The Magnetic Connectivity of Moss Regions

X.P. Zhao, J.T. Hoeksema, A.G. Kosovichev, R. Bush and P.H. Scherrer

W.W. Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA 94305

Received ______________________; accepted ______________________

ABSTRACT

A novel emission feature resembling moss was first identified in high resolution TRACE Fe IX/X 171 Å images by Berger et al. (1999). The moss emission is characterized by dynamic arcsecond-scale, bright elements surrounding dark inclusions in images of solar active regions. Patches of moss elements, called moss regions, have a scale of 20–30 Mm. Moss regions occur only above some of magnetic plages that underlie soft X-ray coronal loops. Using the potential field extrapolation of the photospheric magnetic field into the corona, we find that the magnetic field lines in moss-associated magnetic plages connect with adjacent plages with opposite polarity; however, all field lines from mossless plages end in surrounding "quiet regions". This result is consistent with the idea that the TRACE moss is the emission from the upper transition region due to heating of low-lying plasma by field-aligned thermal conduction from overlying hot plasma (Berger et al. 1999).

1. Introduction

"Moss" is a novel solar emission pattern first identified in high-resolution Fe IX/X 171 Å images of active regions observed by the Transition Region And Coronal Explorer (TRACE) on 30 May 1998. Moss is characterized by arcsecond-scale, bright elements surrounding dark inclusions; patches of elements appear spongy or moss-like. Moss elements are confined to layers approximately 1-3 Mm thick with base heights about 2-4 Mm above the photosphere (Berger et al. 1999). SOHO/CDS and TRACE observations show that the low-lying moss plasma has a temperature in the range 0.6-1.5 MK and an electron density of (2–5) $\times 10^9$ cm^{-3} at a temperature of 1.3 MK. The pressure of 0.7–1.7 dynes cm^{-2} is a few times higher than in coronal loops observed in the TRACE Fe IX/X 171 Å passband (Fletcher and De Pontieu 1999).

Moss elements move and vary in brightness on time scales of one minute or less. The motions are random displacements on spatial scales of 1000 km. "Moss regions" are patches of dynamic moss elements with a scale of 20-30 Mm. The shape and size of moss regions appear, however, relatively static and usually evolve slowly on time scales of 10-20 hours. Moss regions occur only above certain magnetic plages that underlie the 3–5 MK coronal loops seen in SXT images. Based on the one-to-one correspondence of 171 Å moss regions with soft X-ray bright regions, Berger et al (1999) suggest that the moss in the TRACE Fe IX/X 171 Å bandpass is the emission from the upper transition region due to heating of low-lying plasma by thermal conduction along coronal magnetic field lines from overlying hot plasma.

Similar low-lying emission with underlying H_α plage has previously been noted in the normal-incidence soft X-ray. By means of hydrostatic models of coronal arches, the emission pattern in X-ray images can be explained by the characteristics of high-pressure large-scale loops having a thin region of high surface brightness at the base (Peres et al. 1994). On the other hand, the low-lying unresolved bright regions in SOHO/EIT Fe IX/X 171 Å solar images have been explained as small-scale loops (Moses et al., 1997).

Only some magnetic plages are associated with moss regions. What are the unique characteristics of the moss-associated magnetic plages? Comparing the connectivity of moss-associated and mossless magnetic plages with their surrounding magnetic field may provide some clue for understanding the cause of moss regions.

In next section we display the simultaneous distribution of the photospheric magnetic field underlying and surrounding the 1998 May 30 moss regions. The computed magnetic field lines connected with moss-associated and with mossless magnetic plages are presented in section 3. The results are summarized in the last section and discussed.

2. Observations

The 1998 May 30 moss regions occurred over NOAA Active Region 8227. The top panel of Figure 1 shows the full disk magnetic image observed by SOHO/MDI at 1998:05:30_14:24:30 UT. The bright and dark areas denote positive and negative magnetic polarities. AR 8227 was the only active region in the northern hemisphere, though there were several positive and negative magnetic plage networks in the southern hemisphere. AR 8227 consists of a leading sunspot group and an extensive trailing plage network. The dotted lines outline the boundary of the TRACE 171 Å field of view (FOV) at 1998:05:30_14:41:01 UT, which covers AR 8227. The dashed box covers the area where the 1998 May 30 moss regions occurred. It is the same area as Figure 1 of Berger et al. (1999) and Fletcher & De Pontieu (1999). As shown in the bottom panel, the negative plage (A) and the positive plage (B) in the solid box are moss-associated and mossless, respectively.

The bottom panel shows the TRACE 171 Å FOV image observed at 1998:05:30_14:41:01

UT. It includes moss regions and coronal loops (see the colorful Figure 1 of Berger et al (1999) for details). The superimposed white and black contours are for magnetic strength of positive and negative polarities, respectively. The contour levels are ±50, ±200 and ±500 Gauss. Some magnetic plages are associated with moss regions, as shown by symbol A, and others associated with coronal loops, as shown by C. However, the magnetic plage B is nearly devoid of Fe IX/X 171 Å emission, even though the size and strength distributions for plage B are similar to the nearby plage A.

Yohkoh/SXT images obtained after 1998:05:30_06:53 UT show that all hot loops in the northern hemisphere occur above and around AR 8227. In next section, we compute the magnetic connectivity of the moss-associated and mossless magnetic plages with their surrounding magnetic features in the northern hemisphere.

3. The magnetic connectivity

Moss regions are spatially associated with certain magnetic plages in the photosphere, though the details of this association are complex on the small scale (Berger et al. 1999). If a loop that passes through a moss region is a flux tube complex, the field configuration in the complex can not be potential. However, there are loops that connect some moss-associated magnetic plages in the TRACE movies, and those loops appear nearly potential. Thus to the first approximation, the connectivity of moss-associated magnetic plages with other magnetic features and the shape of the loops may be approximated using potential field models (Sakurai 1982, Zhao and Hoeksema 1994).

Figure 2 displays magnetic field lines (green) computed using the potential field model (Sakurai 1982). Input to the model is the MDI magnetogram bordered by dotted lines (see top panel of Figure 1). The computation is carried out using spherical geometry based on

Sakurai's software package for the potential magnetic field model. The starting footpoint of each field line is selected based on the strength of the observed photospheric field being greater than 50 Gauss. To avoid the confusion of too many field lines in the figure, the total number of field lines is limited to 120. We overlay contours of the line-of-sight magnetic field strength in the photosphere (orange and blue for positive and negative polarities, respectively). The contour levels are $\pm10, \pm20, \pm50, \pm100, \pm200, \pm500, \pm1000$ Gauss. The thick white lines are contours of TRACE 171 Å intensity that show the areas of moss regions and coronal loops. Comparing Figure 2 with the bottom panel of Figure 1, it appears that coronal loops observed in 171 Å correspond to field lines that connect to distant magnetic plages of the opposite polarity, while moss regions correspond to the field lines that connect adjacent magnetic plages. The mossless plage B is associated with field lines that connect the plage with "quiet regions" with weaker field of the opposite polarity.

Figure 3 displays computed magnetic field lines (green) within the solid rectangle in Figure 1. Most of the field lines originating within the white outline over magnetic plage A (see also the bottom panel of Figure 1) are connected with the red plage having stronger field strength. The field lines in magnetic plage B all end in the quiet region with weaker field strength and opposite polarity, confirming the above inference.

Figure 4 shows part of the full disk H_α image observed at BBSO. The H_α Plage A corresponds to moss region A in bottom panel of Figure 1, and the thin and short bright lines over magnetic plage B, indicated by the black arrow, correspond to computed field lines that connect with adjacent quiet regions.

4. Summary and discussion

We have shown that moss-associated magnetic plages connect mainly to adjacent magnetic plages with opposite polarity, while mossless magnetic plages connect only with "quiet regions" with opposite polarity. As the distance between two magnetic plages increases, the field lines that connect the two plages extend higher and can be called coronal loops. Is there any critical distance that may be used to distinguish the formation of moss from loop emissions?

The small-scale loop model for the low-lying emission assumes that the low coronal loops are nearly isothermal and in the range of 1.2–1.7 MK. The height of those loops is less than 10–20 Mm (Moses et al. 1997), much less than the height of magnetic loops we computed. Thus the adjacent-plage connectivity found here supports the idea that the TRACE moss emission is due to heating of low-lying plasma by field-aligned thermal conduction from overlying hot plasma (Berger et al. 1999). The thermal conduction requires the existence of a gradient in temperature. In addition to the soft X-ray and H_α 6563 Å images, counterparts of the moss region were observed co-temporally on 30 May 1998 by SOHO/CDS in emission lines with temperature higher than 1.5 MK and lower than 0.6 MK (see Figure 1 of Fletcher & De Pontieu (1999)). This supports the existence of the temperature gradient.

Peres et al's (1994) hydrostatic model considers a semicircular coronal loop with constant cross section that is symmetric with respect to its apex, and the maximum plasma temperature is located at the loop apex. However, moss regions occur only at one end of the field lines, even though the field lines from moss-associated plages connect with other adjacent plages with similar strength and opposite polarity. A new physical model is needed to understand the asymmetry.

We would thank T.E. Berger for helpful discussions and T.Sakurai for allowing us to use his Software Package for the Computation of Solar Magnetic Field (MAGPACK2). Figure 4 is produced using data from the Big Bear Solar Observatory. This work was supported by NASA Grants NAG5-3077 (SOHO/MDI) and NAS5-38099 (TRACE) subcontract SN30G4920R. SOHO is a mission of international cooperation between ESA and NASA.

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This manuscript was prepared with the AAS LaTeX macros v4.0.

Fig. 1.— The SOHO/MDI full-disk magnetic image at 1998.05.30_14:41:01 UT (top) and the TRACE 171 Å FOV image at 1998.05.30_14:24:30 UT (bottom). The bright and dark areas in the top panel denote the line-of-sight field with positive and negative polarities. The dotted box shows that the NOAA AR 8227 is within the TRACE 171 Å FOV and the dashed box is the area where moss regions occurred. The negative and positive plages in the solid box are the moss-associated and mossless plages. The bottom panel shows the moss regions (A), mossless region (B) and coronal loops (C). The white and black curves are contours of magnetic strength of $\pm 50, \pm 200$ and ± 500 Gauss.

Fig. 2.— Magnetic field lines (green) computed using the potential field model and the observed photospheric field bordered by the dotted box in top panel of Figure 1. The orange (+) and blue (-) curves are contours of magnetic strength of $\pm 10, \pm 20, \pm 50, \pm 100, \pm 200, \pm 500, \pm 1000$ Gauss. The thick white outlines denote the 310 unit intensity contour in TRACE 171 Å, marking moss regions and coronal loops.

Fig. 3.— The same as Figure 2 but the field lines are computed using the photospheric field bodered by the solid box in top panel of Figure 1.

Fig. 4.— The BBSO H_α image observed at 1998:05:30_16:48 UT. The loops indicated by the dark arrow confirm the model prediction of field lines for the magnetic plage B in Figure 3.