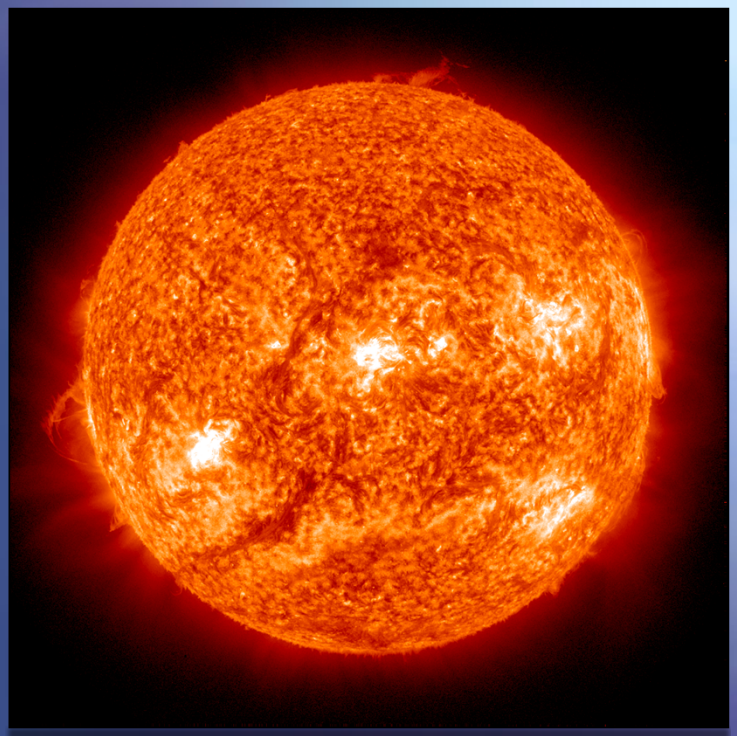
Meridional Flow in Solar Cycle 24: The Impact on the Polar Magnetic Fields



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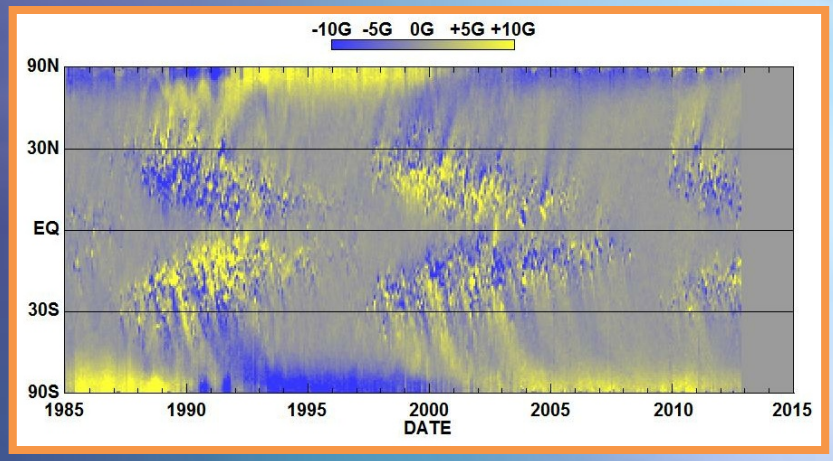
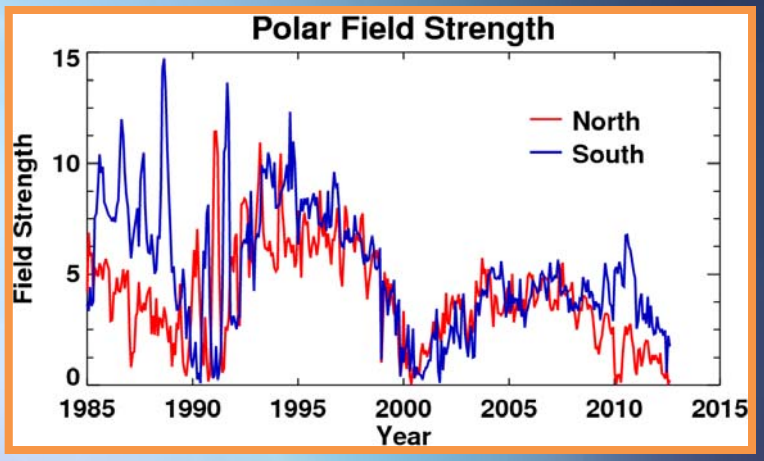
Dr. D.H. Hathaway

REU Student:
Katie Kosak

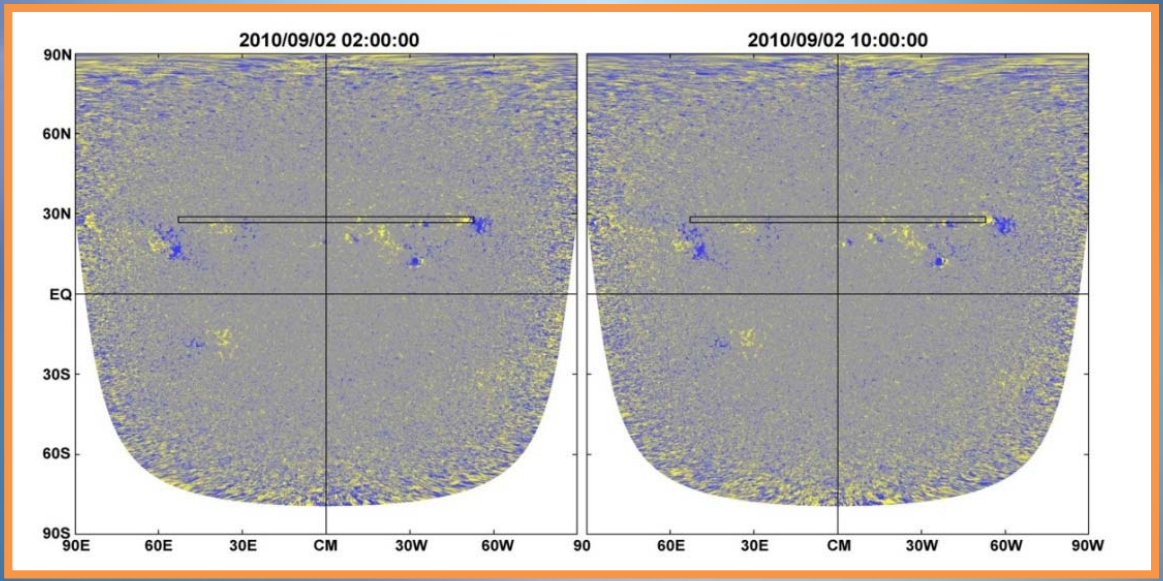
Polar Fields





- Asymmetries in the polar field strengths and reversals have been observed during the onset of Solar Cycle 24 .
- These are the product of asymmetries in active region emergence and asymmetries in the flux transport.
- Differential Rotation and Diffusion have been found to have very little variability, while the Meridional Flow varies considerably.
- Our goal is to examine the variations in the Meridional Flow and determine how it influences the Polar Fields.

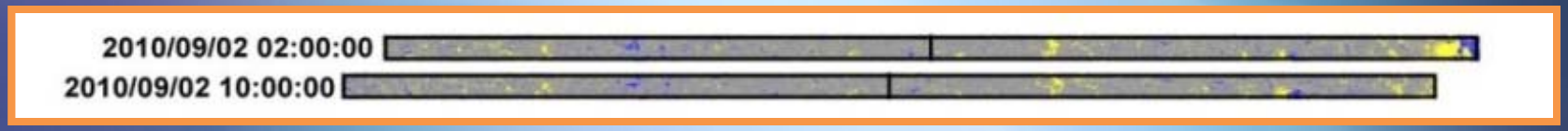
Measuring Flow Speed



- Map magnetograms into heliographic coordinates
  - Extract strips near the central meridian
- Cross Correlate with shifts in latitude and longitude

Cross Correlating

- Start with f(i,j) and g(i,j) = f(i,j, t+**Δ**t) where i = 1,N_x and j = 1,N_y
- Normalize the arrays: $\hat{f}(i,j) = \frac{[f(i,j) - \bar{f}\,]}{f_{RMS}}$ $\hat{g}(i,j) = \frac{[g(i,j) - \bar{g}\,]}{g_{RMS}}$

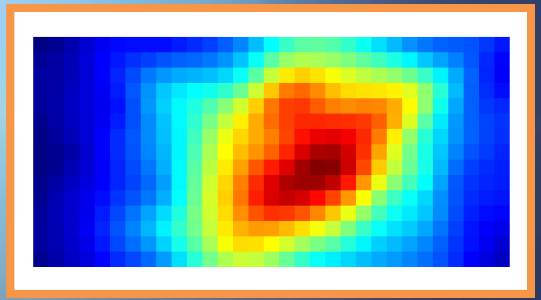


NEW NEW

Forward Step: $\boldsymbol{X_{corr}}(f,g,\Delta x,\Delta y) = \sum_i \sum_j \frac{\hat{f}(i,j)\hat{\boldsymbol{g}}(\boldsymbol{i}+\Delta\boldsymbol{x},\boldsymbol{j}+\Delta\boldsymbol{y})}{N_x N_y}$

Backward Step: $\boldsymbol{X_{corr}}(f,g,\Delta x,\Delta y) = \sum_i \sum_j \frac{\hat{\boldsymbol{f}}(\boldsymbol{i}-\Delta\boldsymbol{x},\boldsymbol{j}-\Delta\boldsymbol{y})\hat{g}(i,j)}{N_x N_y}$

Average the Forward and Backward X_{corr} arrays



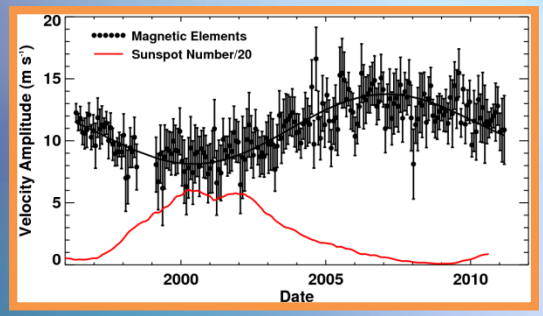
- Find the maximum correlation and the fractional pixel shifts (in latitude and longitude) for that latitude
- Calculate velocity profiles: Meridional Flow and Differential Rotation
- Average all profiles for each 27 day Carrington Rotation

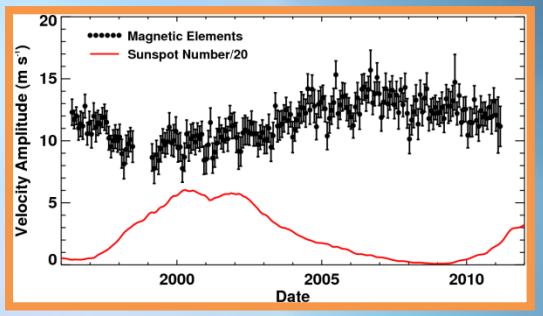
Improved MDI Results

- Principle Meridional Flow Amplitude

(multiplies the Legendre polynomial of 1rst order in sin λ)

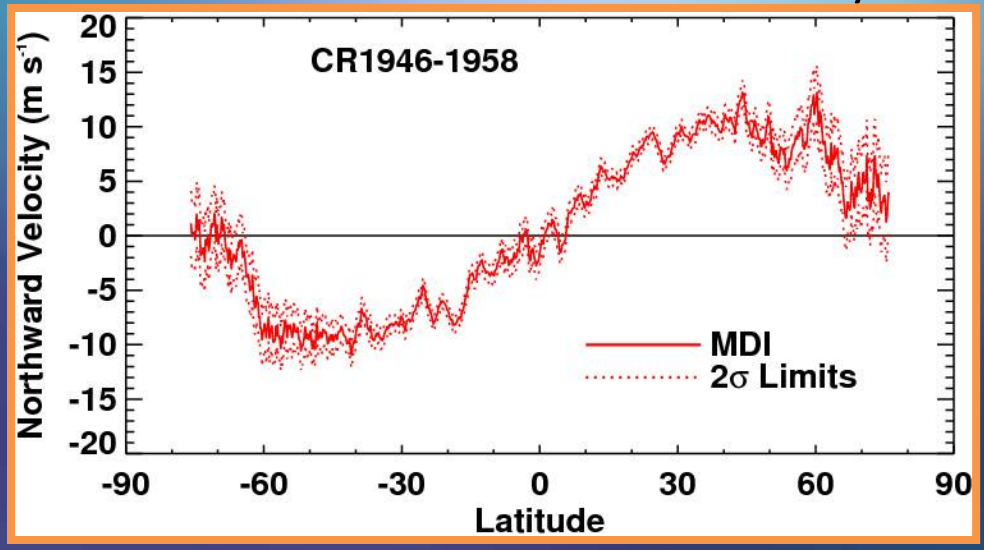
Only Forward X-Corr





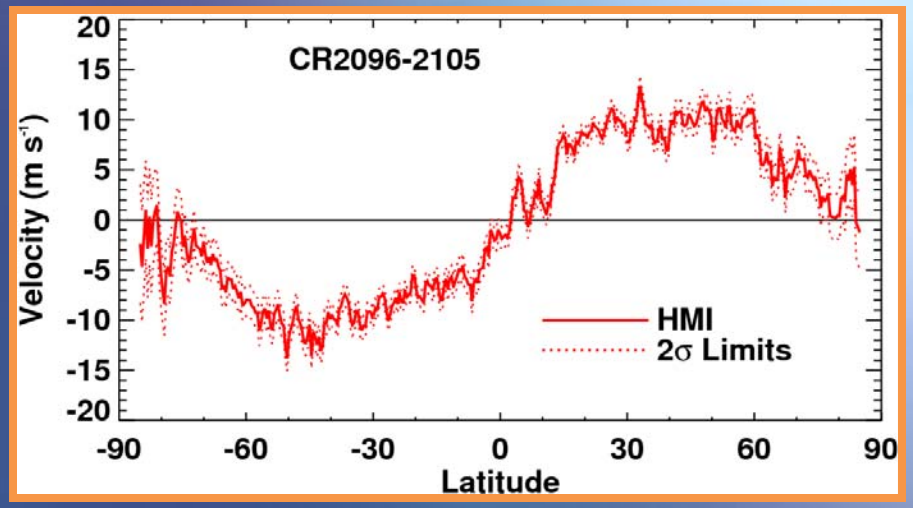
Forward & Backward X-Corr

- Meridional Flow Evolution over Solar Cycle 23

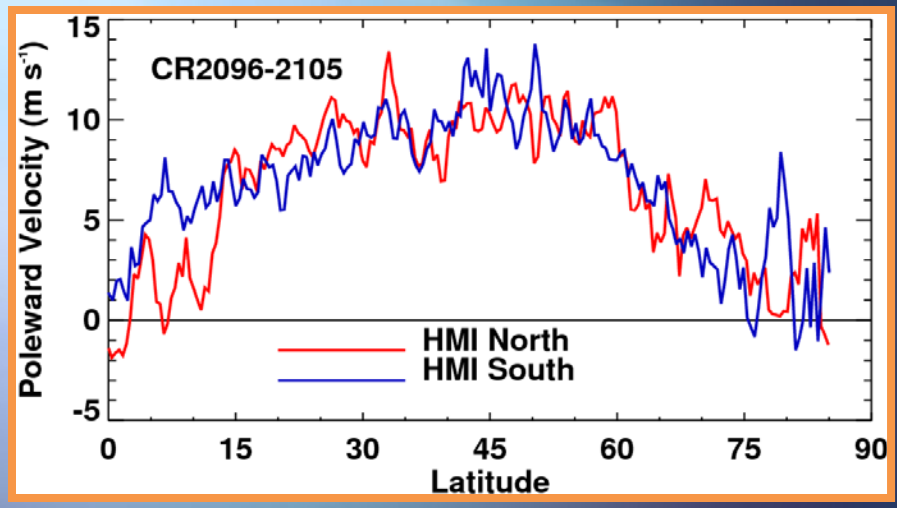


HMI MF – 2010

Average Profile



Average Asymmetry

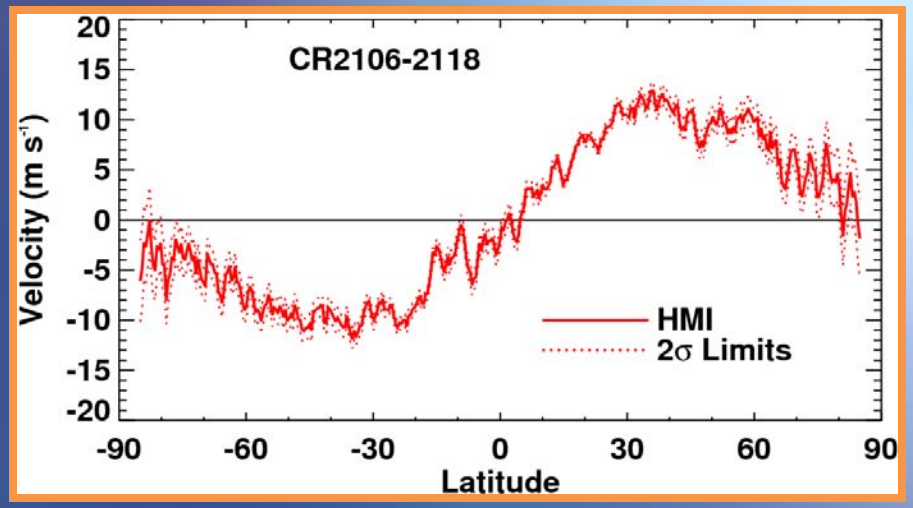


ApJ, 761, L14
"Measurements of the Sun's High Latitude Meridional Circulation"
L.A. Rightmire-Upton, D.H. Hathaway, & K. Kosak

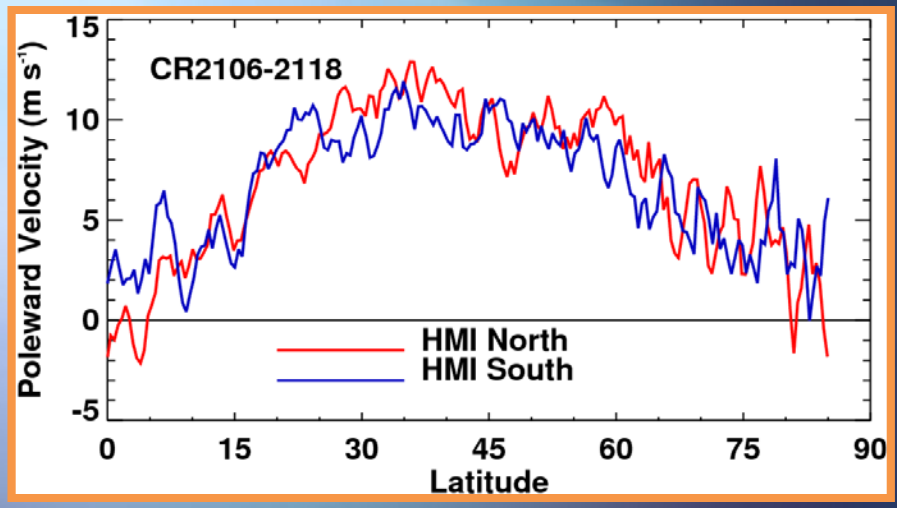
SH13C-2272
High Latitude Meridional Flow on the Sun May Explain North-South Polar Field Asymmetry
M. Kosak; L. Upton; D. Hathaway

HMI MF – 2011

Average Profile

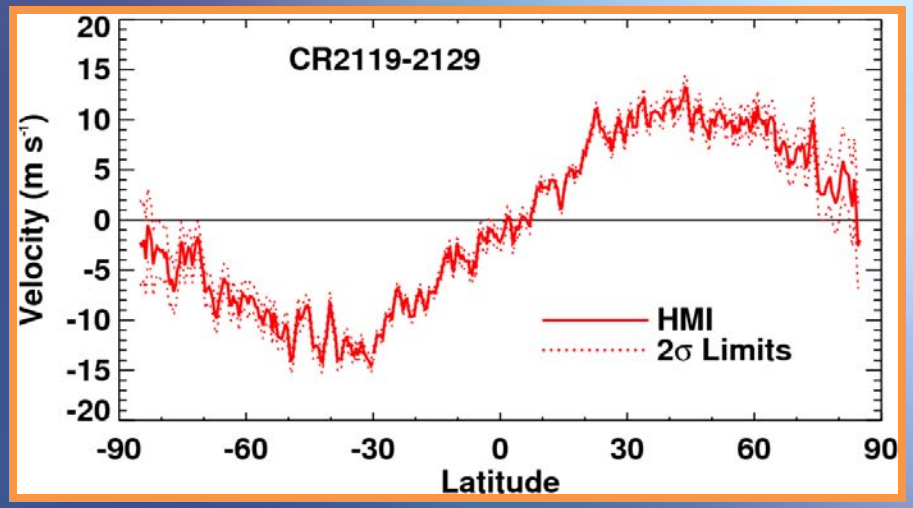


Average Asymmetry

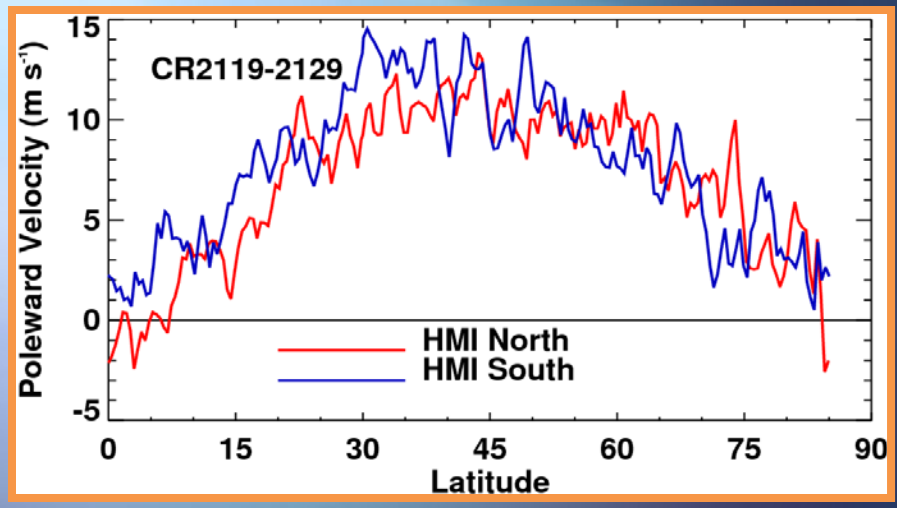


HMI MF – 2012

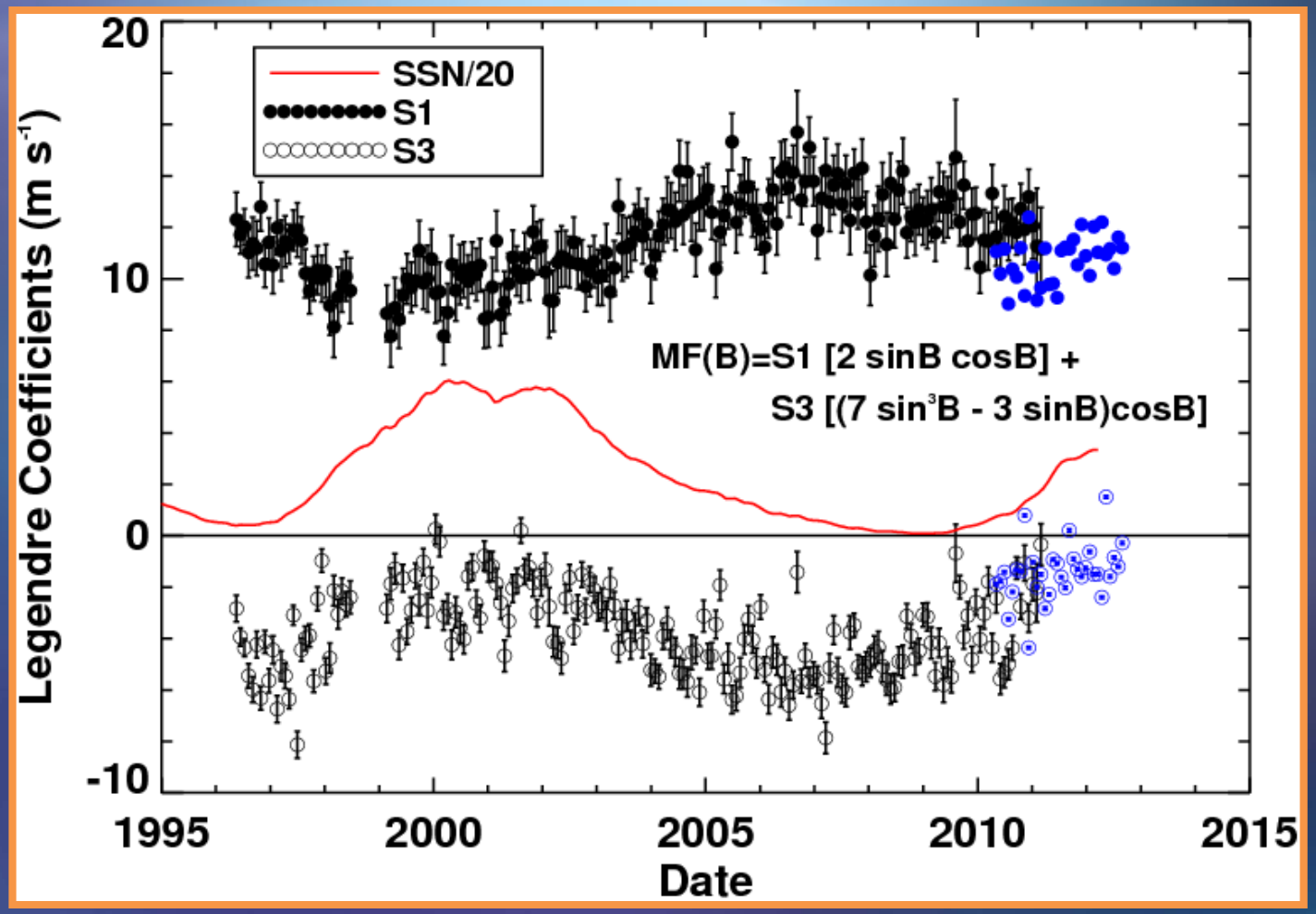
Average Profile



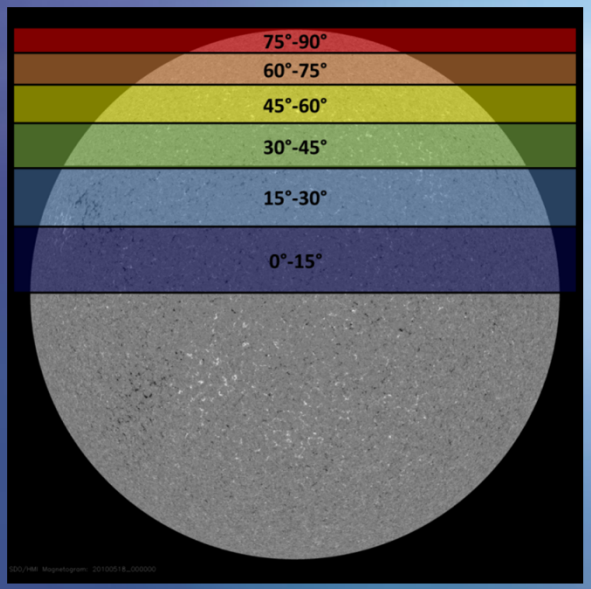
Average Asymmetry

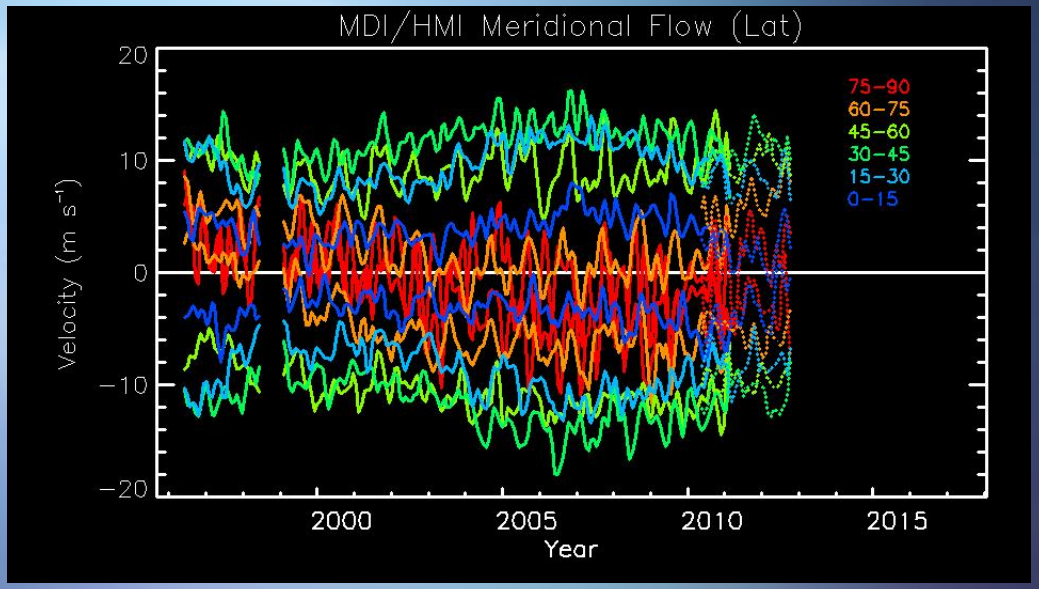


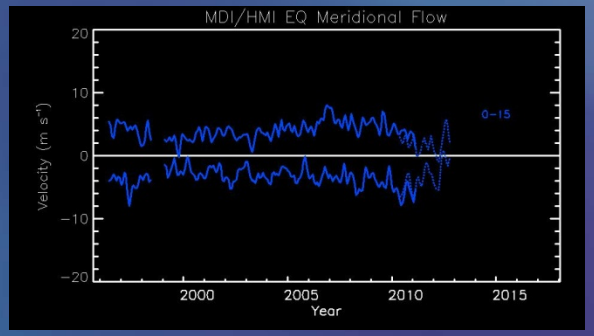
Legendre Coefficients

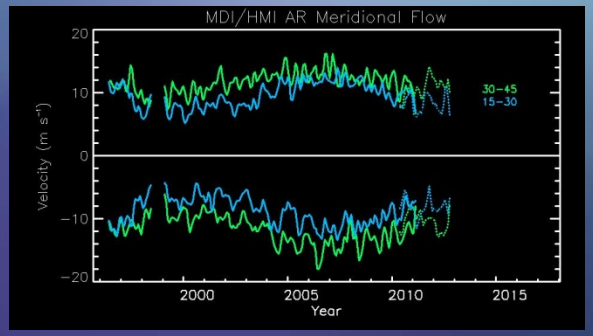


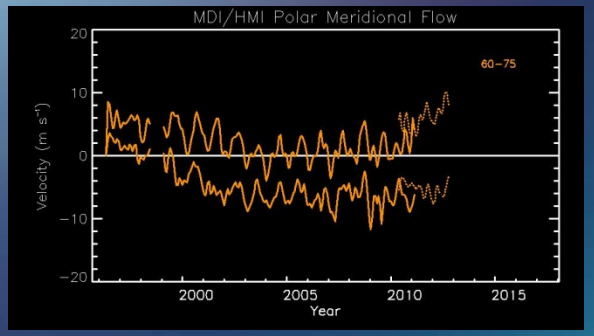
Binned MF


75°-90°
60°-75°
45°-60°
30°-45°
15°-30°
0°-15°

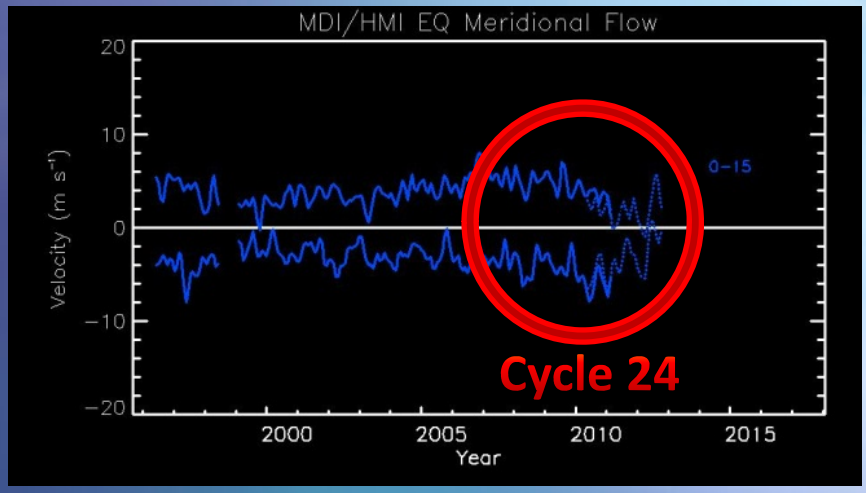

MDI/HMI Meridional Flow (Lat)
Velocity (m s⁻¹)
Year
75-90
60-75
45-60
30-45
15-30
0-15

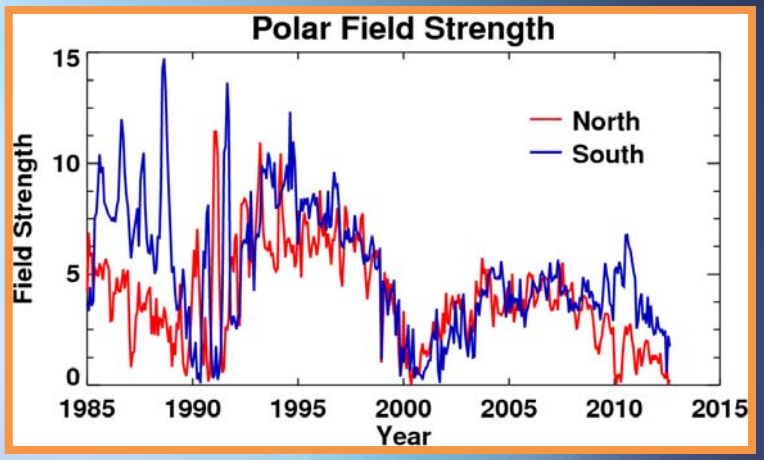

MDI/HMI EQ Meridional Flow
Velocity (m s⁻¹)
Year
0-15


MDI/HMI AR Meridional Flow
Velocity (m s⁻¹)
Year
30-45
15-30

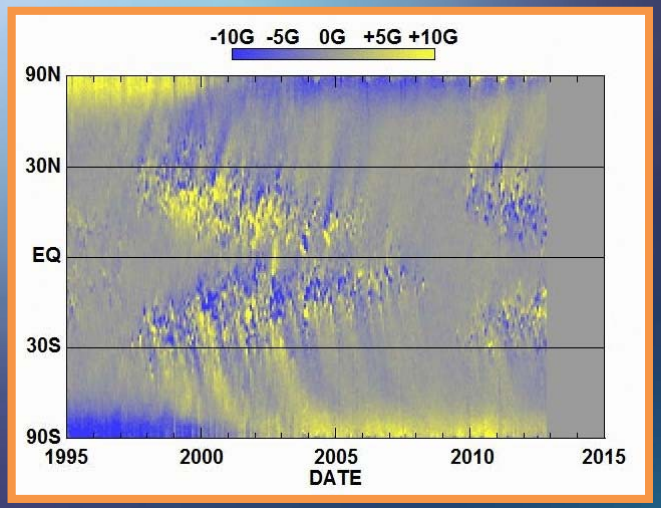

MDI/HMI Polar Meridional Flow
Velocity (m s⁻¹)
Year
60-75

Equatorial N-S Asymmetry

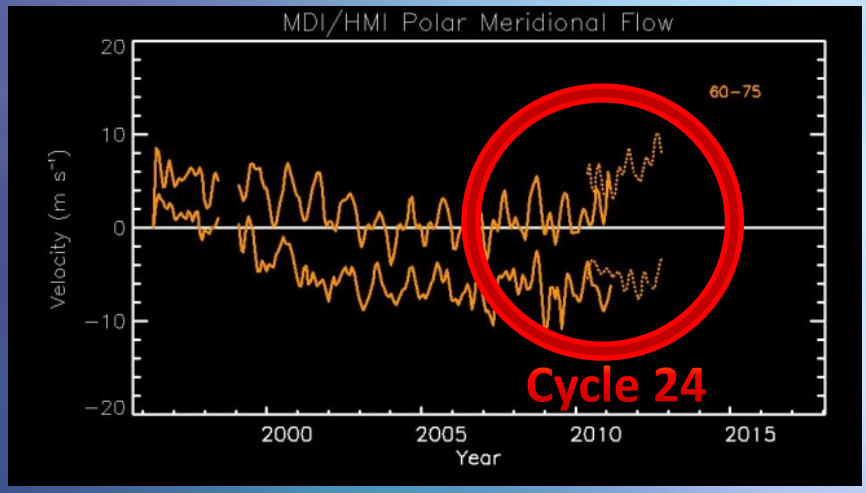


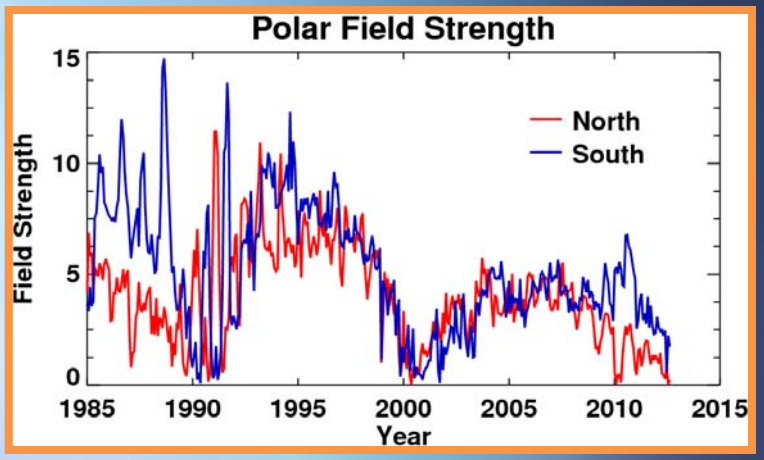


- During cycle 24, a faster poleward flow is seen in the South at low latitudes.
- A fast meridional flow at low latitudes inhibits the cross-equator cancellation.
- The meridional flow carries a smaller excess of the opposite polarity to the poles.
- This produces a slower erosion of the polar fields in the South.

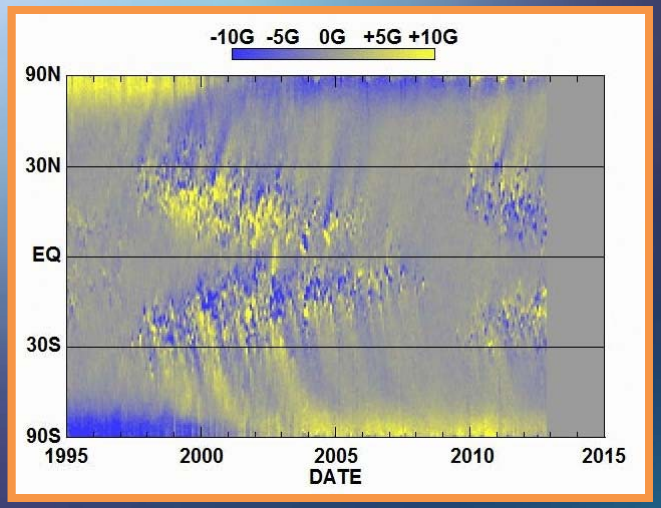


Polar N-S Asymmetry





- The most dramatic asymmetry in the meridional flow is seen at high latitudes.
- During cycle 24, a faster poleward flow is seen in the North at high latitudes.
- This meridional flow carries the dominant following polarity directly to the poles.
- This produces a faster erosion of the polar fields in the North.

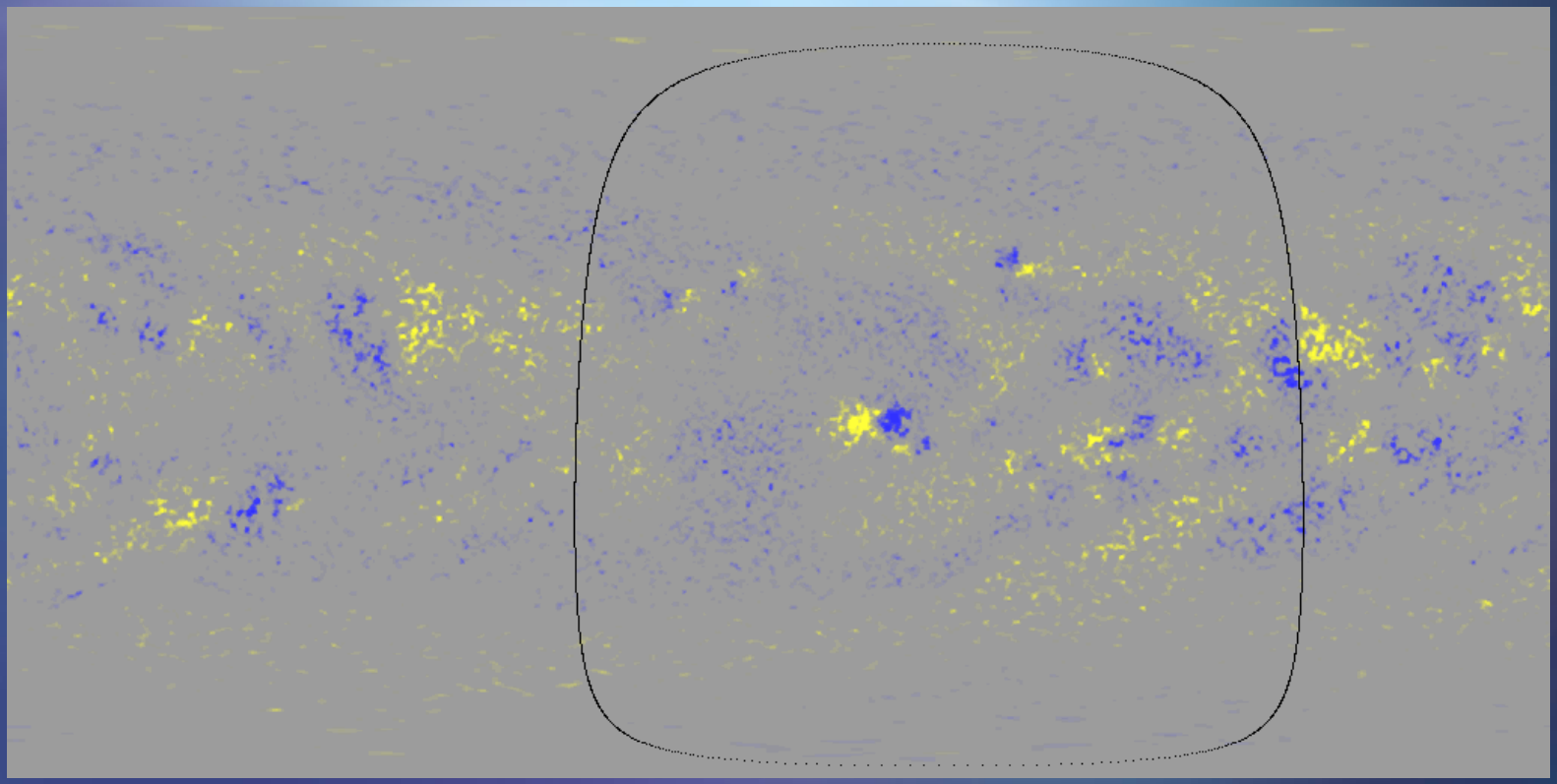


Conclusions

- The addition of the Backwards step dramatically improves the measurements obtained with MDI.
- We do not find evidence for any polar countercells with HMI measurements to date (2010-2012).
- Slight North-South asymmetries are observed in the meridional flow. These asymmetries should contribute to the observed asymmetries in the polar fields and the timing of their reversals.
- We are in the process of using flux transport simulations to determine the relative contribution that variations in the meridional flow have on the polar field strengths.

Flux Transport Movie

Looping video showing 1 year (2001) of Flux Transport



SH13C-2267

Reproducing the Photospheric Magnetic Field Evolution during the Rise of Cycle 24 with Flux Transport by Supergranules

D.H. Hathaway; L. Upton

Atmospheric Display Courtesy of Hurricane Sandy. Huntsville, AL. Oct 30th 2012. Photo Credit: D. H. Hathaway