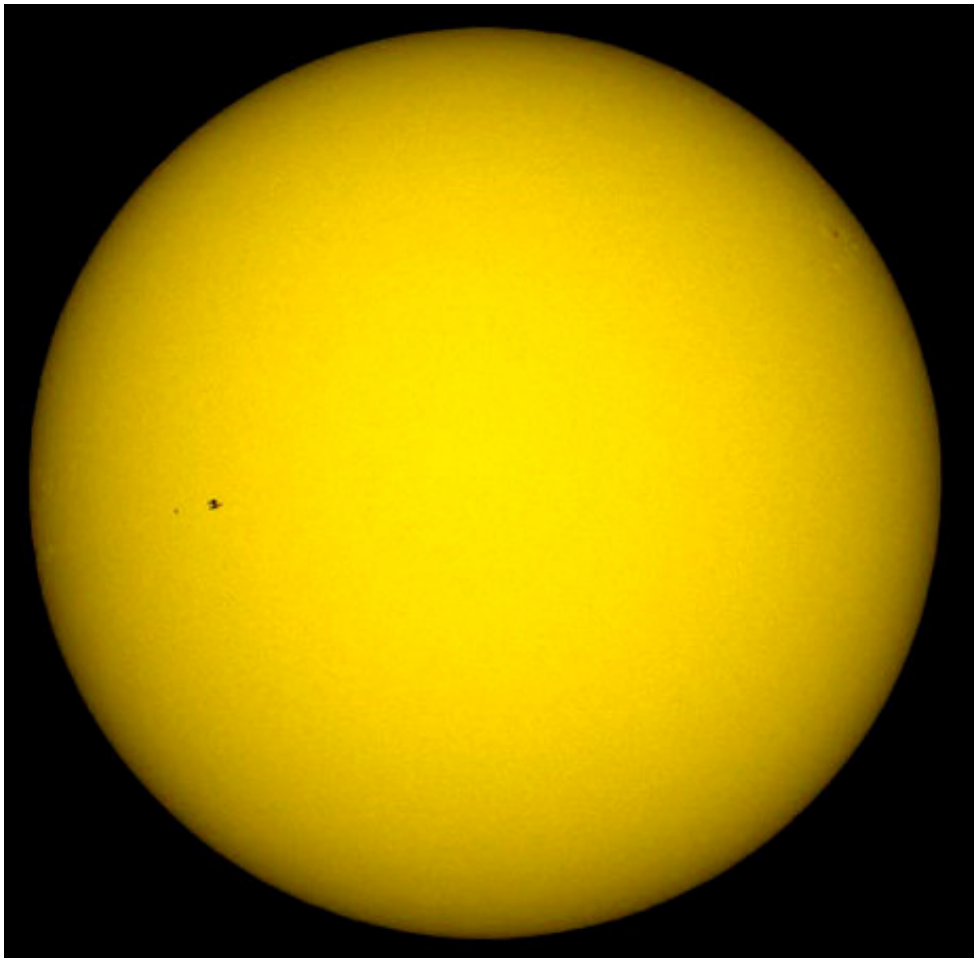
Napa Meeting: Onset of Solar Cycle 24 Global Photospheric Field Evolution and the Coronal Response

A talk about
photospheric fields



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Napa Meeting: Onset of Solar Cycle 24 Global Photospheric Field Evolution and the Coronal Response

A talk about
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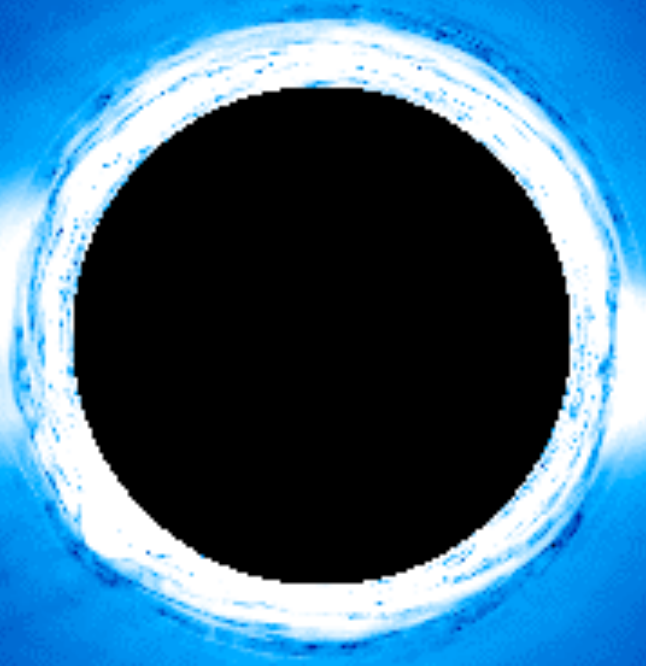
and tie into a recent
paper about the
tilted magnetic
dipole…

The Tilted Solar Dipole Observed Near Solar Minimum

Norton, Petrie & Raouafi, *ApJ*, Aug 2008

Why is the solar magnetic dipole tilted with respect to the rotational axis, even at solar minimum?



Log of the Corona brightness
9 March 1996 LASCO C2

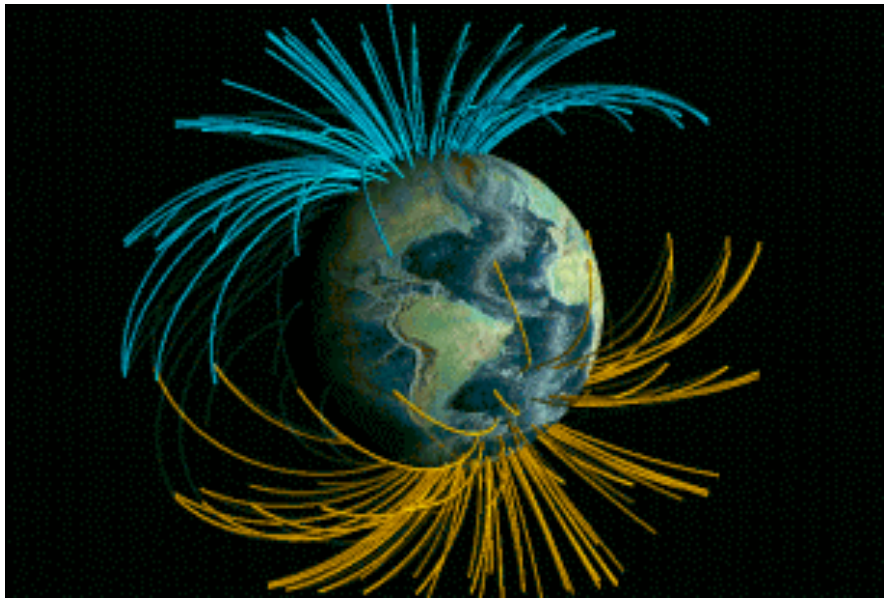
Coronal geometry near minimum - equatorial streamers trace out the positions of the closed field lines & the heliospheric current sheet is in its most simple configuration - a tilted dipole equator.

Astrophysical bodies often have a magnetic axis not aligned with their rotational axis:

In 1905, shortly after composing his specialty relativity paper, Einstein called the Earth's magnetic field one of the great unsolved problems for modern physicists.

⇒ *The geodynamo is the process by which the motion of conductive fluid in the molten core regenerates the magnetic field. (See Glatzmaier reviews.)*

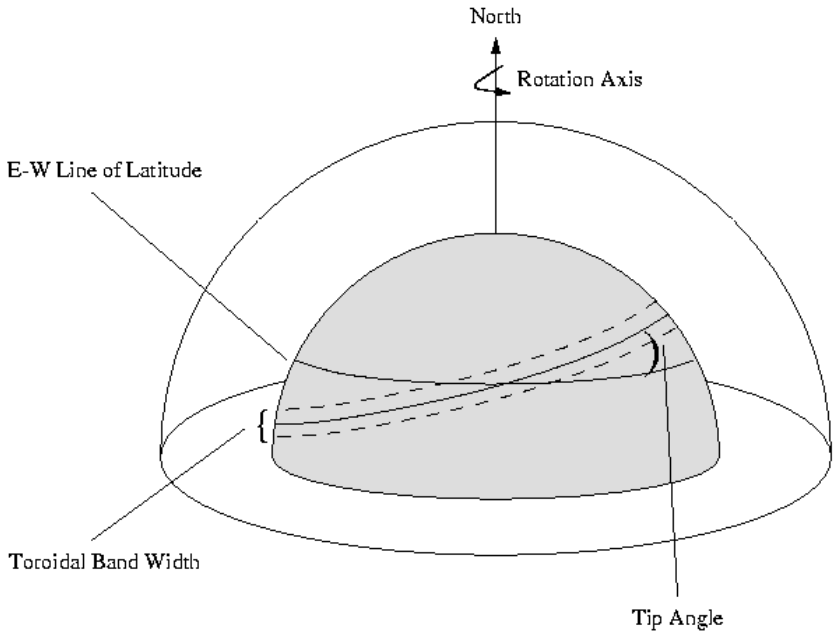
⇒ *The axis of the Earth's magnetic field is tilted 11° with respect to the rotational axis of the Earth.*



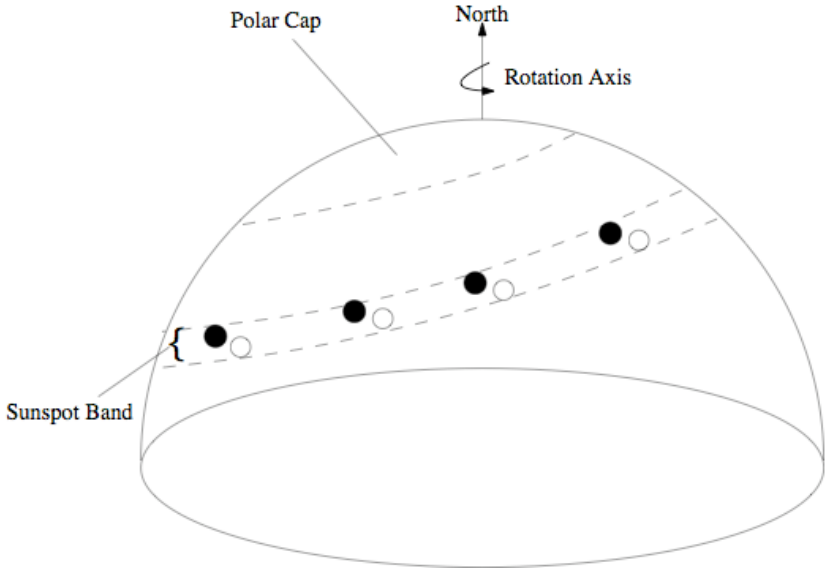
Glatzmaier, Roberts & Foss

How I became interested in the magnetic dipole geometry and resultant HCS…

Peter Gilman and I found the locations of spots early in Cycle 23 (when spots appeared at high latitudes) mapped out an m=1 mode tipping of the toroidal bands in the interior.



Would the dispersal and transport of this non-axisymmetric flux distribution create slightly off-axis magnetic polar caps that could contribute to a tilted dipole geometry? (i.e., a nonzero tilt at solar minimum)



Questions:

- Why is the tilt of the heliospheric current sheet non-zero at all times during solar minimum?

- Do the equatorial streamer locations trace out a tilted dipole geometry as expected if the magnetic poles were not aligned with the rotational axis?

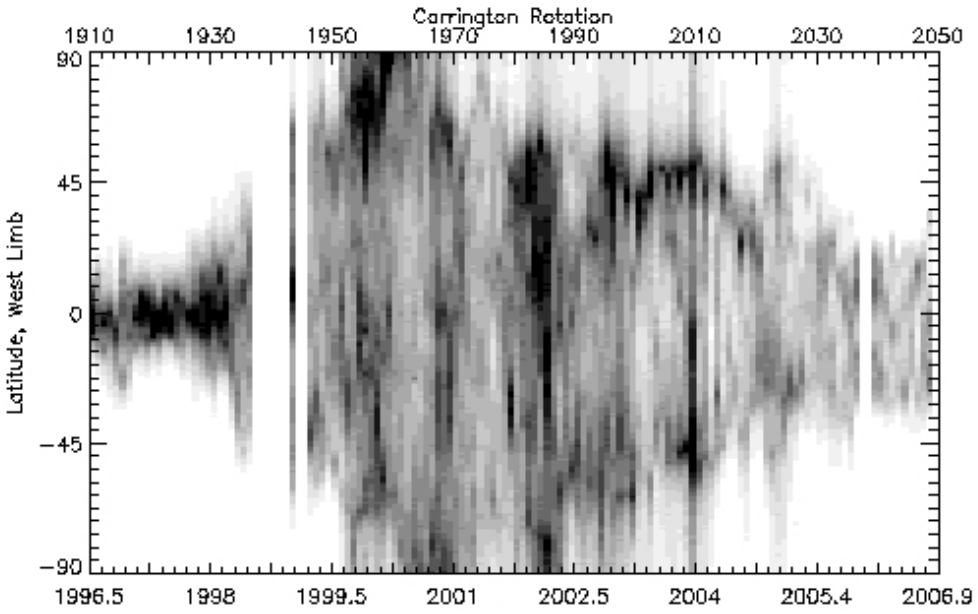
- Is the tilt angle measured from streamer locations different than the value predicted by the PFSS model? If yes, why?

- Are the open field regions (e.g. polar coronal holes) and their underlying uni-polar magnetic caps centered on the N and S poles of the rotational axis?

- Is there persistent symmetry between the N and S polar cap geometry?

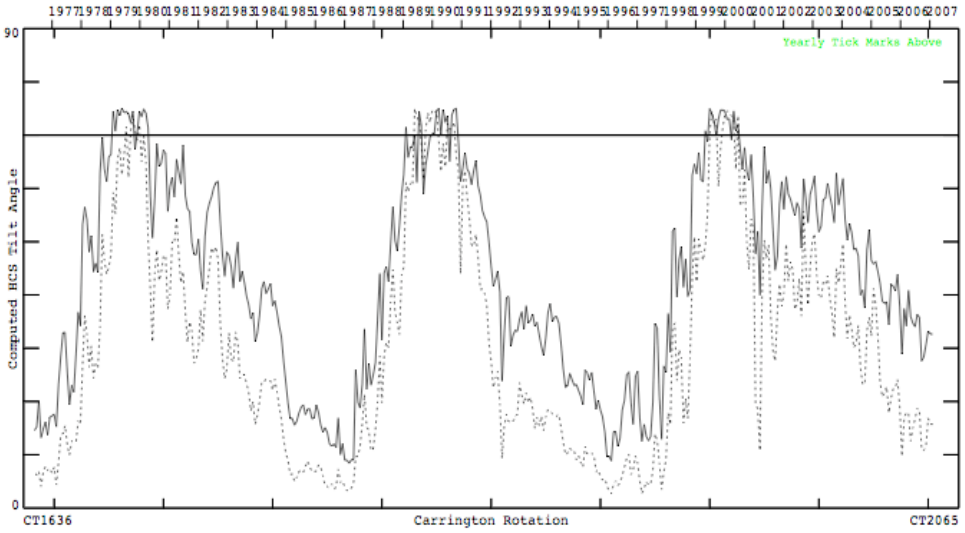
Answer:

Slightly off-axis polar caps could explain some of the observed phenomenon. Perhaps our poor ability to measure the polar fields have allowed a persistent off-axis polar cap geometry to go unnoticed.



- Data from West Limb LASCO K-corona at 5 R are shown for CR 1910 - 2050. Each CR map was compressed into a single vertical strip and plotted. Minimum was between 1909-1914 (Harvey & White).

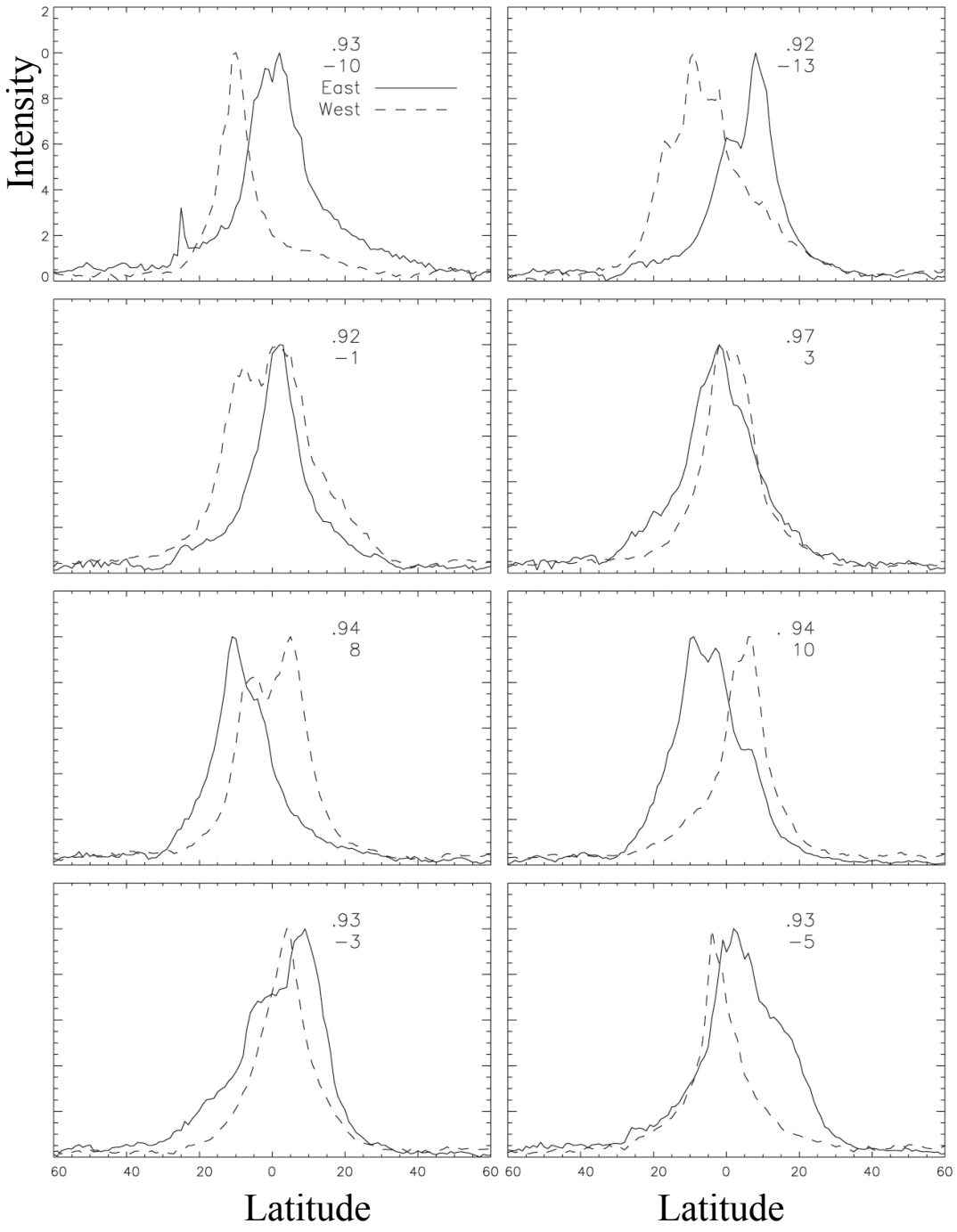
Maximum Inclination of the Current Sheet (N-S Mean): 1976-2007



Solid=Classic PFSS Model

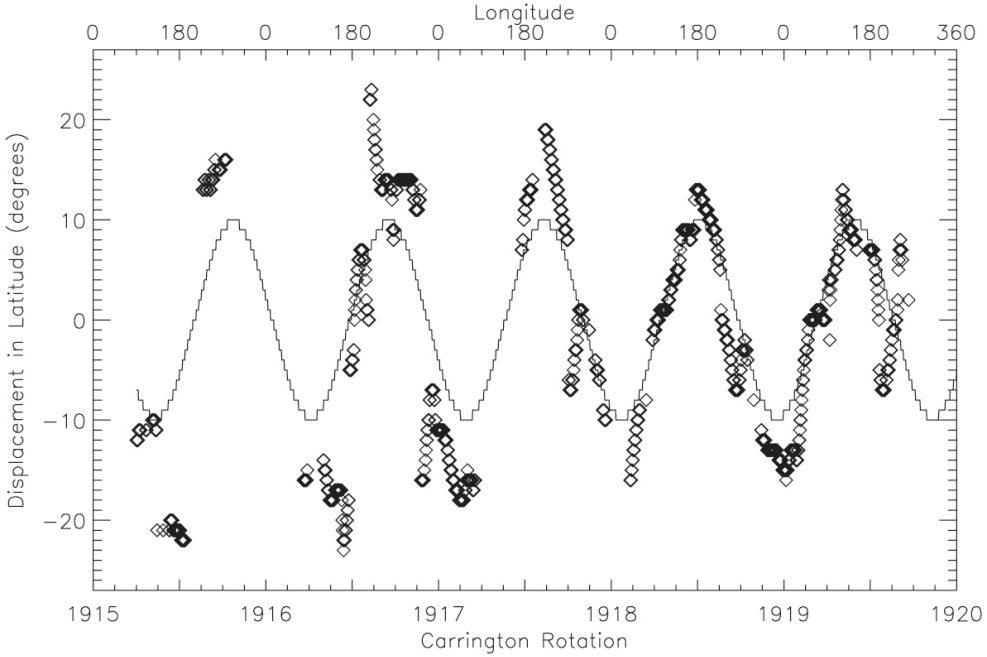
Dashed=Radial Rs=3.25

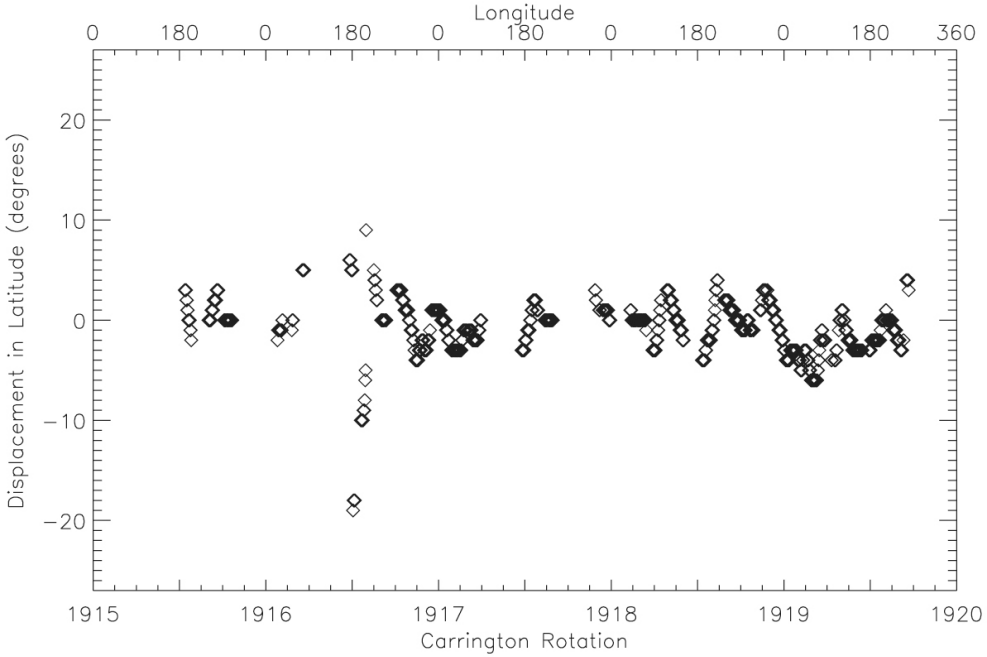
- Calculated inclination of current sheet using Wilcox Solar Observatory data using 2 models:
- 1) the classic PFSS (with polar field correction) model as compared with
- 2) PFSS model with the radial boundary condition in the photosphere and no polar field correction.



Analysis:

Cross correlating E and W limb streamer profiles as observed simultaneously on each limb for Carrington Rotation 1918. Time progresses from right to left, top to bottom and the cross correlation coefficient and shift is noted in the sub-plots.





B0 = 5.6 3.2 -0.3 -3.6 6.1 -7.2

Correlating E and W Limb Streamer Location During the Solar Minimum Between Cycle 22 and 23*

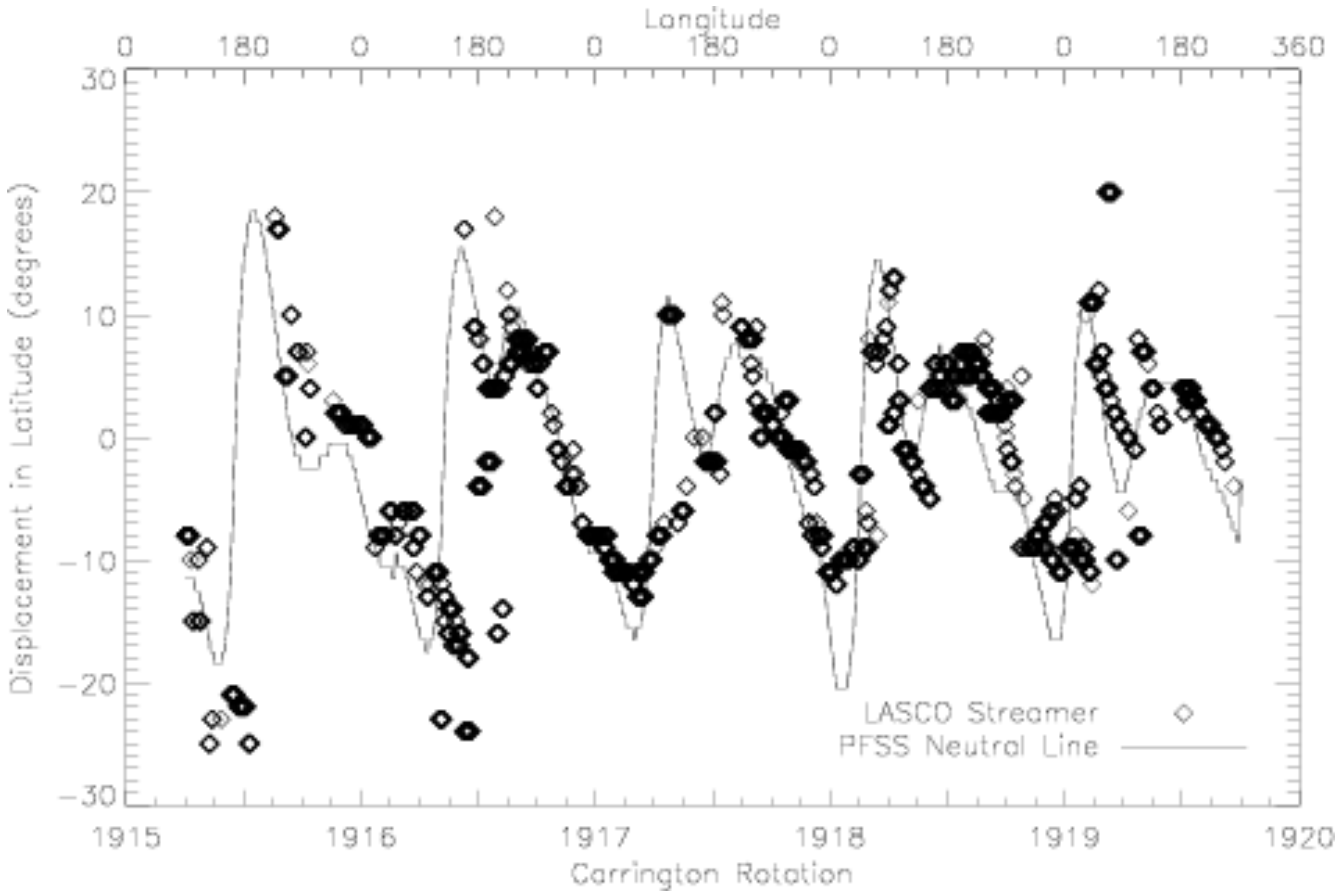
Plotted is the displacement in latitude between streamers on the E and W limb of the sun observed simultaneously. Overplotted is a periodic signal expected from a tilted dipole geometry. By CR 1925 this sinusoidal structure disappears.

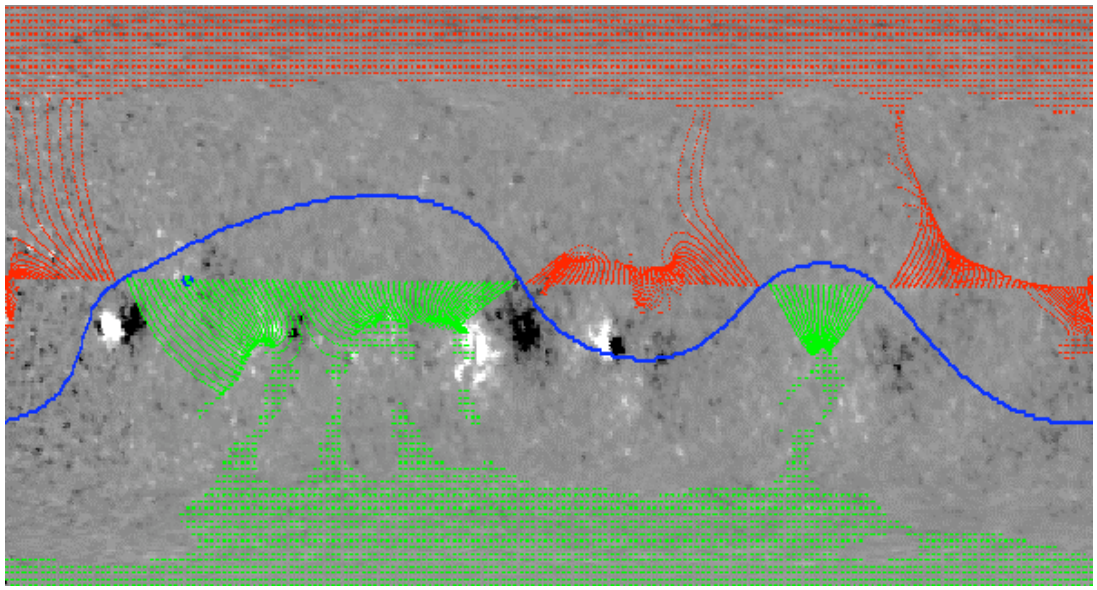
Plotted is the displacement in latitude that result from cross correlation of the West limb with itself when it appears on the East limb 14 days later - a good measure of error in the analysis due to evolution. RMS values ~ 10 (top) and 2(bottom) degrees.

*Minimum was May - Sept of 1996 (Harvey and White, 1999) and CR 1909-1914. There are gaps in the SOHO data during this period so we can only fully analyze data just after the minima proper.

Is this method a good measure of the neutral line location?

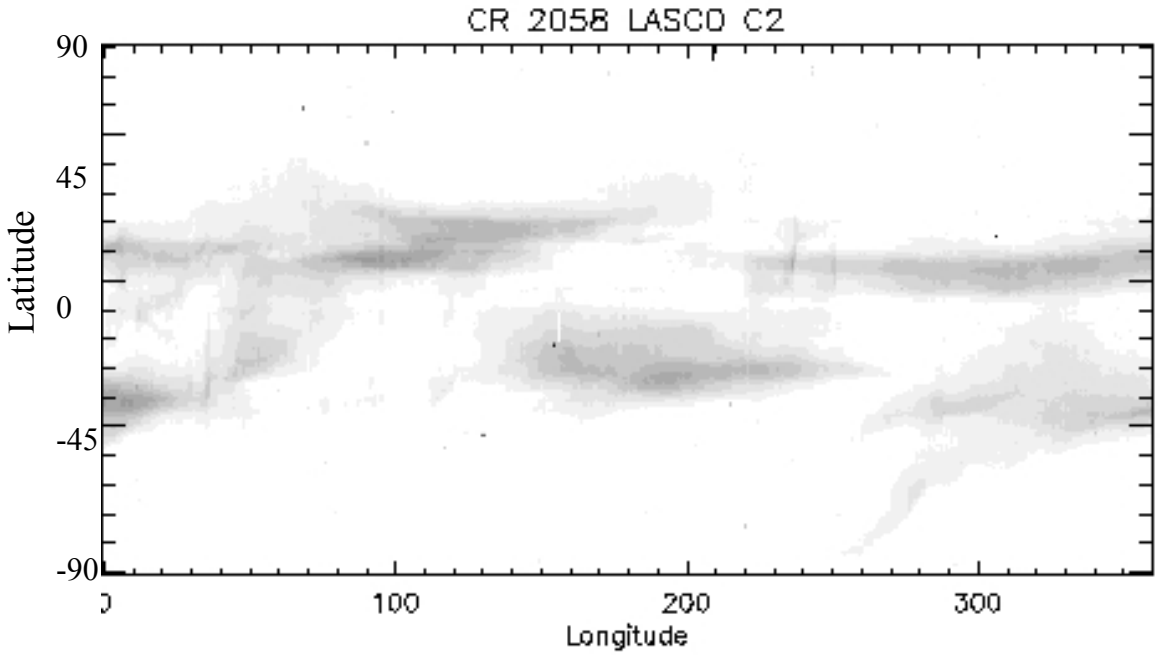
Comparison of PFSS Neutral Line Location and Streamer Location CR 1915-1920



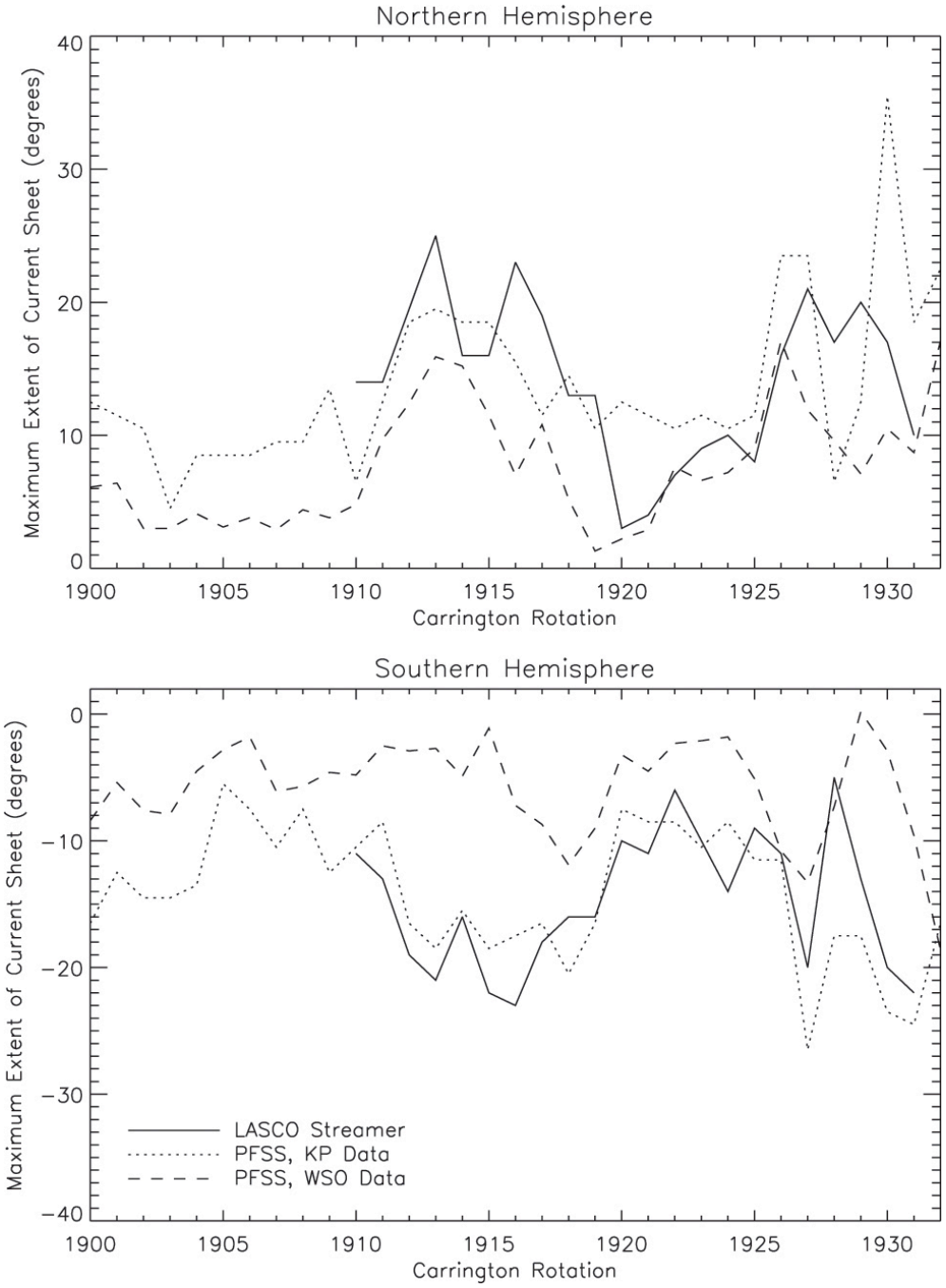


The modeling of the neutral line location compares favorably with the observed location of streamers in coronal intensity.

The PFSS synoptic field plot from GONG magnetograms July 2007. (G. Petrie)



CR 2058 - LASCO observations of streamer location in a Carrington Rotation format



Maximum Extent of Current Sheet For CR 1911-1932

Compare streamer location (solid line) as observed in LASCO data with the predicted PFSS values using Kitt Peak magnetogrrams (dotted) and Wilcox Solar Observatory (dashed).

North hemisphere is top plot
South hemisphere is bottom plot.

Streamer location best agrees with KP PFSS Results. On average, the difference between the observed and predicted (KP) locations are ~5 and 3 degrees in the N and S hemispheres.

The values from KP and LASCO are consistently greater than those predicted by Wilcox Solar Observatory.

Determine the center-of-gravity (or centroid) of the coronal holes in EIT data for successive Carrington Rotations….

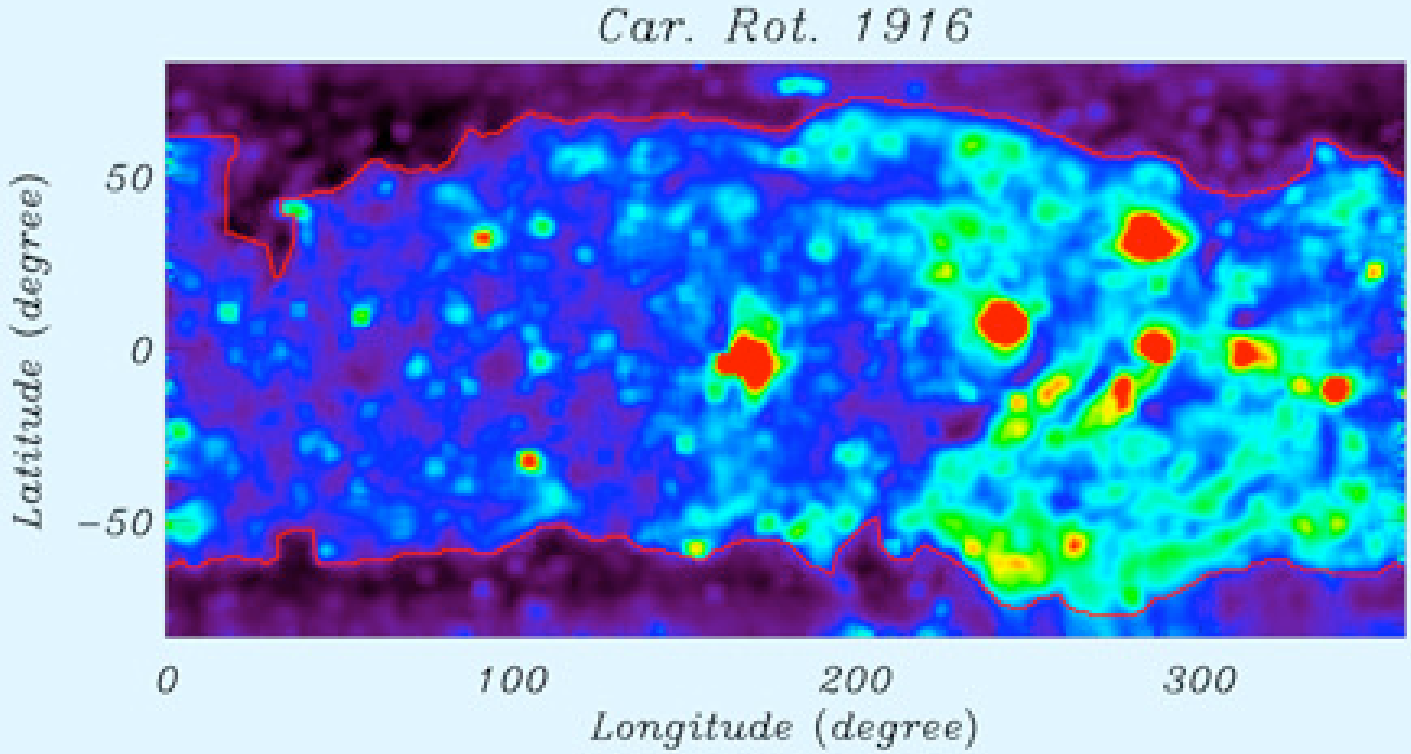
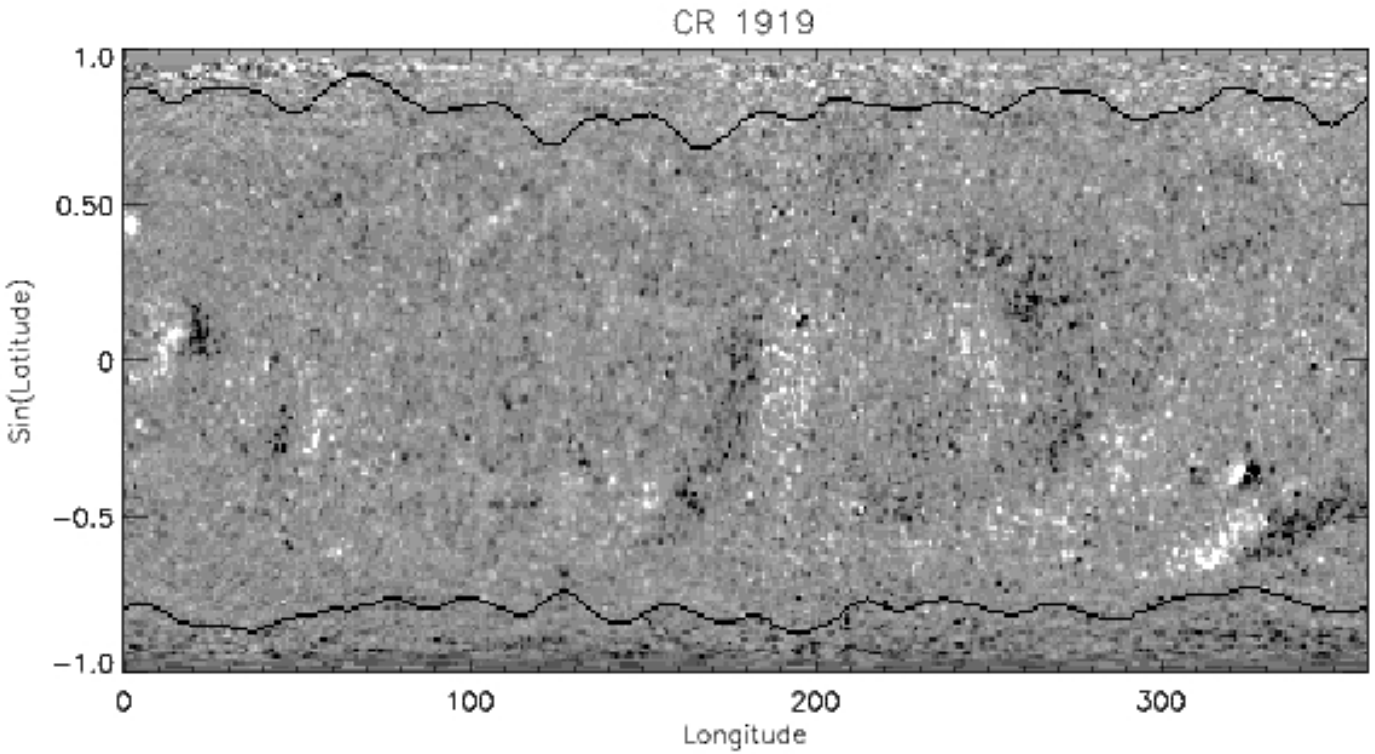
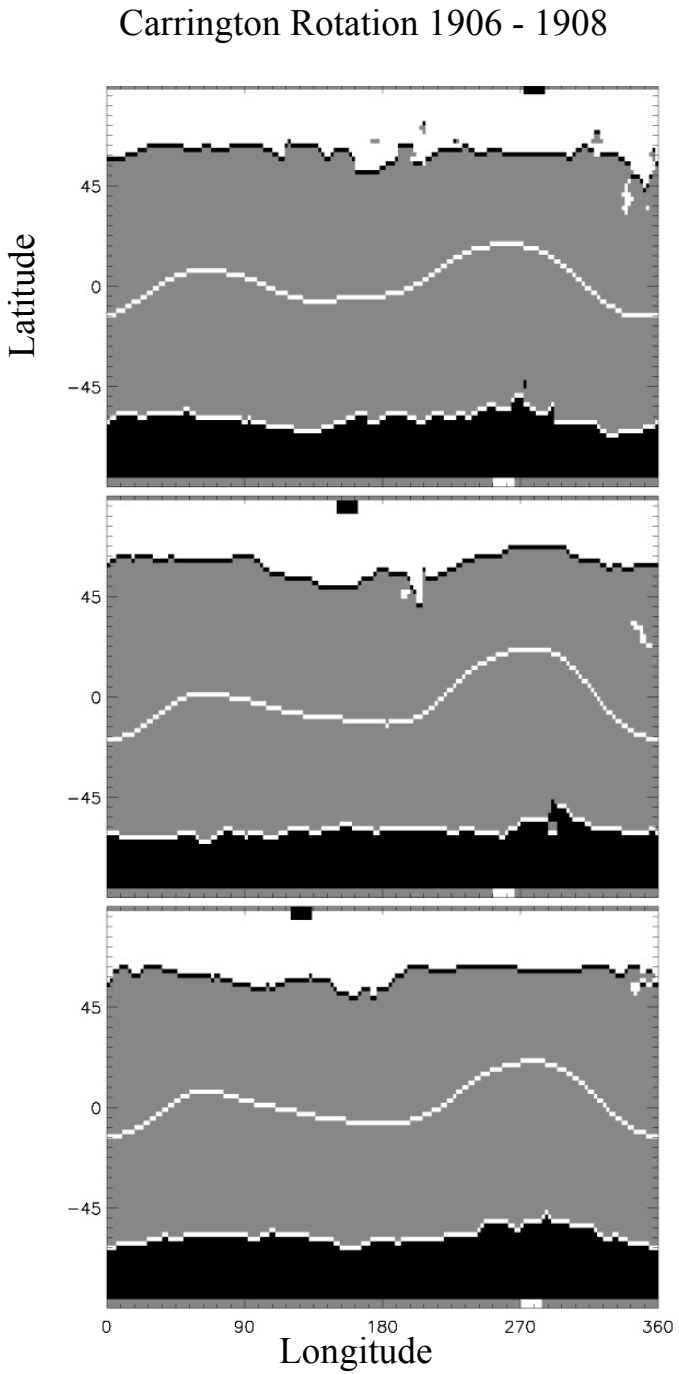


Fig 7. For each EIT 195 Angstrom synoptic map, the edges of the polar holes are selected visually after smoothing the map to remove noise and smooth boundaries. The boundary device coordinates are translated into latitude and longitude and used to compute the COG coordinates of each polar hole.

Determine the center-of-gravity (or centroid) of the polar caps in Kitt Peak magnetogram data for successive Carrington Rotations….



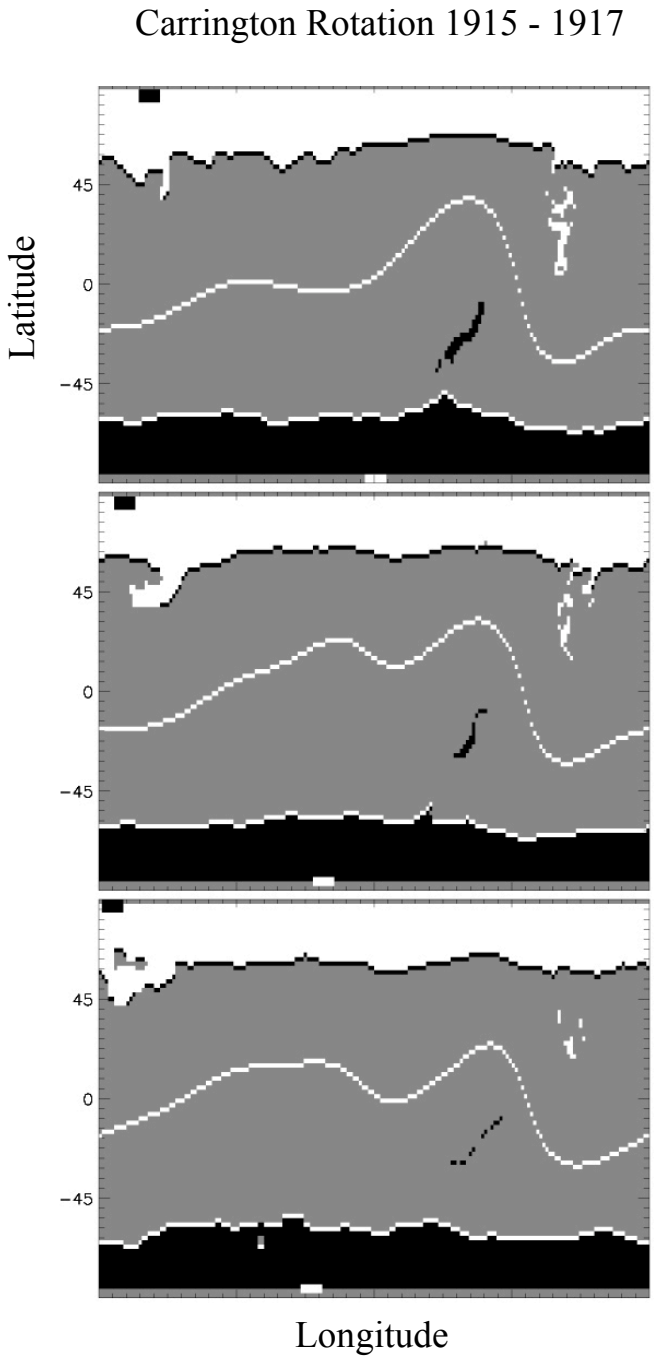
To determine the magnetic boundaries for each longitude, I assign as a function of latitude the sum the field from the pole to that location. The polar cap boundary is defined as the latitude at which the slope of the derivate of this function is zero. (The slope is smoothed 3 pixels). As you can see - a very noisy endeavor. There may be a more optimal way to do this.



Determine the center-of-gravity (or centroid) of Coronal Holes in PFSS maps

Because the PFSS modeling using KP magnetograms captures the observed geometry of the streamers and polar holes, we model the coronal geometry with PFSS to extend our analysis to time periods not sampled by LASCO and EIT.

Black/White rectangular boxes mark location of COG of the coronal holes.

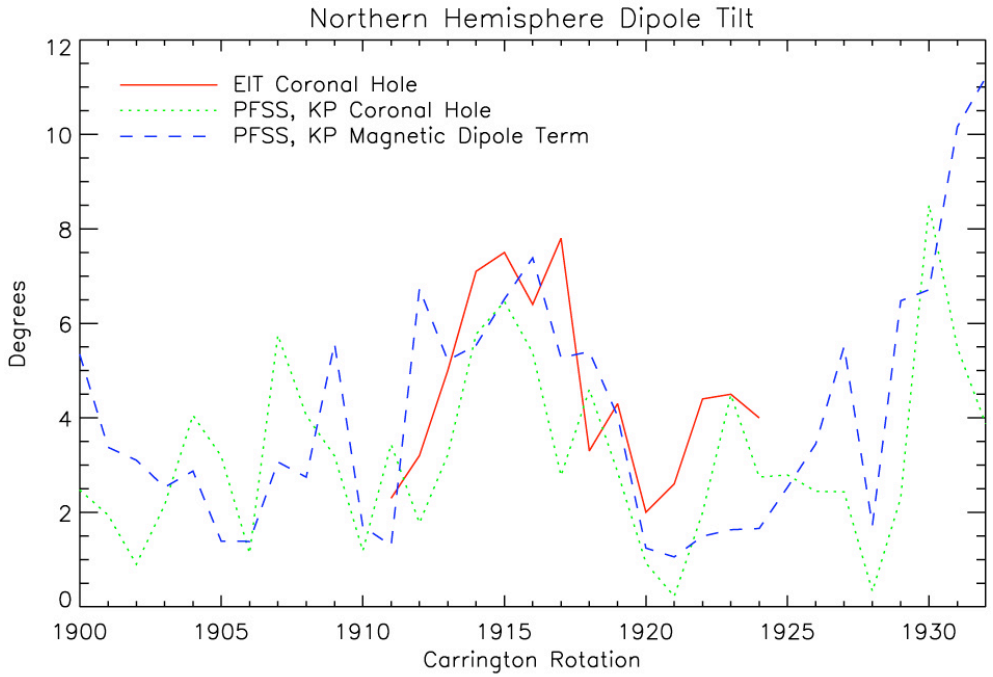


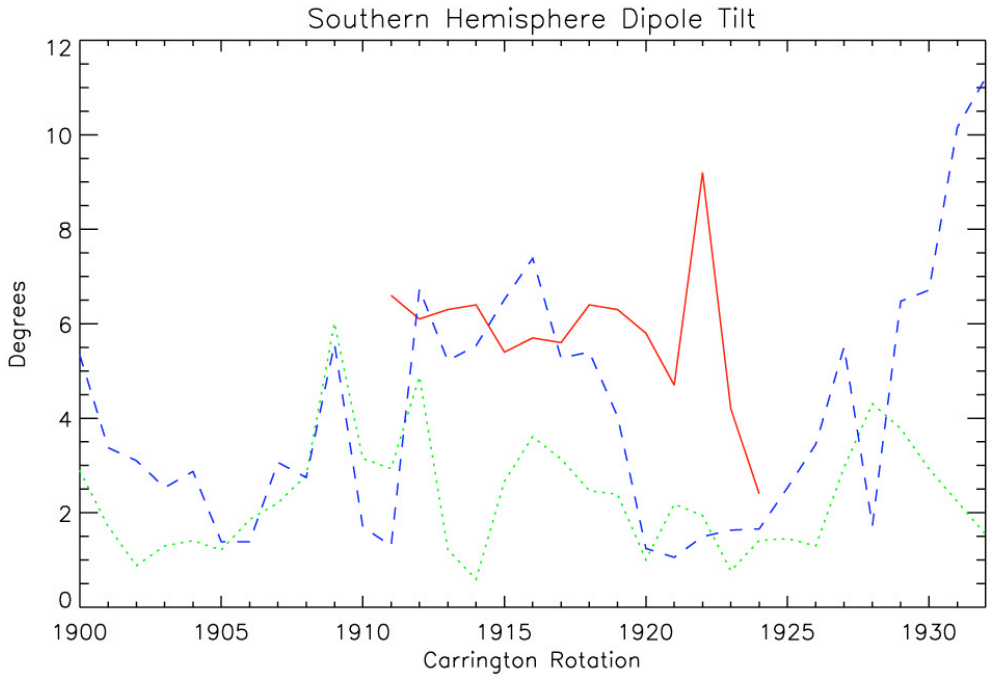
Determine the center-of-gravity (or centroid) of Coronal Holes in PFSS maps

PFSS models using Kitt Peak VT data to determine coronal hole locations and neutral line.

Black/White rectangular boxes mark location of COG of the coronal holes.

Note how responsive the neutral line is to the higher order terms even at minimum when the polar dipole term dominates all other terms.





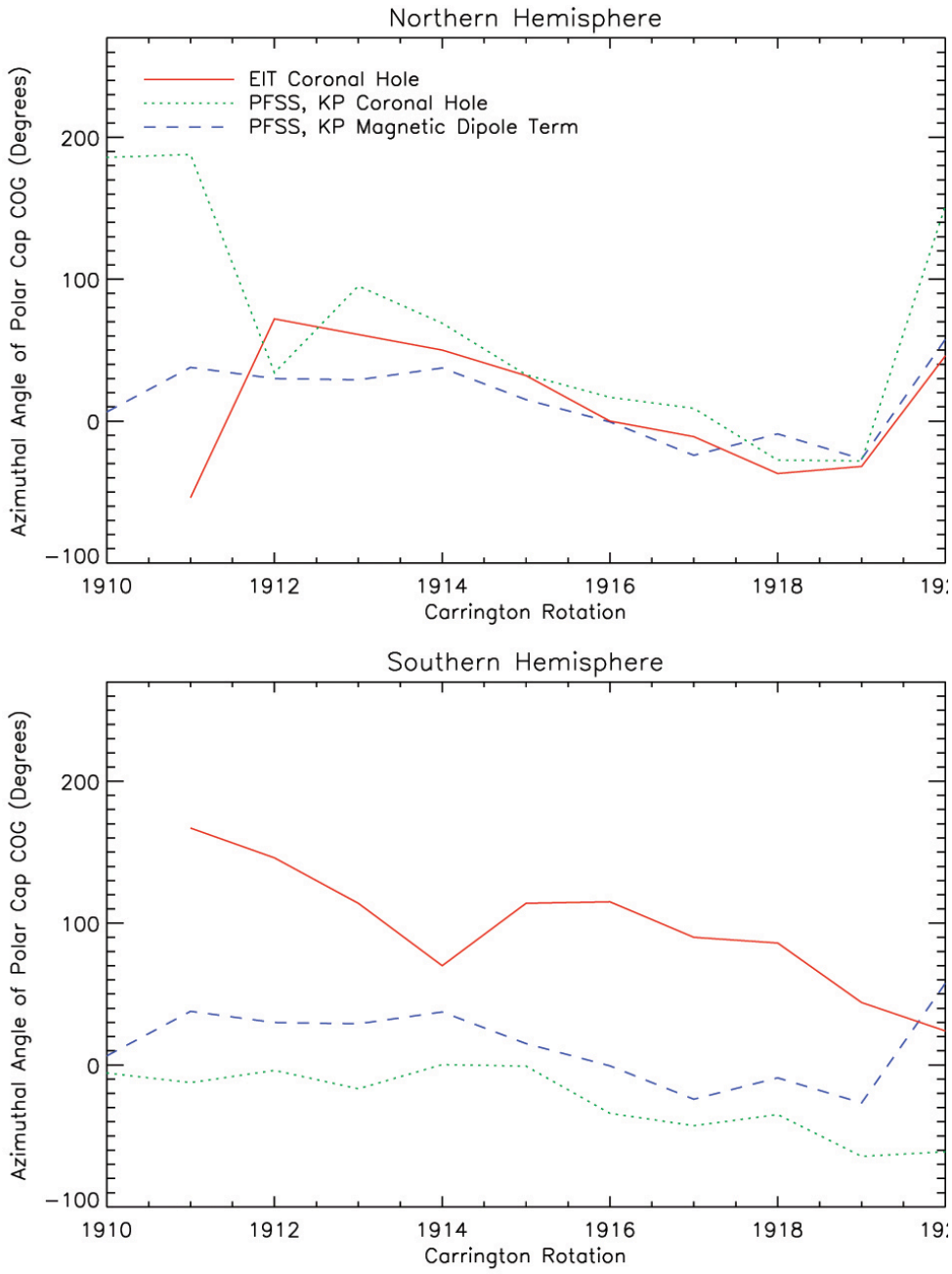
COG Tilt for Polar Cap/ Polar Holes for CR 1910-1932

Compare tilt determined from
EIT polar coronal holes (solid red line).
PFSS coronal hole (dotted green)
And PFSS dipole terms (dashed blue)
determined from Kitt Peak synoptic maps.

North hemisphere is top plot
South hemisphere is bottom plot.

Magnetic signal too noisy to determine Boundaries of polar cap. Some stability in observations of CR 1911-1920.

Average tilt of 4° ± 0.2



Azimuth of COG CR 1910-1920

EIT polar coronal holes (solid red line)
PFSS coronal hole (dotted green)
And PFSS dipole terms (dashed blue)
determined from Kitt Peak magnetogrrams.

North hemisphere is top plot.
South hemisphere is bottom plot.

Azimuthal angle only stable for 8 CRs.
EIT polar coronal holes (solid red line).

Azimuth of COG decreases ~8° per CR,
Indicating a pattern rotating slower than the assumed Carrington rate.

N and S hemisphere COG are not symmetric
Or anti-symmetric, but rather somewhere
in between with their COGs ~60-90° apart.

Azimuth error ~ 6° .

Recipe for a Flat Neutral Line

Wang et al. 1997 -- Flux transport calculation.

Start with a relatively quiet sun photospheric field (CR 1913) and evolve the field with no new emergent flux. Wang et al. assumed a 10 m/s meridional flow that determined the timescale as it carried any flux to mid-latitudes where it is sheared and annihilated.

As the non-axisymmetric field components decay, the streamer belt flattens toward the equator →

but it takes about a year for this occur.

Even if an extended minimum occurred with no activity, Wang et al. did not account for non-axisymmetry of polar caps.

Conclusions

*The research represents an effort to propose a new mechanism for producing/contributing to the tilted magnetic dipole at solar minimum.

*The equatorial streamer locations do trace out a sinusoidal structure in longitude and latitude about the equator for CR 1915-1919 with a > 10° amplitude in latitude and a stable phase in longitude. However, the excursion of the neutral line from the equator is 12°, on average, which is 3× the dipole tilt value. And we observe the neutral line to be very strongly influenced by higher order terms even during solar minimum times when the polar dipole term is the strongest.

* The polar caps' tilt shows a cyclic variation ranging from 0 to 10 degrees with an average value of about 4° from the polar holes. The polar cap COG does not maintain a consistent phase in longitude except for a few Carrington rotations right at solar minimum.

* Dynamo action seems to prefer a tilted dipole geometry.

* ***To do:*** Conduct similar study for the most recent solar minimum. ***Watch for non-axisymmetry at the poles.***