High Latitude Meridional Flow on the Sun May Explain North-South Polar Field Asymmetry

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**Abstract**

We measured the flows of magnetic elements on the Sun at very high latitudes by analyzing magnetic images from the Heliostatic and Magnetic Imager (HMI) on the NASA Solar Dynamics Observatory (SDO) Mission. Magnetic maps constructed using a fixed, and north-south symmetric, meridional flow profile give weaker than observed polar fields in the North and stronger than observed polar fields in the South during the decline of Cycle 23 and rise of Cycle 24. Our measurements of the meridional flow at high latitudes indicate systematic north-south differences. There was a strong flow in the North while the flow in the South was weaker. With these results, we have a possible solution to the polar field asymmetry. The weaker flow in the South should keep the polar fields from becoming too strong while the stronger flow in the North should strengthen the field there. In order to gain a better understanding of the Solar Cycle and magnetic flux transport on the Sun, we need further observations and analyses of the Sun's polar regions in general and the polar meridional flow in particular.

**Results**

We find that we can use HMI to reliably measure the meridional flow to within 5° of the poles (red lines in Figure 3). Our HMI measurements agree with those obtained with SOHO/MDI data (black lines in Figure 3) at latitude below ~20°. In the mid latitudes, ~20-60°, HMI results are slightly slower than was found with MDI. Furthermore, HMI measurements show a poleward MF all the way to the pole. This is contrary to the previous MDI measurements suggesting a counter cell in the North and flow to the pole in the South. We do find a slight, but potentially important, North-South asymmetry in the HMI Meridional flow – the poleward flow is faster in the North and slower in the South. These results provide us with a possible explanation for the annual signal near the poles on the magnetic butterfly diagram (Figure 1).

**Procedure**

We downloaded 720-second averaged Full Disk Magnetograms from the HMI instrument centered at the top of each hour. The data were mapped onto heliographic coordinates. We then measured both the differential rotation and the meridional flow by cross-correlating data steps from pairs of HMI magnetic maps separated by 8 hours. As shown in Figure 2, here we concentrated on measurements of the meridional flow during the one year of the MDI-HMI overlap — Carrington Rotations 2096-2107. Measurements were attempted at latitudes up to 85° in both the North and South but were limited on the poleward side (not shown) to a latitude of ~75° when the tilt of the Sun's rotation axis was far from the Sun's equator. As the active regions decay, the magnetic flux is transported across the Sun's surface by flows in near the surface layers. An important consequence from this transport is the reversal and production of the Sun's polar fields during each 11-year solar cycle (evident in Figure 1). These polar fields are reliable predictors of the strength of the following solar cycle.

The variations in the polar fields can be attributed to variations in the Meridional Flow at high latitudes. Meridional Flow remaining strongly poleward in the polar regions produces stronger polar fields while the weaker poleward fields are produced by weaker meridional flows and/or counter-cells in the polar regions. This project addressed this problem by measuring the Meridional Flow to higher latitudes and with better precision using data from HMI (HMI). We measured the HMI instrument centered at the top of each hour. The data were mapped onto heliographic coordinates. We then measured both the differential rotation and the meridional flow by cross-correlating data steps from pairs of HMI magnetic maps separated by 8 hours. As shown in Figure 2, here we concentrated on measurements of the meridional flow during the one year of the MDI-HMI overlap — Carrington Rotations 2096-2107. Measurements were attempted at latitudes up to 85° in both the North and South but were limited on the poleward side (not shown) to a latitude of ~75° when the tilt of the Sun's rotation axis was unfavorable. Typically, measurements were obtained from about 600 images pairs during each 27-day rotation of the Sun.

**Conclusions**

We have measured the meridional motions of magnetic elements on the Sun by cross-correlating data from magnetic maps derived from SDO/HMI 720-second magnetograms. The measurements are more accurate and extend to higher latitudes than those previously obtained. We find North-South asymmetries in the Meridional Flow that may help explain the asymmetries seen in the Sun's polar magnetic fields. Calculations using North-South symmetric Meridional Flow produce weaker than observed polar fields in the North and stronger than observed polar fields in the South (the annual signal seen in Figure 1). The stronger meridional flow we observe in the North should strengthen the calculated polar fields there while the weaker meridional flow in the South should weaken the calculated polar fields at the South Pole. These conclusions can be confirmed by calculations of the Sun's magnetic flux transport using these newly observed flow profiles.

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