosphere at least up to the transition region.

Key words: Sun: granulation, magnetic fields, oscillations, transition region.

1. OBSERVATION AND DATA CALIBRATION

The target of our observation is the active region AR0554. We utilized the time series from the Normal Incidence Spectrometer (NIS) of CDS, the images from MDI, TRACE, EIT, and the raster images from NIS/CDS. The time sequence corresponds to the dataset s2953600, which was a 95-min observation from 07:59 UT to 09:35 UT on 2004 Feb. 13. During the observation, the pointing of the detector was fixed in space while the Sun rotated under the field of view (FOV). The exposure time is 30 s, and the cadence is approximately 37 s. The two NIS/CDS raster images were taken at 07:37 – 07:59 UT and 14:24 – 14:46 UT, respectively. The available MDI magnetograms on 2004 Feb. 13 are from 06:00 UT to 08:30 UT and from 13:53 UT to 13:59 UT. The resolution of the magnetograms is ~2’. To see the dynamics at the photospheric level, we incorporated TRACE 1600 Å channel images taken at 08:30 UT and 13:40 UT. We also used EIT He 304 Å image taken at 07:19 UT for the features at the chromospheric level.

All the data were calibrated by respective calibration routines in SolarSoft. The NIS/CDS spectral lines at each pixel were fitted by a broadened-Gaussian profile to take into account the line broadening after the SoHO recovery in Oct. 1998. The line intensities and the corresponding errors were then computed accordingly. The noise and cosmic ray contamination in the TRACE images were reduced by a number of smoothing routines. The orientations of EIT and MDI images and NIS raster images were corrected for the effect of SoHO instruments turned 180° during our observation. After all the maps are calibrated, the coordinate difference between maps from a same instrument is corrected by the function coreg.map(), and the coordinate difference between maps from different instruments is determined from the cross correlation between the maps corresponding to same temperature. To be consistent, all the maps were shifted to 07:59 UT, which is the starting time of the NIS/CDS time-series observation, s2953600.

2. ANALYSIS PROCEDURE

The oscillations were extracted from the time-series signals by subtracting the trend of intensity variation (computed by a 25-pt running average) from the intensity variation. We also computed relative oscillations by dividing the oscillations by the trend. The properties of oscillations (e.g., periods, intensities) were determined by a wavelet transform implemented with the standard Morlet wavelet (see Torrence & Compo, 1998; O’Shea et al., 2001, for details). To determine whether or not the oscillations are above noise level, we implemented a randomization method (Limmell Nemec & Nemec, 1985) to estimate the significance level of the peaks in the wavelet spectrum. To examine the oscillations in different frequency ranges, we applied filters to extract the modes in the frequency range to be studied. The filters used in this study are P700 and P300, which respectively filter out oscillations with periods longer than 700 s and 300 s. The filtered signals are called P700-filtered and P300-filtered signals.

To infer the motion of material, we computed the relative
Doppler velocity \( (v_d) \) at each pixel \( i \) as follows:

\[
v_d = c \times (\lambda_i - \lambda_{av}) / \lambda_{av},
\]

where \( c \) is the speed of light, \( \lambda_i \) is the wavelength at the pixel, and \( \lambda_{av} \) is the average wavelength of the data set. Hence, \( v_d \) represents the motion of a point relative to the average motion of the area covered by the observation, and does not reflect the absolute velocity of the material at the location.

3. RESULTS

3.1. Signatures of the MMF at different temperatures

The sunspot in the active region AR0554 was surrounded by a moat, in which several small but very dynamic spots can be seen. Here, we will examine one of the spots, which crossed the FOV of our observation. The moat and the motion of this spot are shown in the series of magnetograms in Fig. 1.

The spot is a positive magnetic monopole moving away from the sunspot of negative polarity throughout 06:00–08:30 UT, which is the first time period covered by MDI magnetograms. The apparent moving speed of the spot is \( \approx 0.5 \) km s\(^{-1}\). During this period of time, a bright patch overlapping the location of the monopole was seen in NIS/CDS He \( \lambda 522.2 \) Å, O \( \lambda 629.7 \) Å raster images and the image of EIT He \( \lambda 304 \) Å (the region in the white square in Fig. 2). The spot disappeared from MDI magnetograms during the second time period, 13:53–13:59 UT. The overlapping bright patch mentioned above also disappeared in the later raster images taken at 14:24–14:46 UT. In addition, the path of the spot appears to overlap the boundary of a supergranulation cell (located at Solar \( X=-50'' \) to \(-25''\), Solar \( Y=0'' \) to \(20''\)) as seen in the TRACE 1600 Å channel image taken at 08:30 UT (cf. Fig. 3). A later TRACE 1600 Å channel image shows that this cell was broken by 13:40 UT (cf. the bottom panel in Fig. 3), when the monopole also disappeared from the magnetograms.

Such coincidence in time indicates a possible connection between the existence of the moving magnetic spot, of the supergranulation cell, and of the bright patches.
3.2. Detected oscillations above the MMF

We show in Fig. 4 the wavelet analysis results of a selected pixel (Solar Y ≈ 3°) to illustrate the common oscillation characteristics seen in the bright patch of NIS/CDS O V. The large “wiggle” seen in the top row (the unfiltered signal) between 35 and 55 min is likely due to the spatial, rather than temporal, intensity variation. The wavelet analysis results of P700-filtered and P300-filtered signals reveal that 5-min oscillations are the dominant mode both inside and outside of the MMF while significant, shorter-period oscillations only exist inside the MMF. The strongest oscillations in the P300-filtered signals are often of periods ≈ 3 – 4 min, which echoes the conclusion by Lin et al. (2005) that 3-min oscillations can exist outside of a sunspot in regions with strong magnetic fields. The results from NIS/CDS He i 522.2 Å and from O v 629.7 Å resemble each other. However, the intensity of He i signal is too weak to be reliable.

Figure 3. The TRACE 1600 Å channel image taken at 08:30 UT is shown in both top and middle panels. In the top panel, the contours are to illustrate the variation of the magnetograms between 06:59 and 08:30 UT, and the two vertical lines mark the FOV of the time-series observation. The path of the MMF is traced by the circular contours, as pointed out by the two “L” shapes. The path coincides the boundary of the supergranule cell enclosed in the square in the middle panel. The cell was broken by 13:40 UT as seen in the bottom TRACE image.

Figure 4. The top row is the de-trended NIS O v 629.7 Å time series along with the error bars. The following two sets of plots are the wavelet analysis of P700-filtered and P300-filtered relative intensity oscillations. In each set, the filtered relative oscillations and their wavelet spectrum are plotted in the upper and lower left panels, respectively; the information of the signal and its primary oscillations is shown in the upper right corner; and the global wavelet (i.e., the sum of the wavelet power over time at each oscillation period) is plotted in the lower right panel. The wavelet spectra are plotted in reversed colour; hence, darker colours correspond to higher power. The white contours enclose the periods of the oscillations that are above 95% significance level as determined by the randomization method, and the hashed lines mark the region where the edge effect becomes significant.
3.3. Detected signature of flows above the MMF

A velocity time-series signal is analogous to an intensity time-series signal except that the amplitude in the velocity signal represents the speed of motion. The relative Doppler velocity reflects the motion of the corresponding point relative to the average motion of the whole area covered by the time-series observation.

In Fig. 5, we plotted the relative Doppler velocities of O \textsc{v} 629.7 Å vs. time at several locations along the slit. The bright patch over the magnetic monopole is between 35 min and 60 min. We see that this 35–60 min region is relatively blue-shifted between 7″ and 0″ and gradually becomes weakly red-shifted above 7″ and below 0″. The Doppler velocities of He \textsc{i} 522.2 Å show the same pattern. This indicates that the bright patch seen in the transition region may be a result of an upflow from the moving magnetic monopole.

4. DISCUSSIONS AND SUMMARY

During our observation on Feb. 13th, 2004, we detected a positive magnetic monopole moving away from the sunspot. The path of the monopole followed the boundary of a supergranulation cell while the monopole itself is correlated in space and in time with a brightening seen in both chromosphere and transition region. The time-series signal at the location of the brightening is blue shifted relative the whole area. The wavelet spectra in Fig. 4 show that a dominant 5-min oscillation runs through the whole time series, both inside and outside of the monopole region. However, a spectrum of shorter-period oscillations are seen only inside the monopole. While the dominant 5-min oscillations may be due to the global p-mode oscillations, the multitude of shorter-period modes in the monopole may be excited by the disturbances in the magnetic fields of the MMF.

The detection of transition-region brightenings, blue shifts, and oscillations that are associated with the MMF indicates that there may be an energy-carrying flow/wave propagating upward from the photospheric MMF. The waves may contribute to the heating of the upper layers. Hence, the MMFs, despite being small in size, do influence the dynamics in the atmosphere and may contribute to the heating of the upper layers, at least up to the transition region.

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REFERENCES


Figure 5. The relative Doppler velocities of the NIS/CDS O \textsc{v} 629.7 Å time series at selected pixels along the slit. The Solar Y coordinate of each pixel is indicated above the corresponding plot. The blue shifts are represented by negative velocities.