Are Solar Magnetic Fields in the Polar Region Radially Directed?

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## Background

*Cyclic solar magnetic fields.* — The solar magnetic field undergoes 11-year cycles. The most pronounced feature is the active region (AR) where sunspots live. Solar activity, namely flares and coronal mass ejections (CMEs), originate from ARs and derive their energy from strong AR magnetic fields. A solar cycle with more ARs (tallied by sunspot number, or SSN) will have greater impact on the near-Earth space environments.

The cyclic behavior also appears in larger-scale magnetic field. When ARs decay, part of the magnetic flux of a particular polarity is carried poleward by meridional flow and accumulates in the high-latitude regions. The opposite polarity flux diffuses across the equator and cancels with its counterpart from the opposite hemisphere. As the solar cycle progresses, the high-latitude magnetic field (polar field, or PF) becomes stronger and more unipolar. PF is strongest during activity minimum.

![Figure 1: Hinode/SP true field strength remapped to polar view. Strong field is concentrated in small patches. Top: Continuum image in observed frame. Bright patches correspond to strong field (Tsuneta et al. 2008).](image)

*Polar field measurements.* — PF measurement is important because it strongly affects the result of global magnetic field modeling. It is also a good predictor of next cycle’s strength. We have a long-running time sequence of averaged PF (say, above 60° latitude) from low-resolution, line of sight (LoS) magnetic maps ($B_l$) such as the Wilcox Solar Observatory (WSO). Because the solar rotation axis is about 7° misaligned from the normal of the ecliptic plane, we see an annual modulation in the $B_l$ signal.

The Spectro-Polarimeter (SP) instrument on the Japanese *Hinode* satellite provides high-resolution measurement of all three components of the magnetic field. From SP data, we learned that PF is not uniformly distributed, but rather concentrated in small patches with strong magnetic field strength (Figure
1. The Helioseismology and Magnetic Imager (HMI) aboard the SDO satellite also measures the full vector. It has a lower resolution compared to SP, but it covers the full Sun and observes all the time.

*Radial field assumption.* — Our current assumption is that PF is radially directed. This means that PF is difficult to estimate from \( B_l \) data alone. At high latitudes, our line of sight will be almost perpendicular to the local normal (radial direction). We will only measure a small component of the true vector. To convert \( B_l \) to true field strength, we will need to divide it by \( \mu^{-1} \), where \( \mu \) is cosine of the angle between LoS and the local normal. This approach greatly amplifies observational noise (\( \mu \) is small at high latitudes). If PF deviates from the radial direction systematically, we will over/underestimate mean PF using \( B_l \) (why?).

**Project description**

Using HMI vector data, we will look at the Sun’s polar region in detail and quantify the local magnetic field. We wish to ask the following questions.

1. What is the typical field strength and orientation of the vector PF? Is it largely radial?
2. How does the mean field from vector data compare to LoS data? How does it change with time?

This project will develop your skills in coordinate transformation, image processing, and statistical analysis. We will obtain HMI vector magnetograms, which include field strength, inclination, and azimuth in the plane-of-sky coordinate. We will need to transform them into a local spherical coordinate. We will then identify the regions with strong enough signal and analyze the values therein.

**Getting Started**

1. Install the SunPy package. Check out AIA/HMI images on the SolarMonitor/Helioviewer website. Retrieve one AIA 193 Å and one HMI LOS magnetogram for a particular time. Inspect and plot the images using ds9/Python.
2. Figure out the center of the solar disk, its radius, the latitude and longitude of each pixel of your selected image. Compute the normal vector (perpendicular to the solar surface) at each pixel.
3. Check out the polar field time sequence of WSO and HMI from the links below. Check the polar region in AIA/HMI images. Compare one image from 2014 and one from 2018.

**Reference & Software**


*Measurements from WSO:* [http://wso.stanford.edu/gifs/Polar.gif](http://wso.stanford.edu/gifs/Polar.gif)


*SunPy:* [http://sunpy.org/](http://sunpy.org/)

*SolarMonitor:* [https://solarmonitor.org](https://solarmonitor.org)

*Helioviewer:* [https://www.helioviewer.org](https://www.helioviewer.org)

*ds9:* [http://ds9.si.edu/site/Home.html](http://ds9.si.edu/site/Home.html)