Constraints on the Heating Time Scale in Active Regions

David H. Brooks and Harry P. Warren

Space Science Division, Naval Research Laboratory, Washington, DC

Abstract. Understanding the heating time scale is important for constraining models of active region emission. Hinode observations of moss at the bases of high temperature active region core loops are allowing us to study this problem in unprecedented detail. Here we discuss some of our recent results studying the variability of moss properties such as intensity, magnetic flux, Doppler and non-thermal velocity. We find that most of these quantities are relatively constant. One interpretation is that the heating is therefore effectively steady, i.e., heating events occur with a rapid repetition rate. Alternatively, the heating could be low frequency, but only if it occurs on sub-resolution spatial scales.

1. Background

The time scale of energy release is an important parameter for constraining models of active region heating. High temperature active region emission appears to be reproducible by hydrostatic simulations (Warren & Winebarger 2006). Such emission originates in hot (3-5MK) loops that are rooted in transition region moss (Martens et al. 2000). Steady heating models, however, fail to explain the warm (1MK) overdense loops that persist much longer than expected loop cooling times (Lenz et al. 1999). These loops are often seen cooling in active regions and are clearly evolving (Ugarte-Urra et al. 2009). Their properties are consistent with a scenario whereby sub-resolution threads are heated impulsively and allowed to cool substantially (Aschwanden et al. 2000; Reale & Peres 2000).

The complexity of the emission in the core of an active region makes it difficult to isolate individual loops for analysis. Warm loops are somewhat easier, so greater emphasis has been placed on findings related to these structures. The prevailing view is that the core loops are also likely to be heated impulsively but that the emission comes, e.g., from multiple structures along the line of sight, complicating the interpretation. Studying the moss emission alleviates the problem of complex core emission and allows us to diagnose properties of the hot loops. The moss emission itself is often clearly visible and shows only low variability (Berger et al. 1999), perhaps due to obscuration by overlying spicules (de Pontieu et al. 1999). The intensities appear to be consistent with steady heating (Antiochos et al. 2003). Our objective here is to search for previously undetected dynamic signatures using new data from EIS and SOT.

2. Results and Discussion

Hinode observed AR 10960 in early June 2007. This region afforded us a relatively clear view of the moss because most of the overlying loops were located away from the core (Warren et al. 2010). It also showed fairly stable emission in TRACE and Hinode/XRT movies (Brooks & Warren 2009), yet it was flare-productive, with numerous C- and M-class flare occurring in and around the moss. Since the magnetic field in
Brooks and Warren

Figure 1. Top row: EIS Fe xii 195.119 Å maps of intensity, non-thermal, and Doppler velocity in AR 10960. The solid contours outline the moss. Bottom row: evolution of intensity, non-thermal, and Doppler velocity in the three boxed regions in the images.

the core of this region was clearly changing, we felt that it was a good candidate for detecting any dynamic signatures in the moss, should they exist. We derived Doppler and non-thermal velocity maps from rapid cadence (few mins) scans of the moss in the EIS Fe xii 195.119 Å line. The reduced data are the highest cadence spatially resolved maps of moss Doppler and non-thermal velocities ever obtained in the corona.

Figure 1 shows example intensity, non-thermal, and Doppler velocity maps. The bright moss regions are outlined by contours. The moss is not characterized by strong flows or non-thermal mass motions. Brooks & Warren (2009) analyzed these observations in detail and found that the moss non-thermal and Doppler velocities were 22 km s$^{-1}$ and 3 km s$^{-1}$ on average. The non-thermal velocities are no larger than typical quiet Sun values (25 km s$^{-1}$). Examples of the evolution of these quantities are shown in the lower panel of Figure 1. The areas selected are shown as boxes in the images of the upper panel. The non-thermal and Doppler velocities vary by only a few km s$^{-1}$ over 16 hours. The variation from location to location in the moss is usually larger. These examples are representative of others in the Brooks & Warren (2009) analysis.

Using SOT SP data, Brooks et al. (2010) performed potential field extrapolations to obtain a realistic distribution of lengths for loops rooted in the moss. They then computed hydrodynamic cooling times for a grid spanning this distribution of lengths and found that all the simulated loops cool from 5 to 1MK on time scales less than ~ 30 mins. This time scale is much shorter than the time scale over which the moss velocity measurements appear to be constant. One interpretation of the results therefore is that if the heating is impulsive, it occurs at a high enough frequency that it appears to be effectively steady.

Another interpretation is that the heating could be low frequency on sub-resolution spatial scales. If so it does not give rise to large nonthermal broadening or Doppler shifts at the spatial scales that we have observed. Resolution is key. Clearly we can temporally resolve the critical loop cooling time scale, and we can already detect spatial
sub-structure in other phenomena, e.g., blinkers (Brooks et al. 2004). Filling factor measurements made in active region loops (Warren et al. 2008a) and moss (Fletcher & de Pontieu 1999; Warren et al. 2008) and in the core of this region (Brooks et al. 2010) are typically 10-20% of an EIS pixel. This suggests that EIS itself cannot resolve the relevant spatial scales, but interestingly, these values are comparable to the SOT pixel size. We therefore decided to investigate the magnetic field evolution below the moss, using SOT.

SOT performed a combination of large FOV SP (Fe i 6301 Å) scans and time-series of FG (Na i D 5896 Å) magnetograms covering the moss. We processed the FG data using standard procedures, and obtained the SP map from the SOT level-2 archive. Figure 2 shows example magnetograms from this dataset. A TRACE image is also shown to highlight the moss regions.

The moss is unipolar, with unmixed flux, and corresponds to the positive and negative polarity ‘lobes’ to the lower left of the sunspot. The three magnetograms shown span a time-period of 10 hours, and it can be seen that, as in other active regions (Brooks et al. 2008), the magnetic flux distribution evolves only slowly. Brooks et al. (2010) put this statement on a quantitative basis by showing that the linear Pearson cross-correlation coefficient between magnetograms remains high (>0.9) even when they are separated by time-intervals longer than the cooling times calculated in their simulations.

Examples of the evolution of the magnetic flux in the small boxes shown in the third magnetogram of the upper panel are shown in the lower panels. The magnetic flux varies by <15% over a period > 5 hours in these regions. Since EIS filling factors suggest that individual SOT pixels may be needed to resolve the relevant spatial scales, we studied the variation of the magnetic flux within one of the boxes: 85% of the pixels show variabilities of less than 20% on loop cooling time scales.
These results suggest a picture whereby the magnetic field in the moss evolves slowly. Further analysis in more locations is needed before a definite conclusion can be drawn.

3. Concluding Remarks

We have studied the evolution of intensities, Doppler and non-thermal velocities, and magnetic flux, in small boxed regions close to the limit of current state-of-the-art instrumental capabilities within the moss in the core of a flaring active region. Our objective was to uncover signatures of dynamic activity, but we found that none of the observables show significant variability on time scales longer than typical loop cooling times. These results could be interpreted as being consistent with steady or pseudo-steady heating (i.e. the repetition time between impulsive heating events is short). Strictly speaking, the magnetic flux results are only consistent with heating that is truly steady, because if the heating is impulsive at high frequency and reconnection related we would expect to see rapid, high frequency changes in the magnetic field. It is unclear how much variation would be expected, however. Are the small (~100G) detailed changes in Figure 2 sufficient? Further comprehensive studies also examining the vector magnetic field are needed and are being pursued.

Acknowledgments. Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway).

References