THE SECOND HINODE SCIENCE MEETING
ASP Conference Series, Vol. 415, ©2009
B. Lites, M. Cheung, T. Magara, J. Mariska, and K. Reeves

Expansion of Magnetic Flux Concentrations with Height: A Comparison of *Hinode* SOT Data and MHD Simulations

A. Pietarila, R. Cameron, and S. Solanki

MPI for Solar System Research, Max-Planck-Str. 2, 37191 Katlenburg-Lindau, Germany

Abstract. The *Hinode* SOT (Tsuneta et al. 2008) NFI Na I D_1 and SP Fe I data sampled at different positions on the solar disk provide a unique diagnostic for studying the expansion of magnetic flux concentrations with height. We make a comparative study of SOT observations and 2-dimensional (2D) radiative MHD-simulations to see how well the simulations capture the expansion properties. The expansion of flux concentrations is clearly seen in the SOT Na I D_1 data, where most of the magnetic features appear unipolar at disk center while close to the limb bipolar appearance strongly dominates. This trend, albeit not as strong, is seen in the SP data as well. Some aspects of the observations are qualitatively reproduced by simulations with a potential (as opposed to vertical) upper boundary condition for the magnetic field.

1. Introduction

The formation height range of spectral lines increases with increased viewing angle: the lines are formed effectively higher close to the solar limb than at disk center. Additionally, the Na I D_1 589.6 nm line, observed by one of the SOT narrowband filter imager (NFI) channels, samples a higher part of the solar atmosphere than the pair of purely photospheric Fe I lines at 630 nm observed by the spectro-polarimeter (SP). In both cases the lines are sensitive to magnetic fields mainly via the Zeeman effect. Thus, a combination of data taken with the Na I D_1 NFI channel and SP at different positions on the solar disk can be used to probe magnetic flux concentrations at different heights in the atmosphere. Of particular interest is how the flux concentrations expand with height.

2. *Hinode* SOT Observations

For the following data analysis we use 27 Stokes V filtergrams from NFI and 23 SP-maps (produced with solar software[1] routines `sotsp_stks2struct` and `sotsp_stks2index`) taken at varying positions, from disk center to limb.

Maps of Na I D_1 circular polarization at disk center are dominated by unipolar features (Fig. 1). In contrast, close to the limb the Na I D_1 magnetic concentrations appear as bipolar structures. In Fe V_{tot}-maps the bipolar features are not as strongly dominant as in Na I D_1. In both SP and NFI data

[1]http://www.lmsal.com/solarsoft/

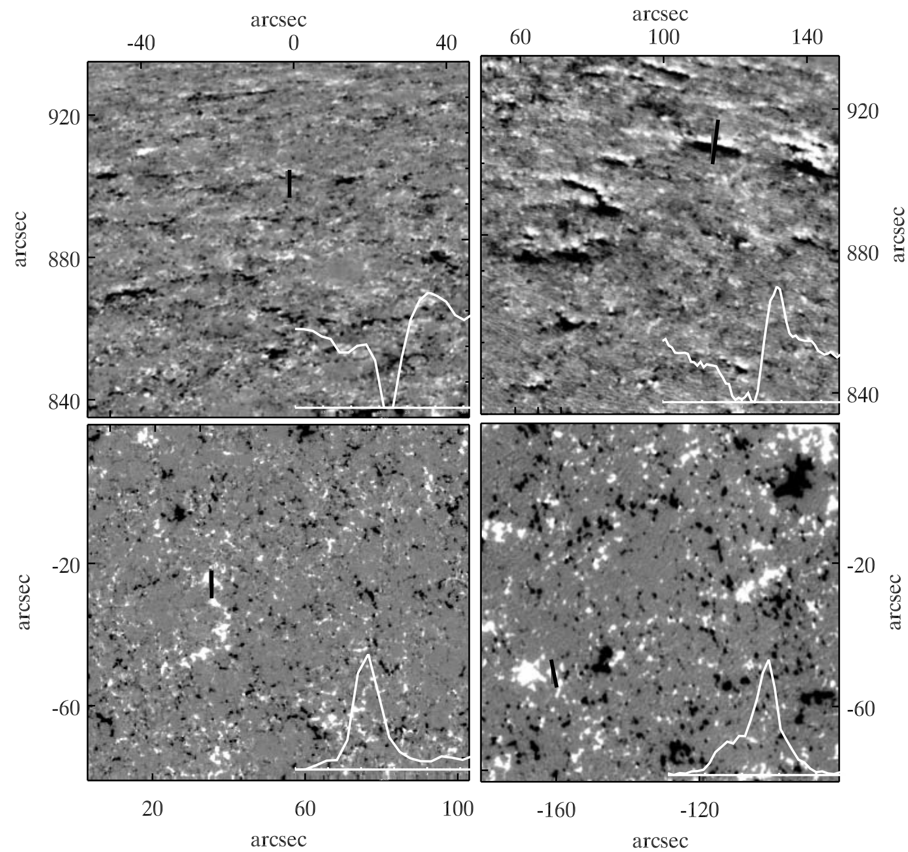

Figure 1. Maps of circular polarization in the Fe I lines (left, V_{tot}) and Na I D_1 (right) close to the solar limb (top) and at disk center (bottom). Profiles show radial cuts of the features indicated by black lines in the images.

radial cuts of the magnetic structures usually have two peaks of opposite sign (corresponding to the bipolar structures) at the limb while at disk center the cuts usually have a single peak or multiple peaks with the same sign.

Histograms of the number of peaks in a radial cut of a magnetic structure (Fig. 2) show that: 1) unipolar features dominate at disk center; 2) Bipolar features become more common closer to the limb; 3) Bipolar features are the most dominant structure close to the limb in Na I D_1. In Fe both unipolar and bipolar features are seen at the limb.

In Na I D_1 the ratio of the amplitude of the positive and negative peaks in the radial cuts tends towards one towards the limb and the bipolar pattern becomes very clear.

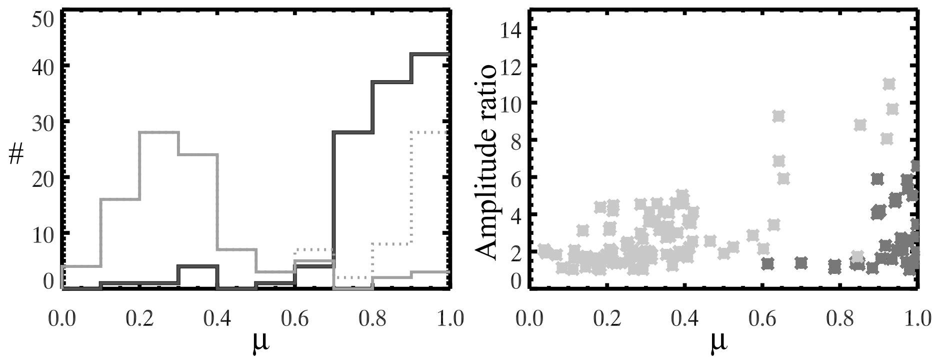

Figure 2. Left: histograms of number of peaks in Na I D_1 radial cuts versus position the solar disk for single peaked (dark gray), double peaked (dotted light gray) and double peaked with opposite signed peaks (light gray) radial cuts. Right: Scatter plot of peak amplitude ratio in Na I D_1 radial cuts with two peaks as a function of position on solar disk. Dark asterisks are for double peaked profiles with same sign and light gray for opposite signed peaks.

3. MHD Simulations

We used the MURaM code (Vögler et al. 2005) to test how well radiative magnetohydrodynamic (MHD) simulations capture the observed expansion. MURaM is a multi-dimensional MHD code with non-gray radiative transfer, partial ionization, full compressibility and open boundary conditions. As a first step we made simulations in 2D (1.68Mm x 24 Mm) with 2 different magnetic field upper boundary conditions (BC), potential and vertical.

The initial condition for the magnetic field was a vertical magnetic field strip (Gaussian squared profile with FWHM 4.56 Mm and peak 300 G) at the bottom in the middle of the simulation box. The density in the flux concentration after a transient period is strongly reduced and the velocities in the region are high near the top of the box. At large line of sight (LOS) angles the high velocities and large gradients make line synthesis in the 2D simulations unfeasible.

The upper BC for the magnetic field has a significant effect on the field configuration in the upper part of the box: the potential field BC (Fig. 3) allows for the field to fan out to a greater extent, producing a field configuration in qualitative agreement with the observations.

Cross-cuts of the LOS magnetic field at increasing viewing angles show how the appearance of the structure changes gradually from unipolar at disk center to bipolar close to the limb. The change from uni- to bipolar is also clearly seen in the ratio of the positive and negative LOS B-components as a function of position on the solar disk, again in qualitative agreement with *Hinode* SOT data.

Preliminary results of 3D simulations indicate similar results as for the 2D simulations.

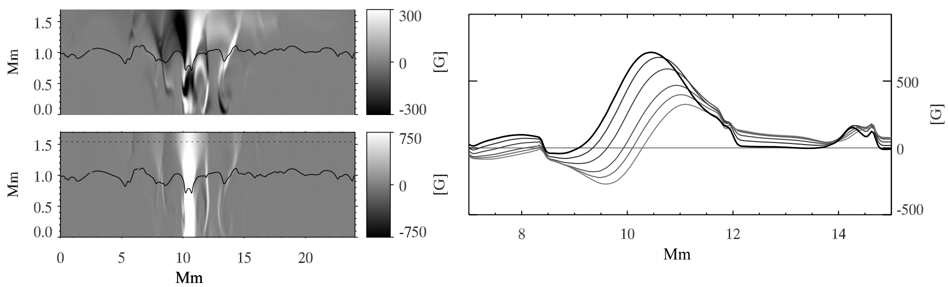

Figure 3. Left: Horizontal (top) and vertical (bottom) magnetic fields in the 2D simulation with potential field BC. Solid black line shows location of log(τ)=0. Right: LOS magnetic field component at z=1.54 Mm when viewed at varying angles (from 0 (in black) to 80 (gray) degrees).

4. Conclusions

The expansion of magnetic flux concentrations with height is clearly seen in *Hinode* SOT Na I D_1 and SP data. At disk center a given feature is seen as unipolar while at the limb both polarities are seen. The more inclined the LOS is, the higher the formation height of the signal is. Therefore, a larger part of the Stokes V signal originates from the horizontal (relative to solar surface) component of the magnetic field.

The expansion is more clear in Na I D_1. This is due to differences in formation height (Na I D_1 is formed higher) and perhaps also to differences in sensitivity. Na I D_1 has a smaller Landè g-factor and samples mostly the strong network fields. In contrast, the Fe I lines may also sample the weak horizontal internetwork fields which close to the limb appear as unipolar features in circular polarization.

Radiative MHD simulations with a potential field upper BC can reproduce qualitatively the observed characteristics.

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

Tsuneta, S., Ichimoto, K., Katsukawa, Y., et al. 2008, Solar Phys., 249, 167
Vögler, A., Shelyag, S., Schüssler, M., et al. 2005, A&A, 429,A 335