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 Helioseismic and Magnetic Imager (HMI) on the NASA Solar Dynamics Observatory (SDO) Mission. Magnetic maps constructed using a fixed, 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.

Introduction

All solar activity including sunspots, solar flares, prominence eruptions and coronal mass ejections is a product of the Sun’s magnetic fields. The interaction between plasma flows and the magnetic field within the Sun’s convection zone (the outermost 30% of the solar interior) produces the magnetic flux. This flux erupts through the Sun’s photosphere in active regions (sunspots) which appear in few latitude bands on either side of 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.

Hathaway and Rightmire (Science 327, 1350 2010) measured the asymmetric transport of magnetic flux over the course of Solar Cycle 23 (1996-2008) and initial rise of Solar Cycle 24 (2009-2010) using line-of-sight magnetograms from the Michelson Doppler Imager (MDI) instrument on the SOHe/ESA Solar and Heliophysical Observatory (SOHO) Mission. Significant and systematic variations in the strength and structure of the poleward Meridional flow were clearly observed over the 11 year period. A key aspect to these variations is their effect on the polar magnetic fields.

The variations in the polar fields can be attributed to variations in the Meridional Flow at high latitudes. Meridional Flow remaining strong poleward in the polar regions produces stronger polar fields while the weaker polar fields are produced by weaker 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 Helioseismic and Magnetic Imager (HMI) on board the NASA Solar Dynamics Observatory (SDO) satellite.

We downloaded 720 second averaged Full-Disk Magnetograms from the HMI instrument centered at the top of each hour. The data were mapped into heliographic coordinates. We then measured both the differential rotation and the meridional flow by cross correlating data strips from pairs of these 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 89° in both the North and South but were limited to latitudes less than 70° when the tilt of the Sun’s rotation axis was unfavorable. Typically measurements were obtained from about 600 image pairs during each 27–day rotation of the Sun.

Results

We find that we can use HMI to reliably measure the meridional flow at latitudes to within 5° of the poles (red lines in Figure 3). Our HMI measurements agree with those obtained with SDO/MDI data (black lines in Figure 3) at latitude below ~20°. In the mid latitudes, ~20–60°, HMI results are slightly weaker than those 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-flow 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. This result provides us with a possible explanation for the annual signal seen near the poles on the magnetic butterfly diagram (Figure 1).

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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