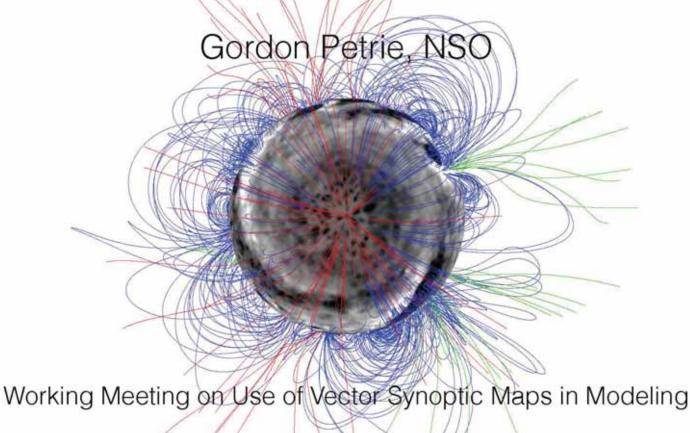
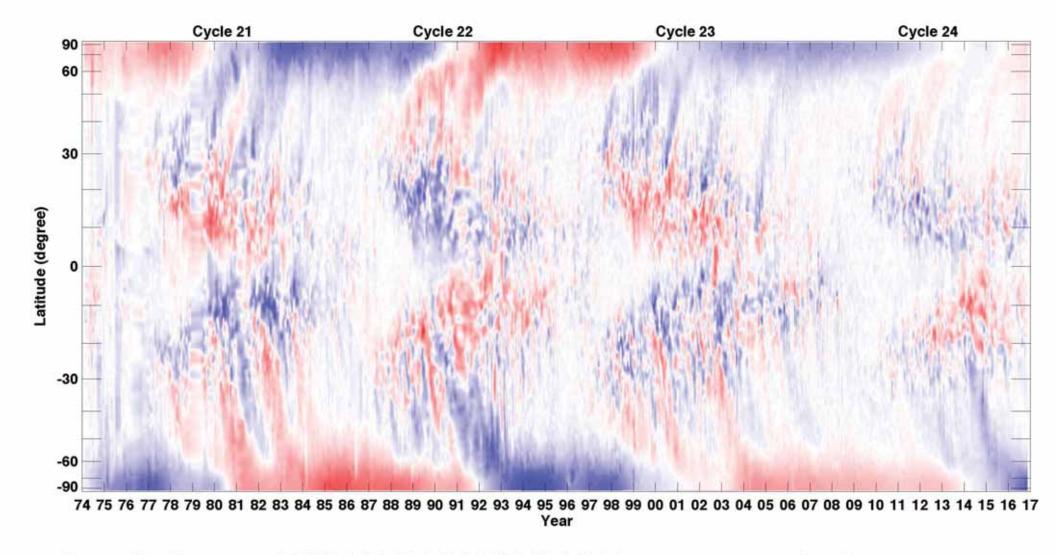
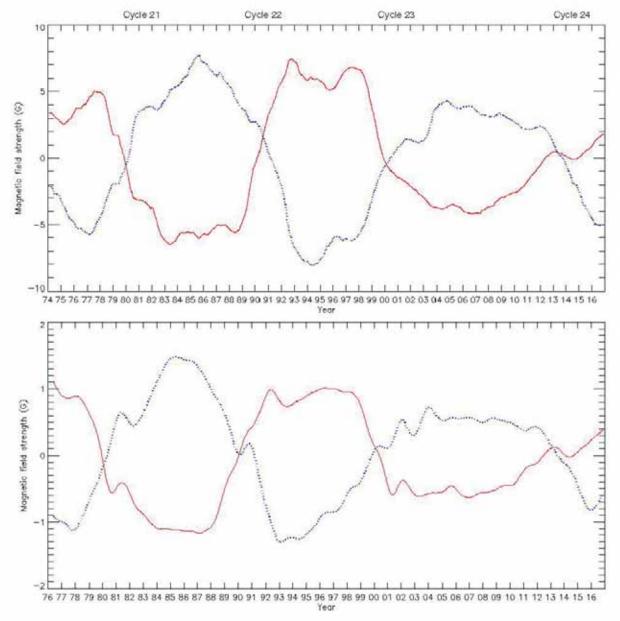
Importance of Polar Fields for Modeling, and Approaches to Improve Polar Field Representation in Vector Synoptic Maps





Butterfly diagram of NSO KPVT & SOLIS/VSM field measurements (1974-present, bad images filtered out). Red=positive, blue negative, saturates at ±15G. Recent highlights: hemispheric activity asymmetry, asymmetric polar field changes. Flux is transported from active latitudes to poles in unipolar surges. Polar fields respond to these surges.

Polar reversals can be fast (cycle 21, 22) or slow (cycle 23 S, 24 N).



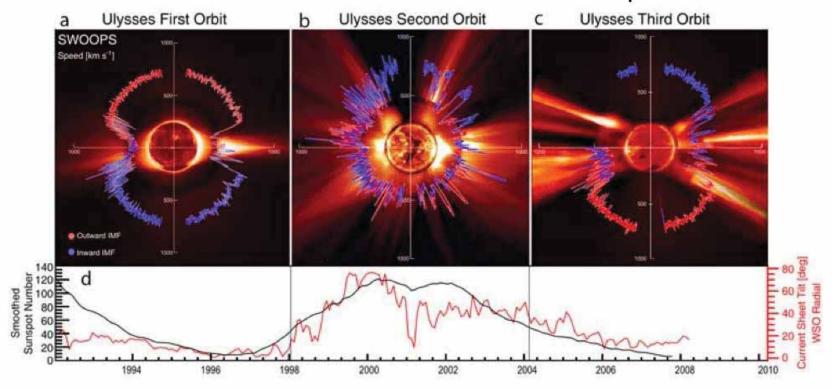
Cyclical polar field reversals

The north (red solid lines) and south (blue dotted lines) polar fields measured by NSO (from ±65°, top) and Wilcox (from ±55° to the poles, bottom) are plotted against time.

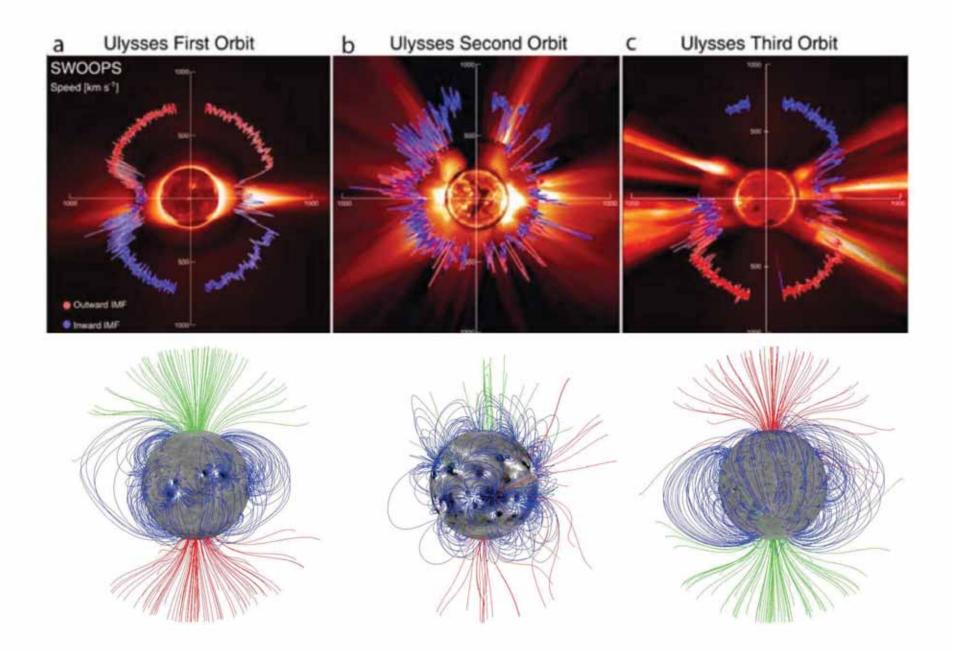
Cycle 23 polar fields only 60% as strong as previous two cycles.

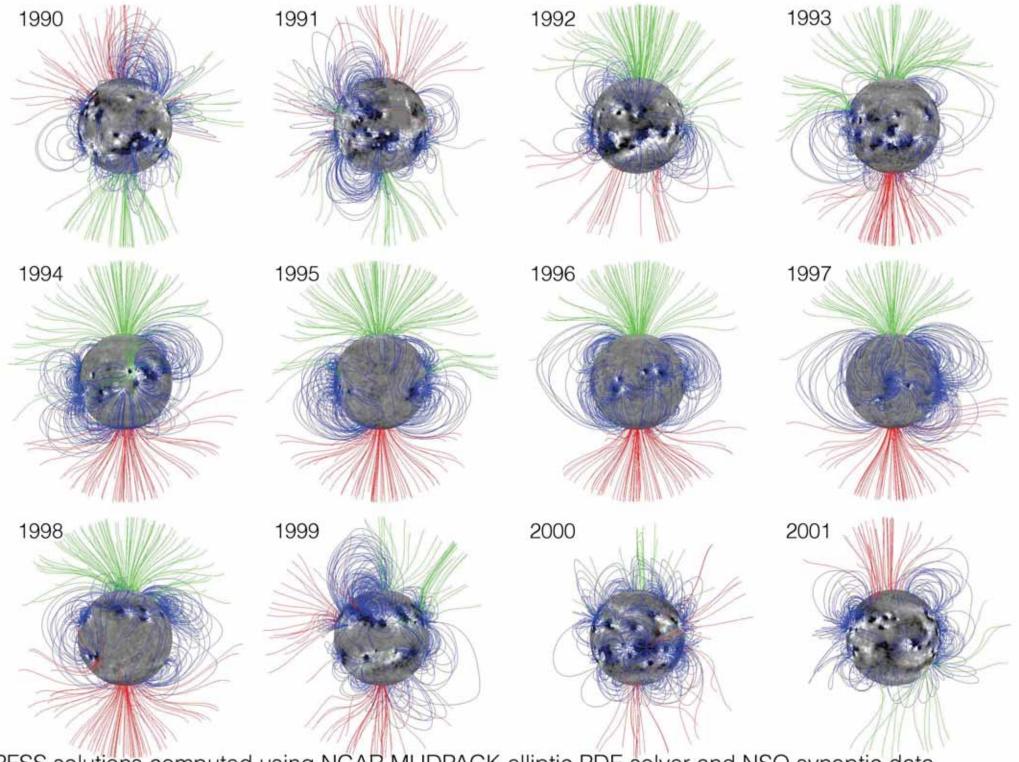
Cycle 24: the north polar field reversed earlier, then reversed two more times, is slowly strengthening. The south polar field reversed quickly, looks healthier.

Influence over corona and heliosphere

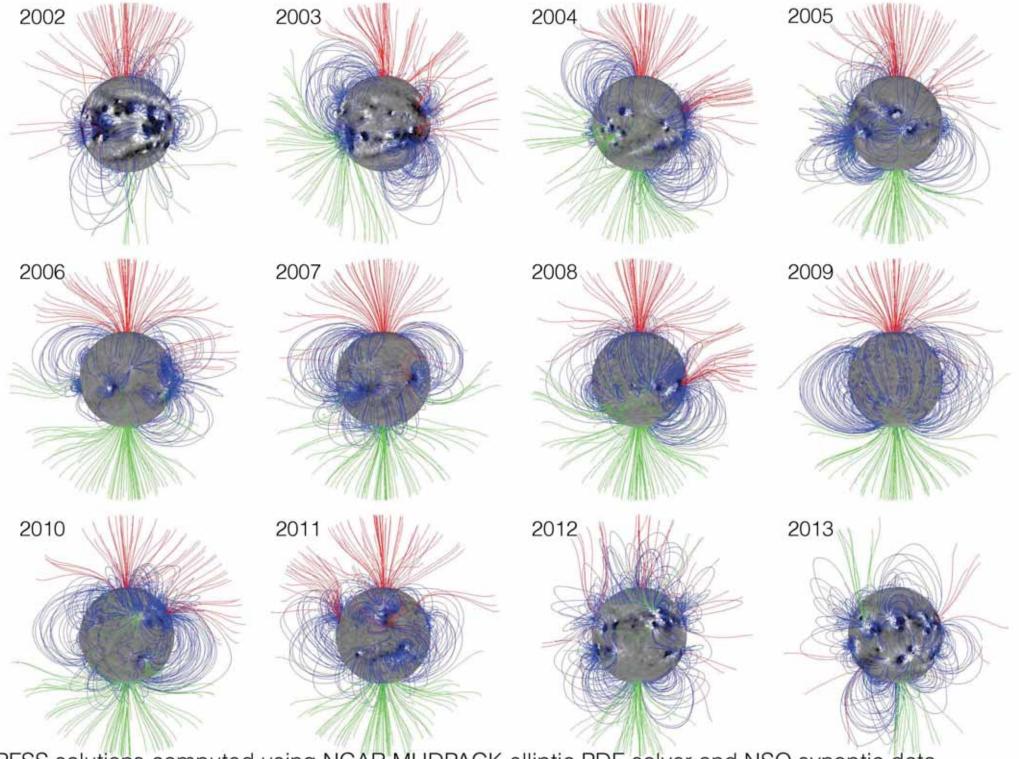


(a-c) Polar plots of the solar wind speed, colored by IMF polarity, for Ulysses' three polar orbits. The earliest times are at nine o'clock and time progresses counterclockwise. (d) Contemporaneous values for the smoothed sunspot number (black) and heliospheric current sheet tilt (red). In Figures a-c, the solar wind speed is plotted over characteristic solar images for solar minimum for cycle 22 (8/17/96), solar maximum for cycle 23 (12/07/00), and solar minimum for cycle 23 (03/28/06) from SOHO/EIT, the Mauna Loa K coronagraph, and the SOHO C2 white light coronagraph. From McComas et al. (2008).

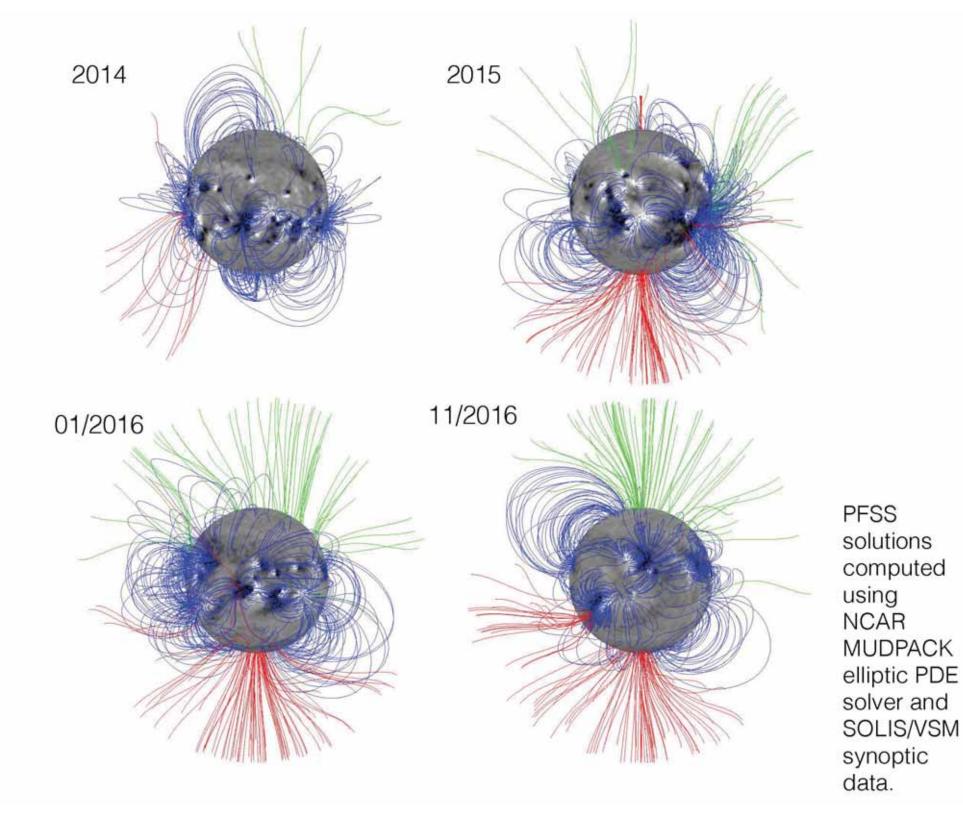


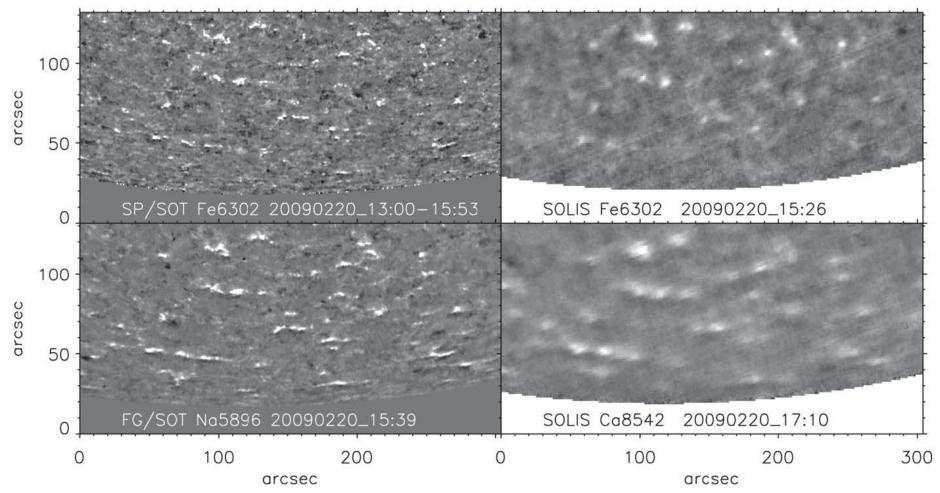


PFSS solutions computed using NCAR MUDPACK elliptic PDE solver and NSO synoptic data.



PFSS solutions computed using NCAR MUDPACK elliptic PDE solver and NSO synoptic data.





Nearly simultaneous south pole line-of-sight field observations with the pole tipped toward Earth by 7°.04. Left: Hinode observations. Right: SOLIS/VSM observations. Top row shows photospheric (630.2 nm) observations, bottom row shows low and mid chromosphere observations. White represents the fields directed toward the observer and black away. VSM and SP observations saturate at ±30G, and FG observation saturates at ±0.006 I_C in circular polarization. From Jin et al. (2013).

Outline

Will discuss two approaches to improving polar vector field representation in synoptic maps

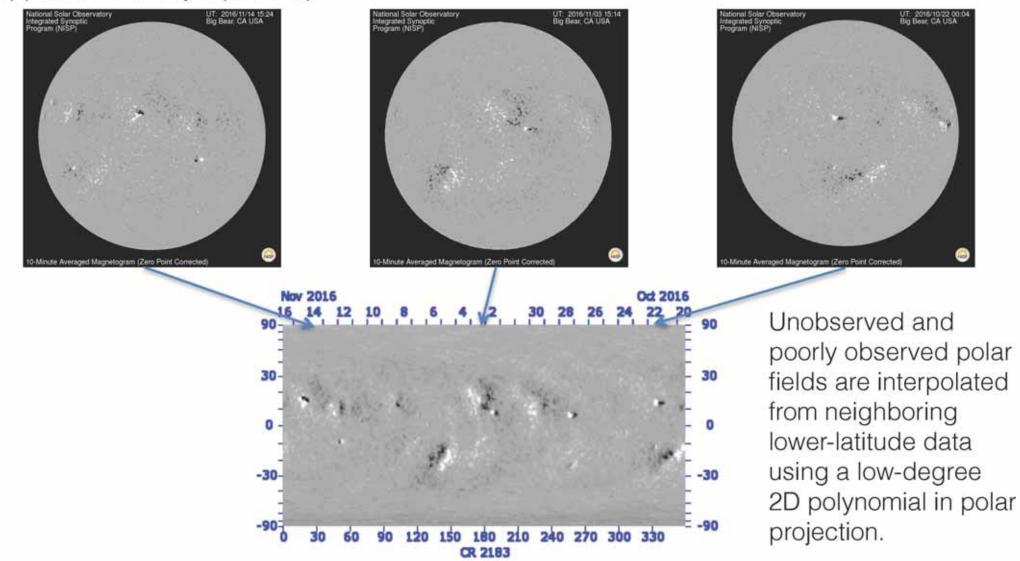
- Use high-resolution data to resolve polar vector field structure at relevant spatial scales.
- 2. Exploit superior sensitivity of the line-of-sight data at the highest latitudes and combine with full-disk vector data at lower latitudes

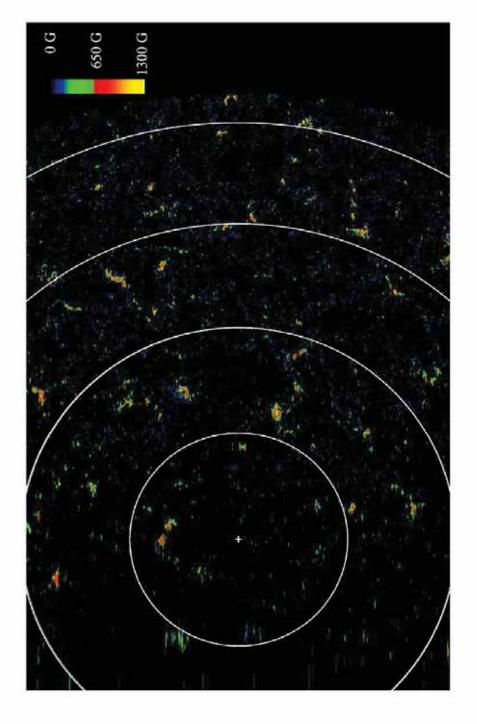
Alternative solutions not covered here:

- 1. Launch new vector magnetograph missions to other viewpoints such as L₄ and L₅, or a polar orbit (Alexei involved in discussions).
- Develop flux-transport model for photospheric vector field (Marc's future project?).

Diachronic photospheric synoptic map construction

Three full-disk images are shown: one from Oct 22 early during CR 2183 (right), one from Nov 3 near the middle of that rotation (middle) and one from Nov 14 near the end (left). The images are remapped to heliographic coordinates and positioned on the time/longitude axis of the synoptic map (bottom). The arrows show where the central meridian of each image appears on the synoptic map.



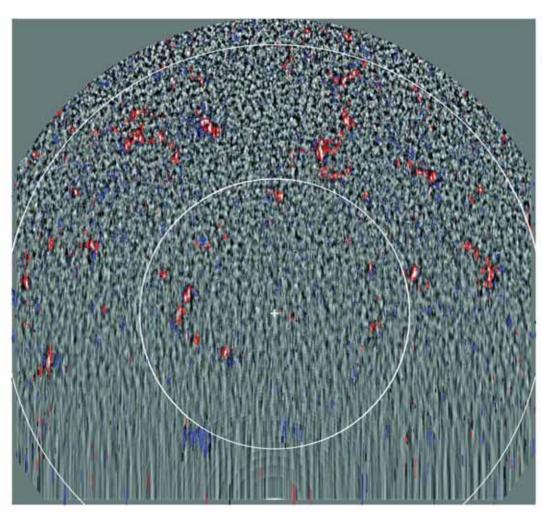


High-resolution observation of the polar field

South polar view of the magnetic field strength taken by Hinode/SOT/SP at 12:02:19-14:55:48 UT on 2007/3/16. East is to the left, west is to the right, and the observation was carried out from the top down. Spatial resolution is lost near the extreme limb (i.e., near the bottom of the figure). The pixel size is 0.16". Latitudinal lines for 85°, 80°, 75°, and 70° are shown as large circles, while the plus sign marks the south pole.

From Tsuneta et al. (2008).

Large flux elements tend to be nearly vertical, associated with faculae

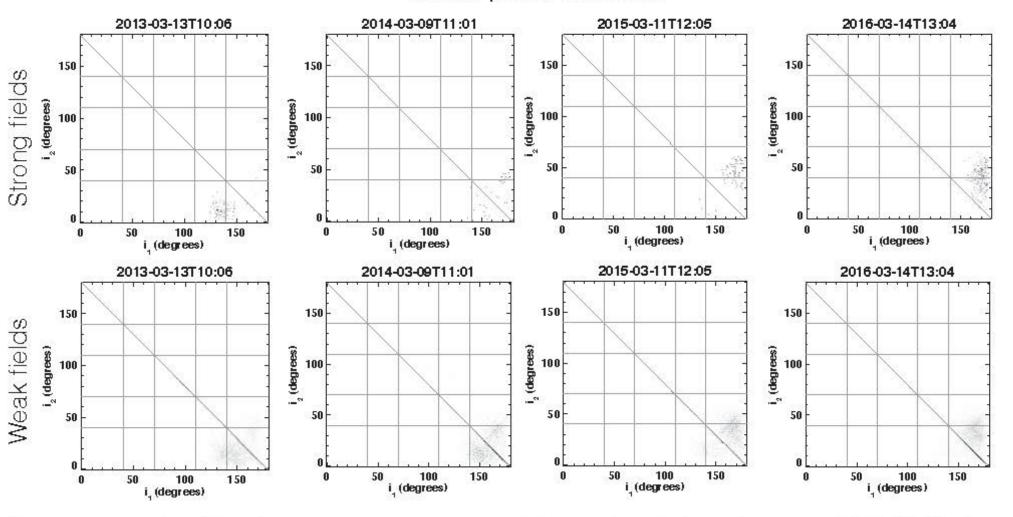


Polar view in the continuum for latitudes above 80°.

Colored contours contain locations with average field strength >200 G. Red indicates regions where the local inclination i < 25° (vertical), while blue shows regions i > 65° (horizontal).

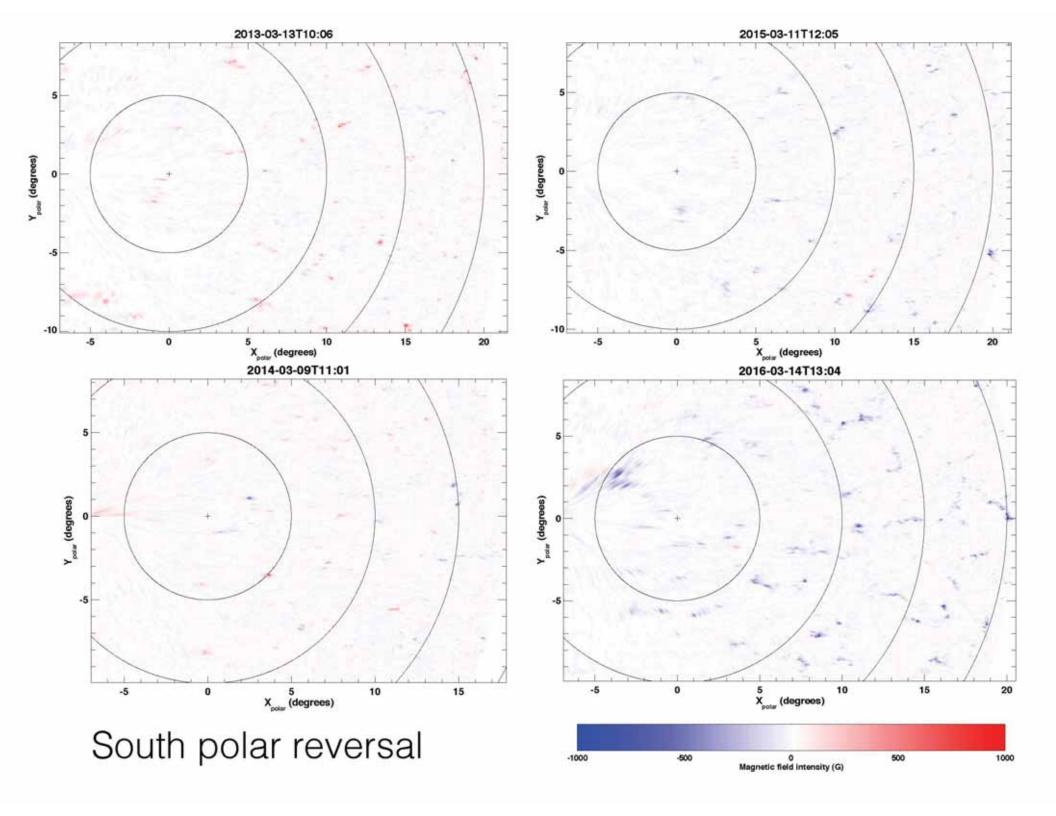
Latitudinal lines for 85° and 80° are shown, with the plus sign indicating the south pole. From Tsuneta et al. (2008).

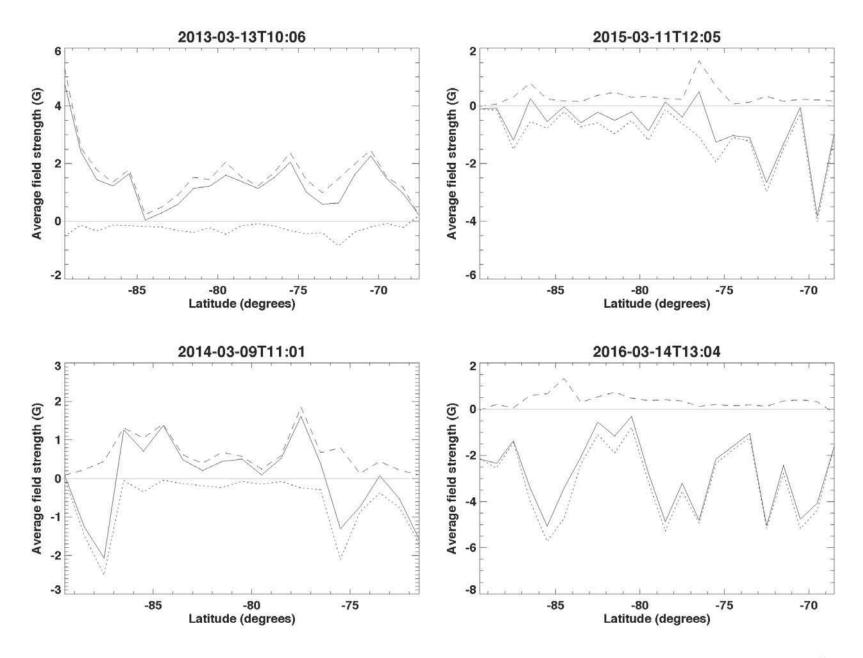
South polar reversal



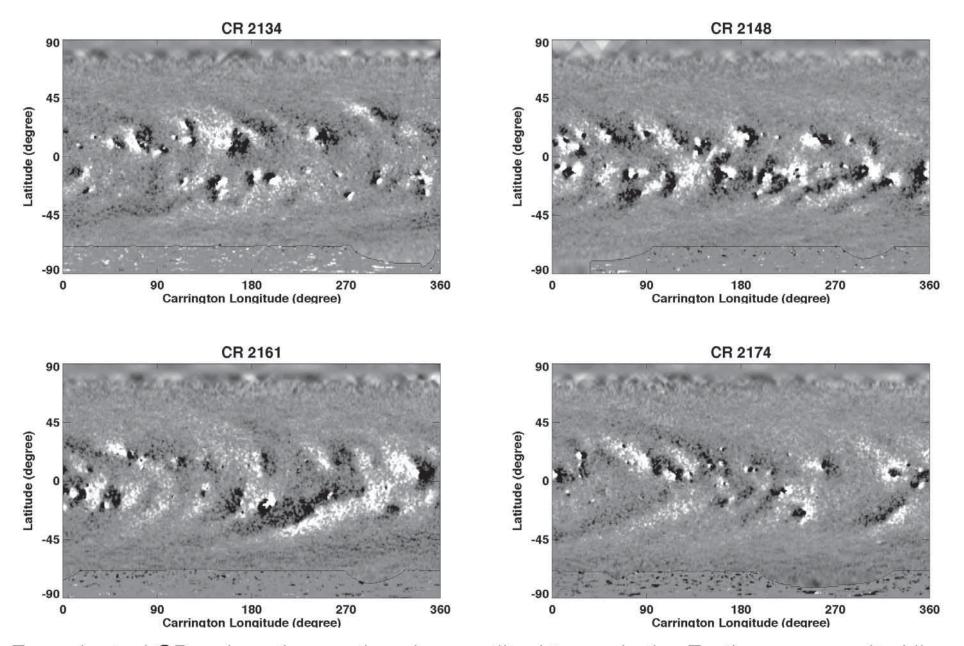
For representative Hinode vector magnetograms of the south pole from the years 2013-2016, the distributions of the two solutions i_1 and i_2 for the local inclination angle are shown, for strong ($|\mathbf{B}| \ge 500$ G, top plots) and weak (50G $\le |\mathbf{B}| \le 100$ G, bottom plots) fields.

The azimuth angle disambiguation method of Ito et al. (2010) was used, where magnetic fields are classified as vertical to the local surface if they are located either close to 0° or 180° and as horizontal if located near 90° (dashed lines). Besides, corrections for the finite distance between the Sun and Earth (Smart & Green, *Spherical Astronomy*, 1977). From Petrie Solar Physics, 292, 13 (2017).

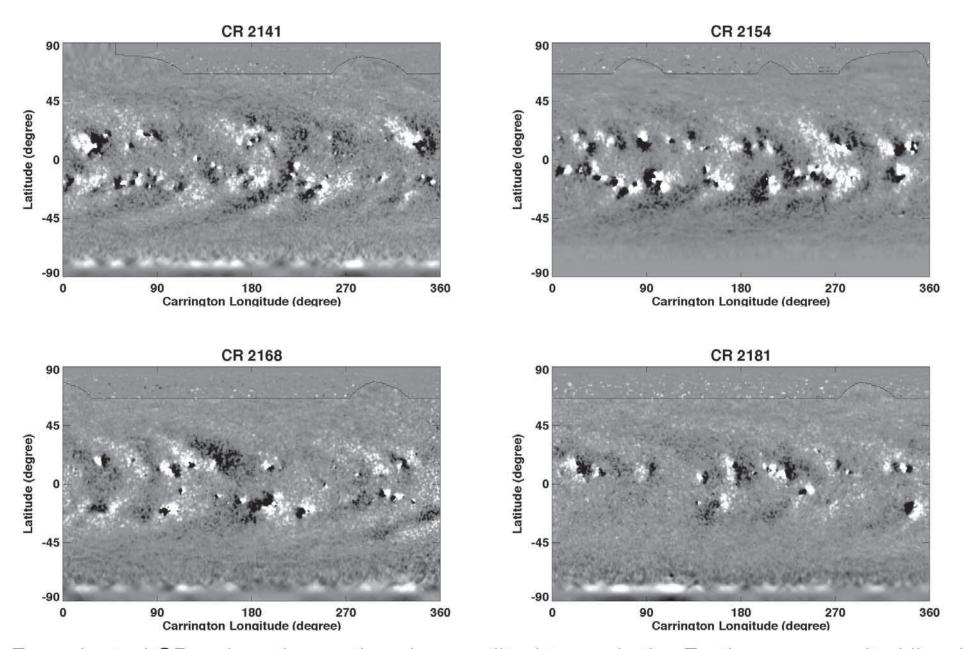




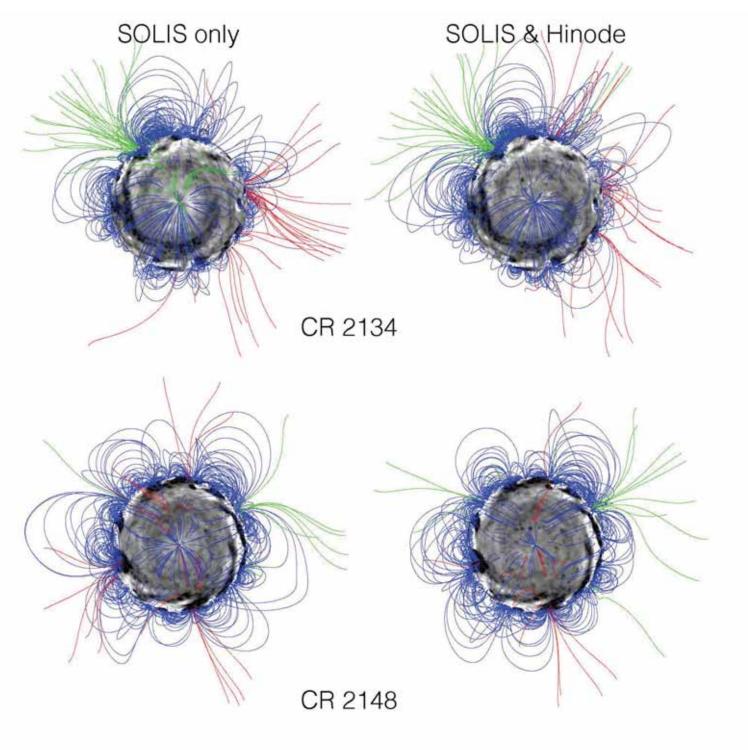
For the south polar data from March 2013-16, the average net flux density (solid lines) plotted as a function of latitude, accompanied by the positive (dashed lines) and negative (dotted lines) flux densities. Thin grey dotted lines mark zero flux.



For selected CRs when the south pole was tilted towards the Earth, a composite Hinode/SOLIS synoptic magnetogram is plotted. The measurements were taken during March of 2013, 2014, 2015 and 2016. The flux density is represented by a greyscale saturated at ±30G, with light/dark grey representing positive/negative flux.

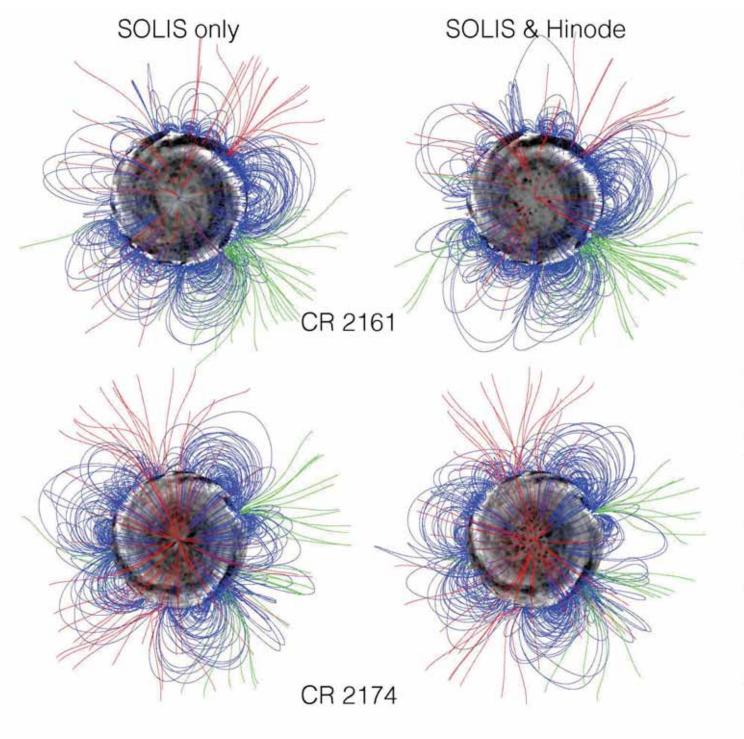


For selected CRs when the north pole was tilted towards the Earth, a composite Hinode/SOLIS synoptic magnetogram is plotted. The measurements were taken during September of 2013, 2014, 2015 and 2016. The flux density is represented by a greyscale saturated at ±30G, with light/dark grey representing positive/negative flux.



Polar projections of coronal PFSS field lines overplotted on magnetograms for CRs 2134 and 2148 from March 2013 and 2014, respectively.

Open positive/negative field lines are plotted green/red and closed field lines blue. The photospheric radial flux density is represented in greyscale saturated at ±10G with light/dark grey representing positive/negative flux density.



Polar projections of coronal PFSS field lines overplotted on magnetograms for CR s 2161 and 2174 from March 2015 and 2016, respectively.

Open positive/negative field lines are plotted green/red and closed field lines blue. The photospheric radial flux density is represented in greyscale saturated at ±10G with light/dark grey representing positive/negative flux density.

Combining line-of-sight and vector magnetograms: Construction of the vector map for ISSI team "Comparison and Validation of Global NonPotential Magnetic Models of the Solar Corona"

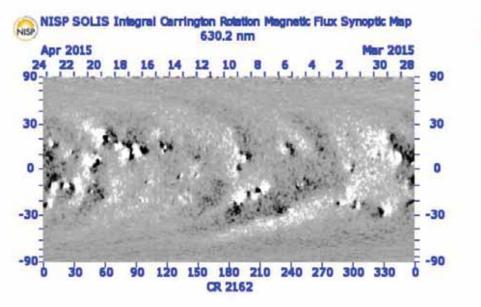
The vector synoptic magnetogram data came from maps for two integral Carrington rotations, 2161 and 2162. These were merged to simulate the solar surface field at the time of the eclipse with central meridian on 20 March 2015 at the center of the map.

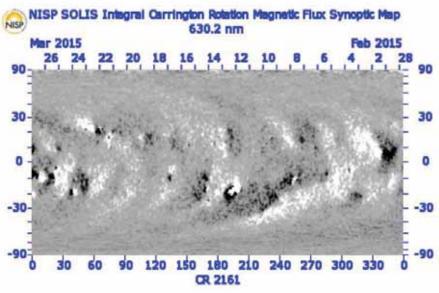
HMI data were used. The vector maps were from Yang Liu, constructed with their usual pipeline but using (azimuth-angle disambiguated) full-disk images to derive data for B_r , B_θ and B_{ϕ} .

Boxcar smoothing was applied to the quiet-Sun fields, an attempt to beat down the noise while preserving signal.

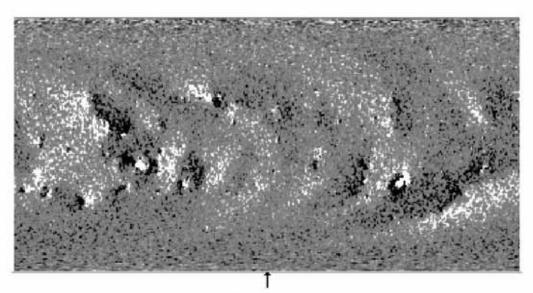
There were three inputs: strong fields are represented by unsmoothed vector data, low-latitude quiet-Sun fields (IBI<50G) by smoothed vector data, and high-latitude fields (poleward of ±70°) by pole-filled line-of-sight radial-corrected data.

Based on HMI synoptic maps for vector field components B_r , B_θ and B_ϕ , combining maps for CRs 2161 and 2162, with central longitude corresponding to 20 March 2015



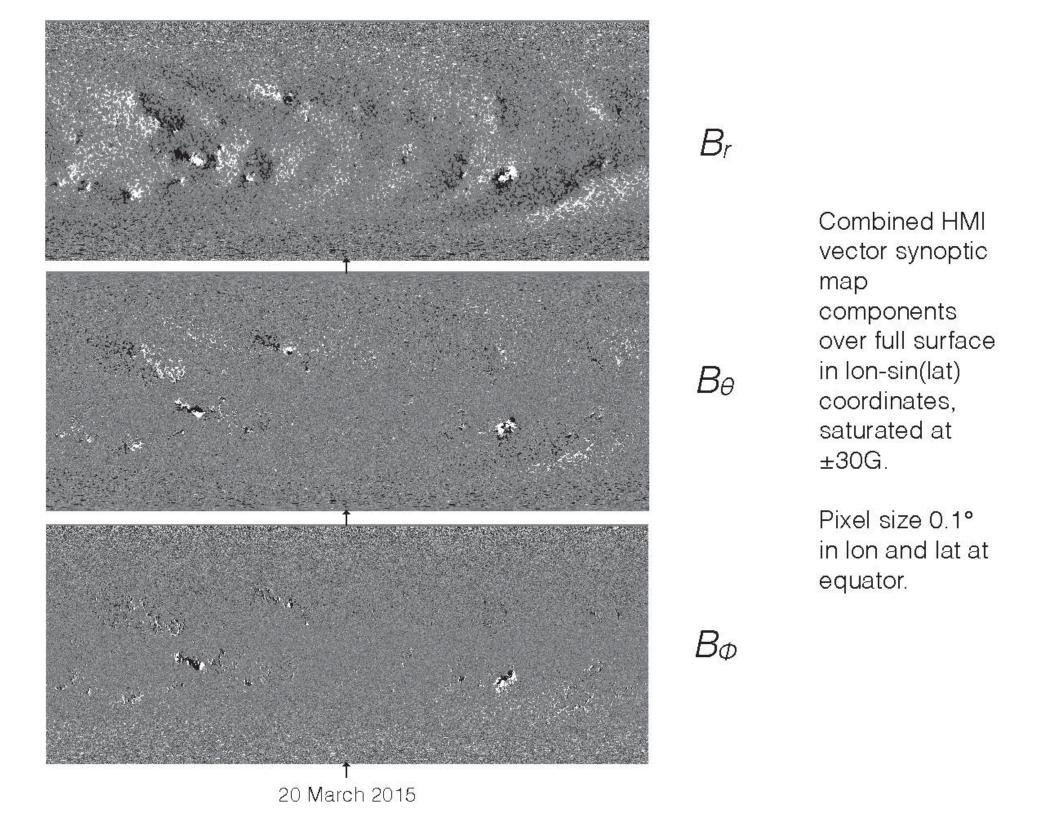


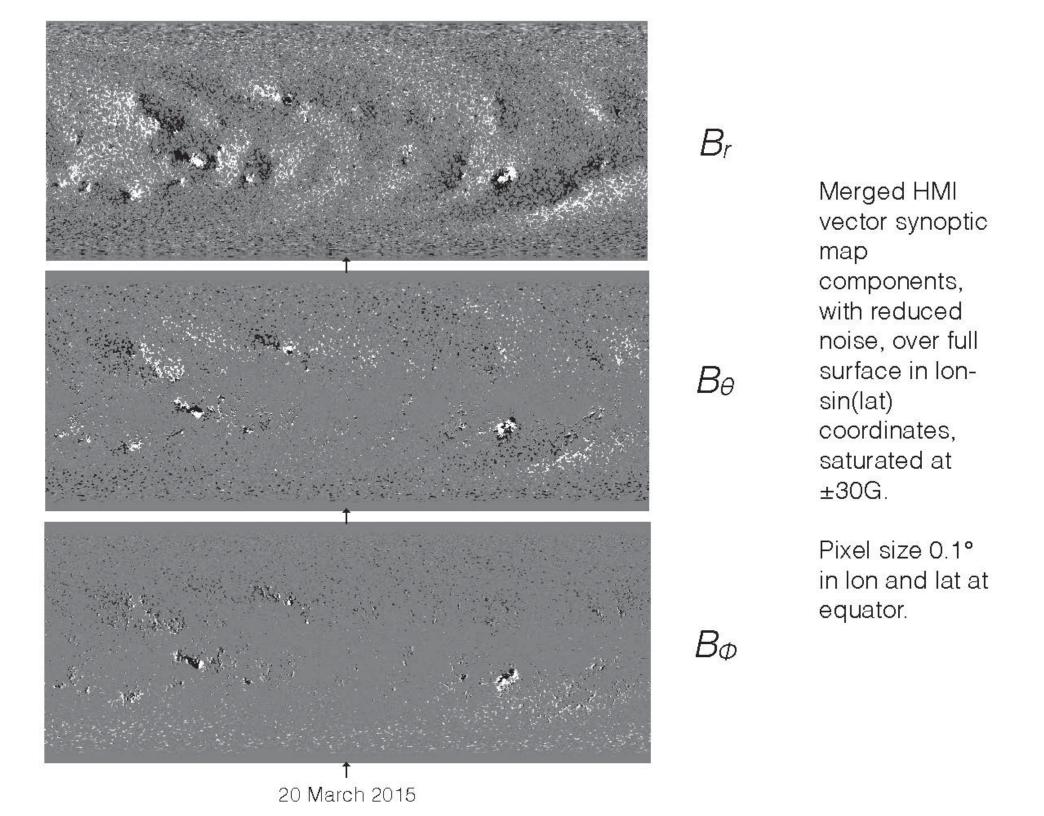
Merged HMI line-of-sight diachronic synoptic map with March 20 data at centre.

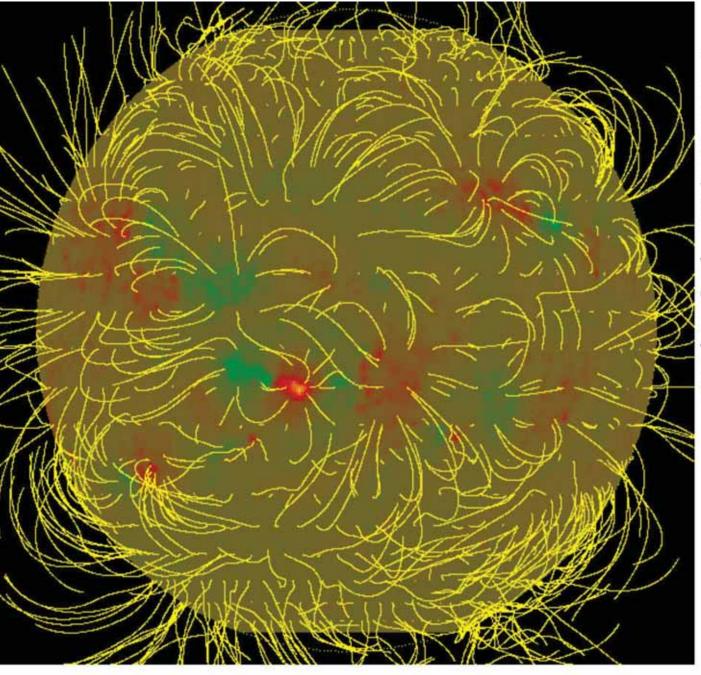


Choice of longitude range hides discontinuity between old and new data at far side of Sun, opposite central meridian for 20 March 2015.

20 March 2015







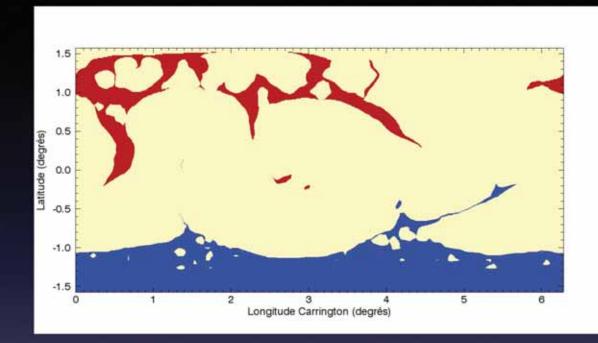
NLFFF coronal magnetic field model.
Resolution: half a degree.
Polar regions cutted out.
A synoptic vector magnetogram (prepared by Gordon Petrie from HMI) was used as boundary condition.

Thomas Wiegelmann, MPS Göttingen

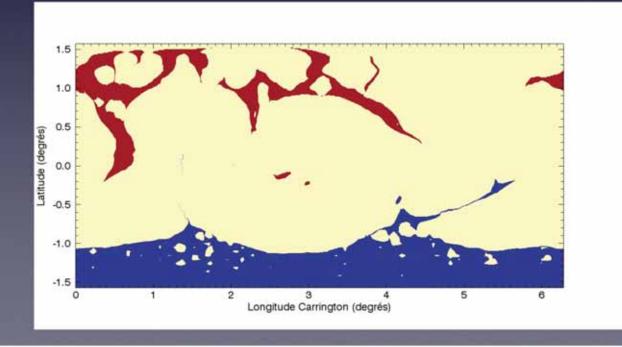
Canou A

Amari T., Chopin P., Coronal Holes/Synoptic

Potential



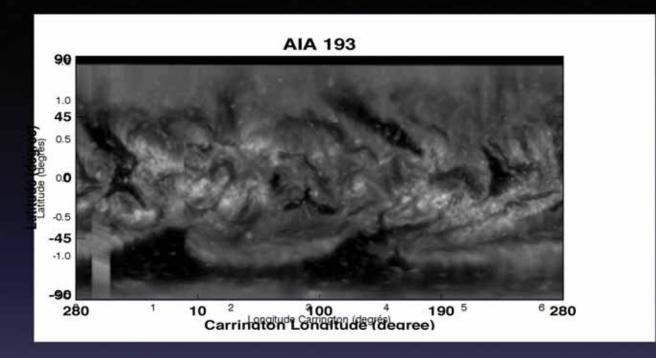
Force-Free



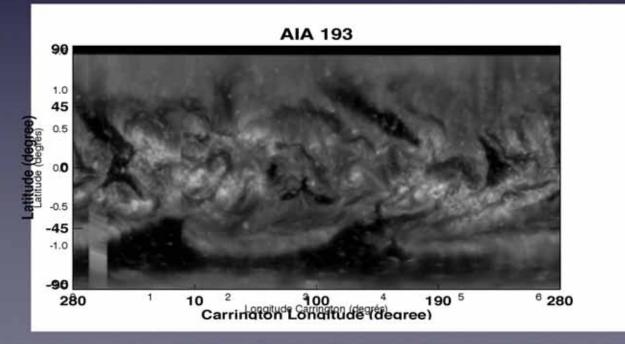
Canou A

Amari T., Chopin P., Coronal Holes/Synoptic

Potential

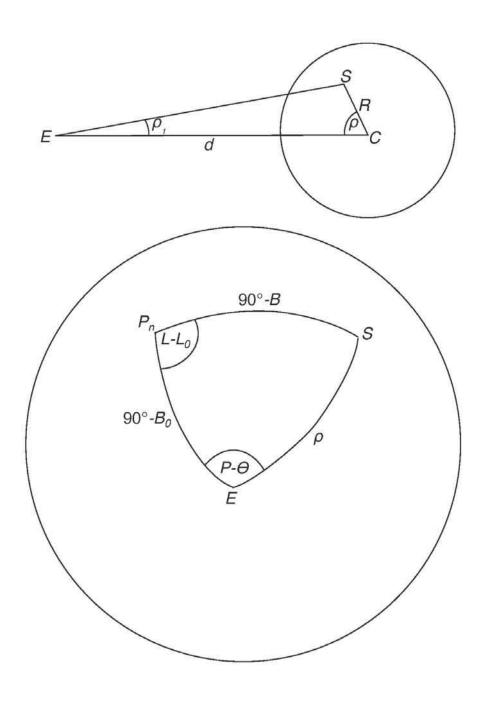


Force-Free



Summary & Conclusions

- The influence of the polar fields extends to the global coronal magnetic structure, the solar wind distribution, and the IMF. The polar fields also play a key role in the solar cycle.
- Knowledge of the polar flux distribution is mostly derived from lower-resolution line-ofsight synoptic data deprojected assuming an approximately radial photospheric field.
- Hybrid synoptic magnetograms were constructed from Hinode/SOT-SP polar vectorfield measurements and full-disk magnetograms from SOLIS/VSM. These gave excellent signal/noise at the highest latitudes for large flux concentrations.
- There was some evidence of reduced signal for small flux concentrations at the highest latitudes due to loss of effective spatial resolution there. However, this is difficult to verify without detailed coronal field observations.
- Vector synoptic map based on HMI vector data, with relatively noisy quiet-Sun fields smoothed out and polar data reinforced with reprojected line-of-sight data.
- Extrapolated force-free modeling efforts (Wiegelmann, Amari) have begun.



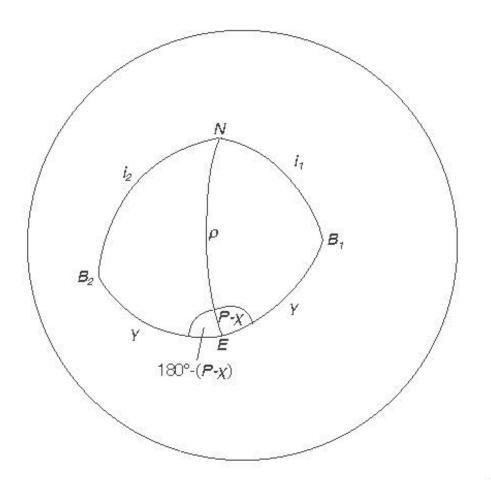
Summary of the angles involved in the determination of the possible local inclination angles i_1 and i_2 .

The top diagram shows the viewing angle from the Earth's location *E* of the pixel location *S* with respect to disk-center *C*.

The bottom diagram shows the spherical triangle with vertices the sub-Earth point E, the observed pixel location S and the solar north pole P_n . This triangle is used to determine the heliographic longitude L and latitude B of the pixel.

 $\sin B = \sin B_0 \cos \rho + \cos B_0 \sin \rho \cos (P - \theta),$ $\sin(L - L_0) = \sin \rho \sin(P - \theta) \sec B.$

Smart & Green, Spherical Astronomy (1977)



The diagram shows the two spherical triangles whose common vertices N and E represent the local normal at the pixel location and the sub-Earth point, respectively, and whose outer vertices B_1 and B_2 are defined by the two possible magnetic vectors.

This diagram is used to determine i_1 and i_2 (Ito et al. 2010):

$$\cos(i_1) = \cos y \cos \rho + \sin y \sin \rho \cos(P - \chi),$$

$$\cos(i_2) = \cos y \cos \rho + \sin y \sin \rho \cos[\pi - (P - \chi)].$$