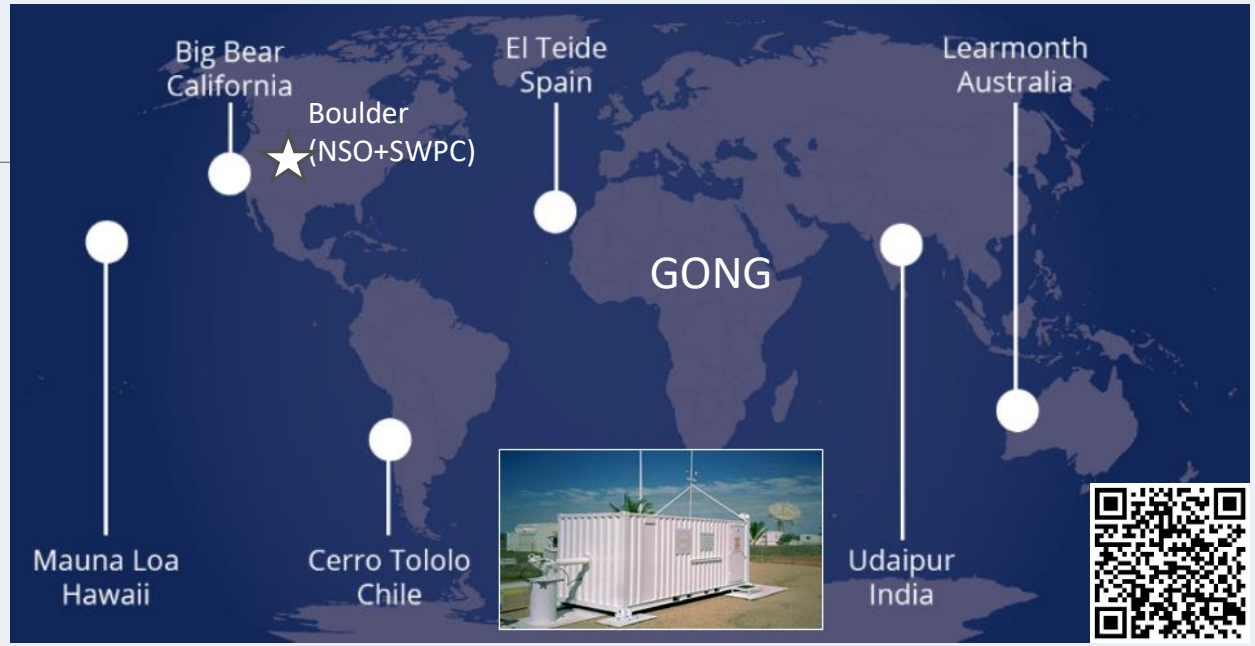
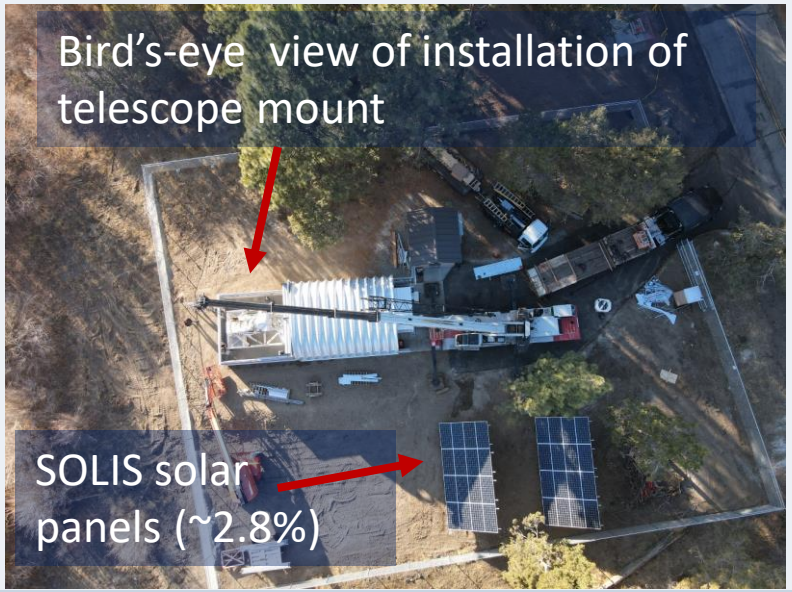
Magnetic field from NSO Synoptic Program

Alexei Pevtsov

GONG and SOLIS

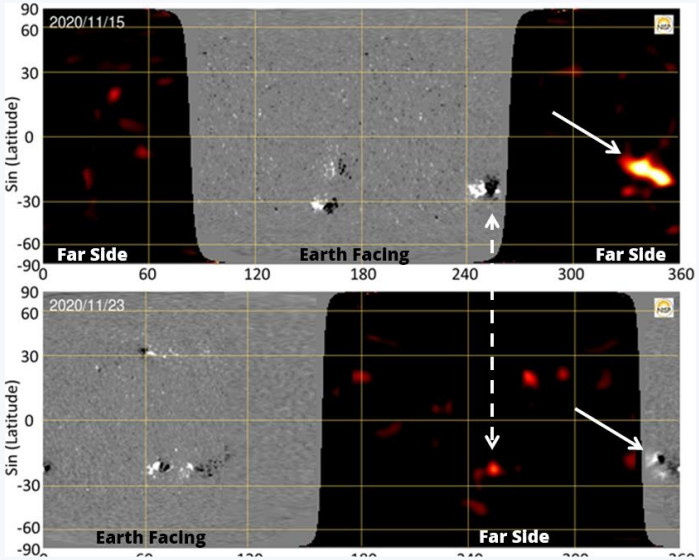




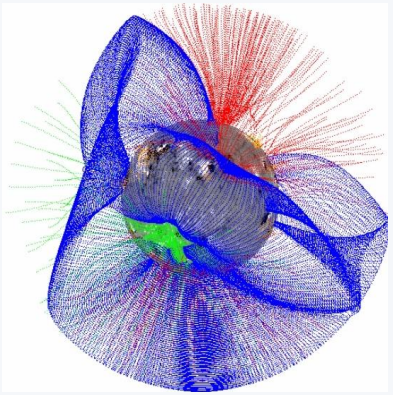
GONG: Helioseismology and Magnetic Fields

Data for Research and SW Forecast

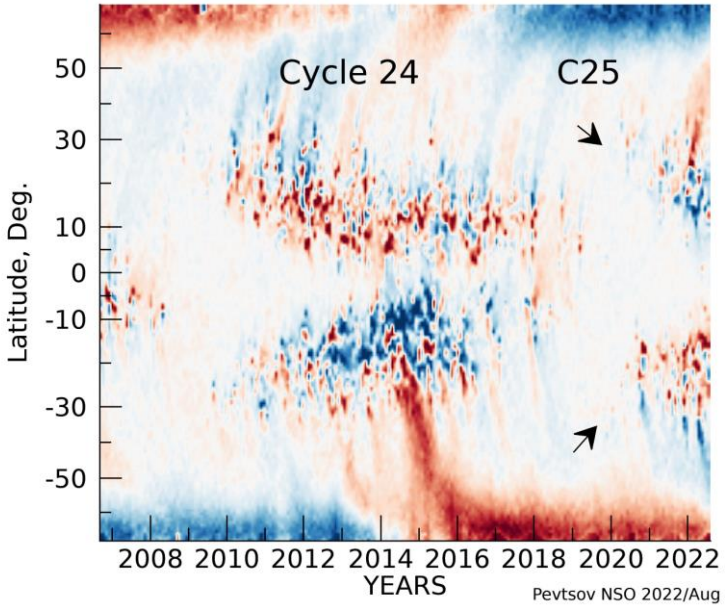
- Helioseismology: Plasma flows inside the Sun (dynamo, cycle prediction, far-side imaging etc)
- Magnetic fields: LOS photosphere, 3D structure and evolution, flare & CME initiation, irradiance, modeling of solar wind, geomagnetic disturbances etc



Full disk magnetic, Doppler, and H-alpha data

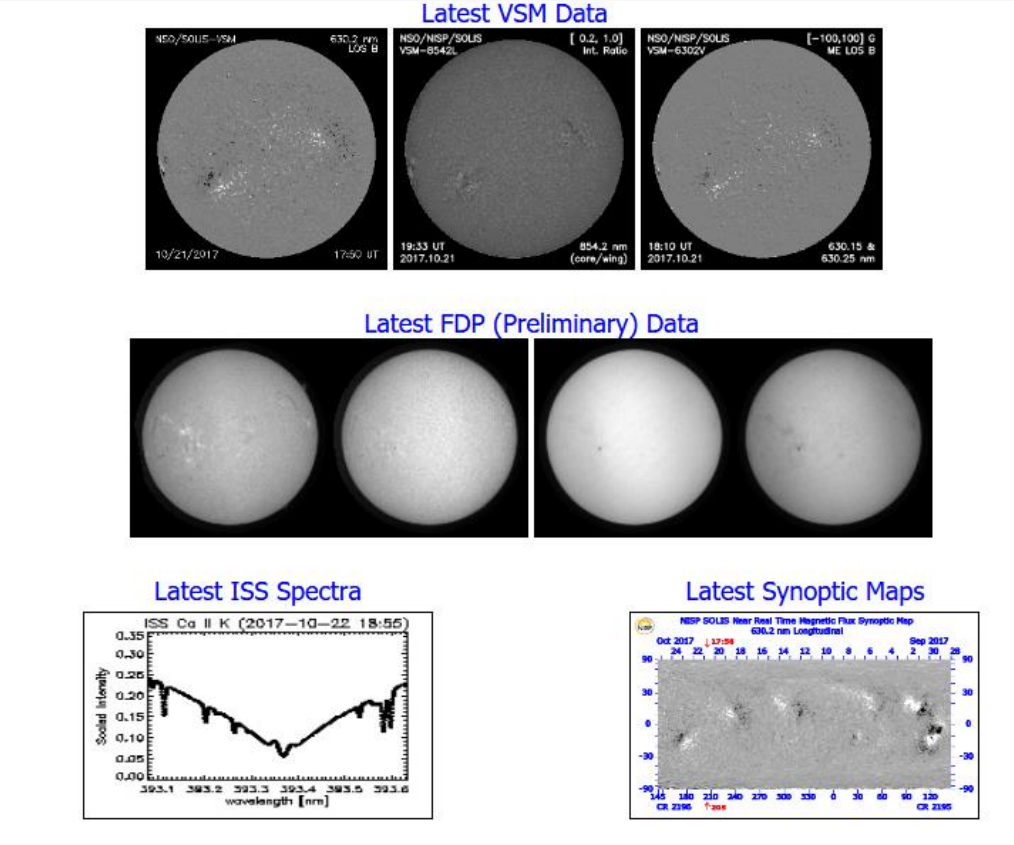


Modeling of coronal magnetic fields

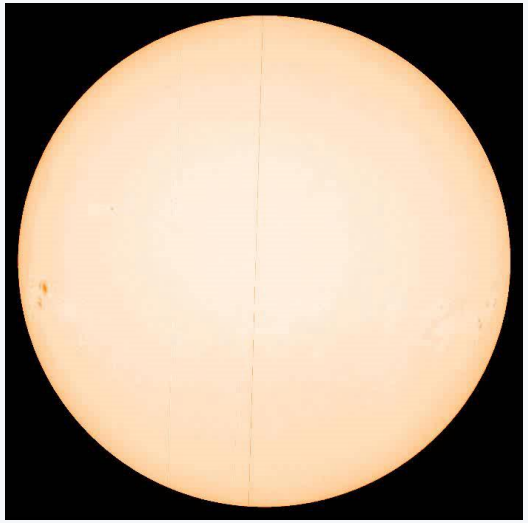


SOLIS: Vector Polarimetry, Imaging, and Sun-as-a-star

Full disk magnetic, Doppler, and H-alpha data

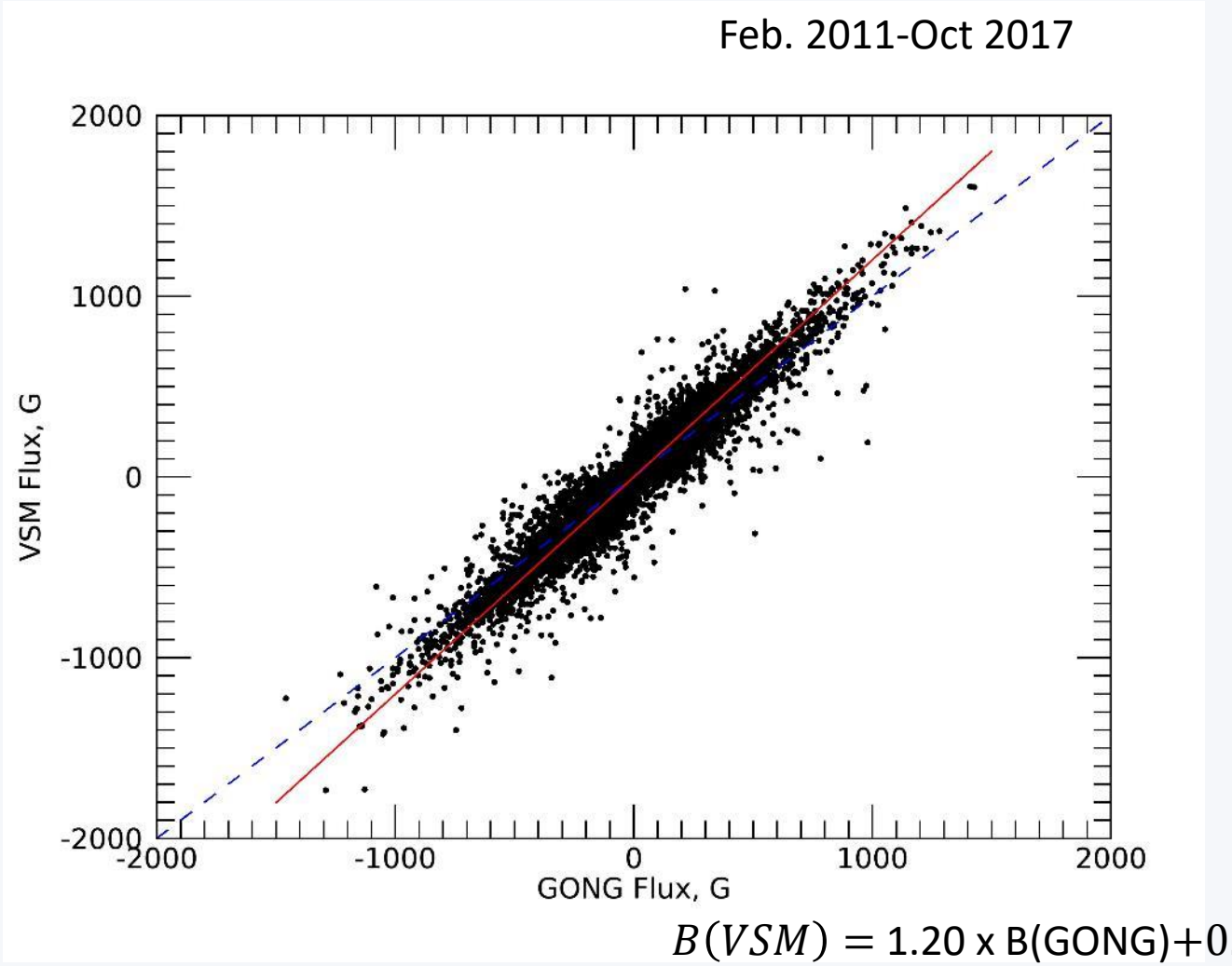


- Evolution and 3D orientation of magnetic fields on the Sun
- Physics of solar phenomena (e.g. solar flares, sunspots)
- Solar-stellar research



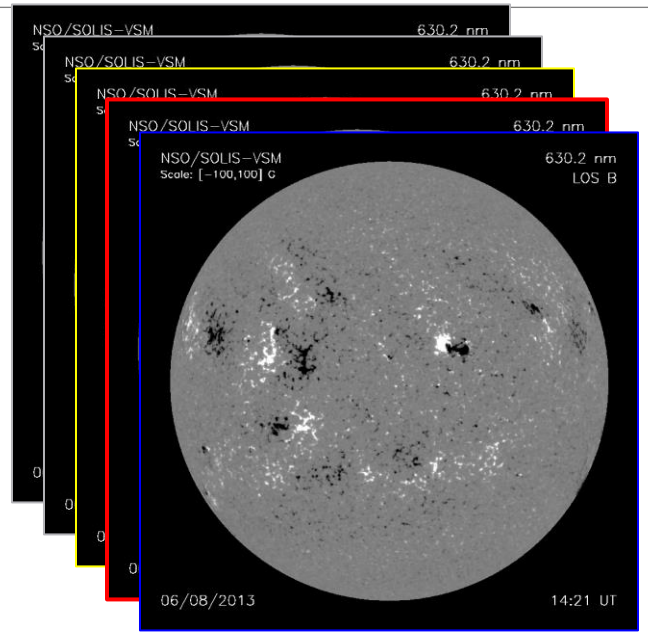
Beck et al. solar atmosphere in 3D

GONG-SOLIS comparison



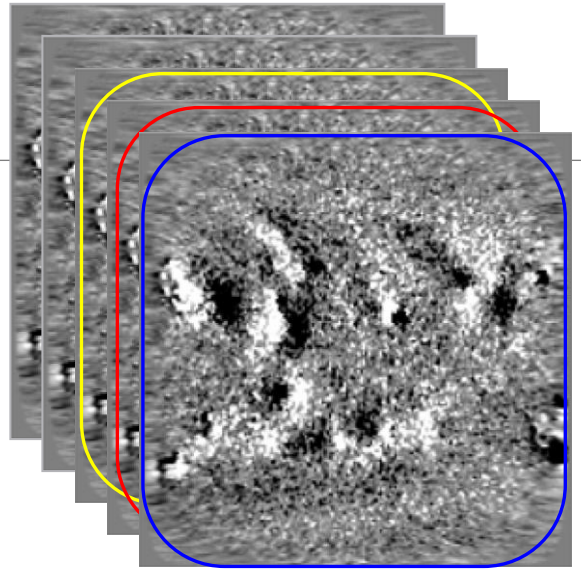
$B(VSM) = 1.20$ x B(GONG)$+0.06$

NSO Method

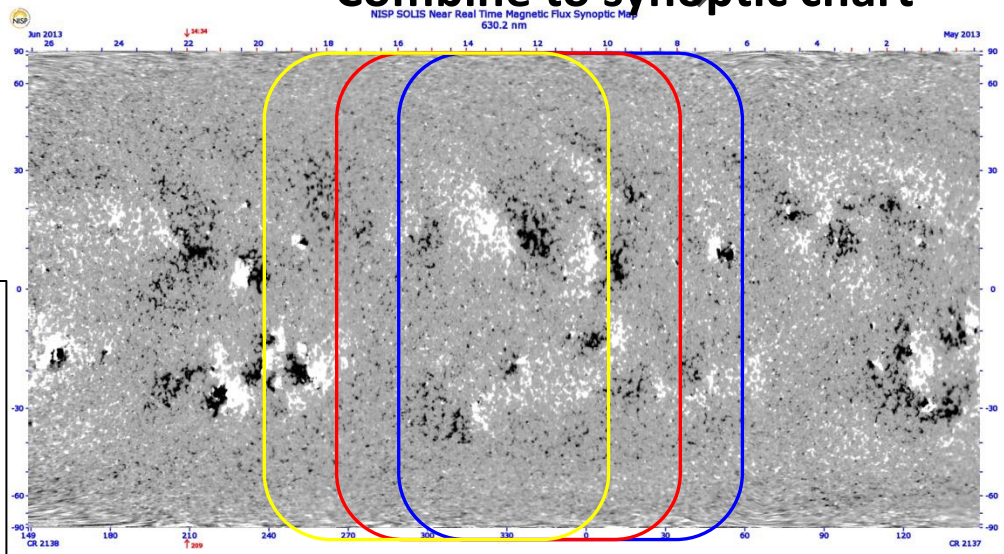


Full disk daily observations in sky-coordinates.

Remap to heliographic coordinates

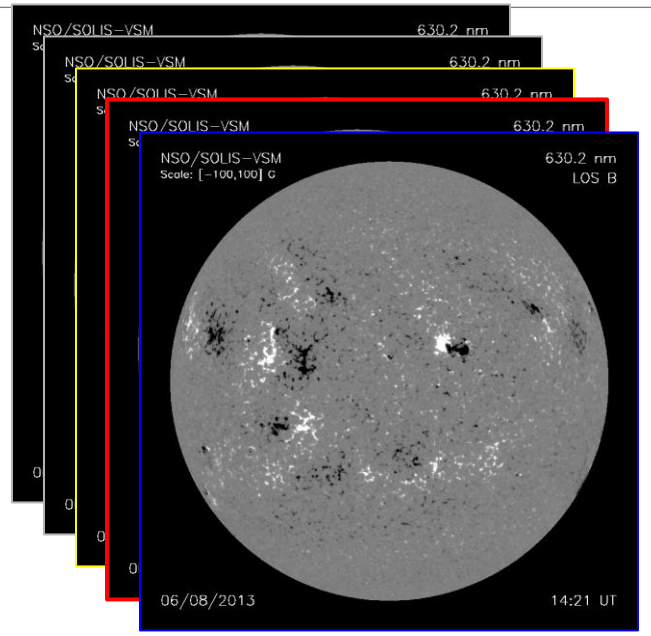


Combine to synoptic chart



NSO-method uses full disk images weighted by $\cos^4(\lambda)$ function and latitude-dependent "blending" of observed pixels smoothed by a running Gaussian function

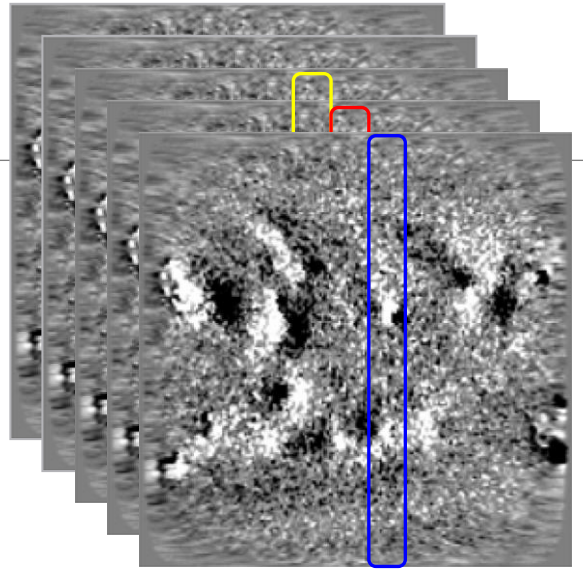
HMI method



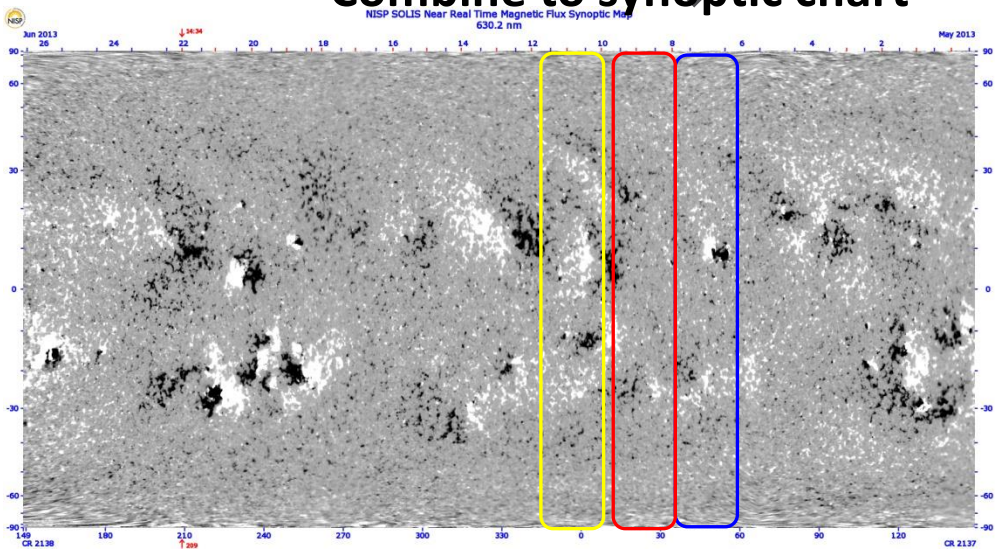
Full disk daily observations in sky-coordinates.

HMI-method uses 2-degree strips at the central meridian

Remap to heliographic coordinates



Combine to synoptic chart



Traditional maps:

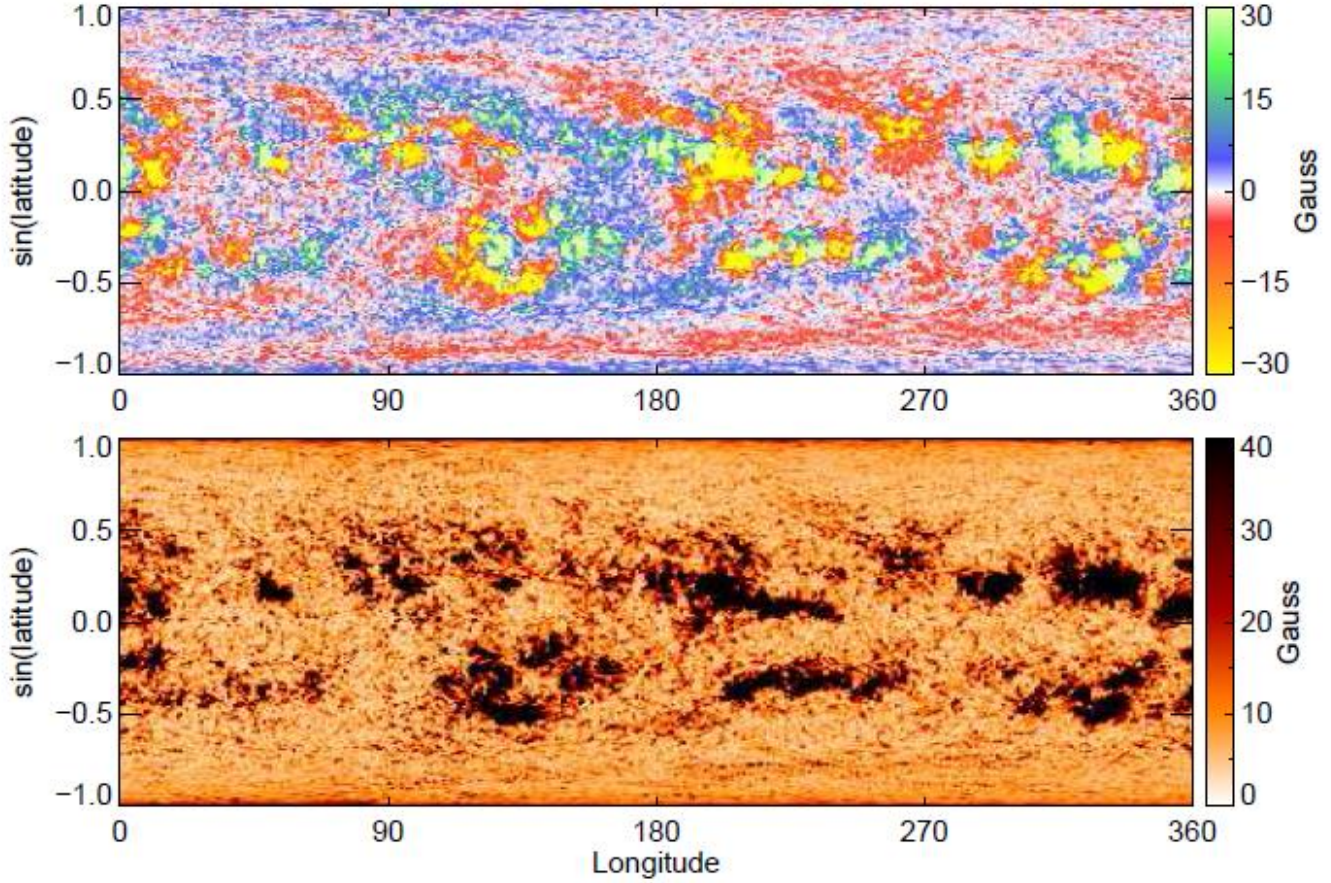
- Pseudo-radial magnetic field: $B_{r\text{-}p} \sim B_{LOS}/\cos(r/R)$
- Pole fill (cubic polynomial, for review, see Sun et al: 2011, Solar Physics, **270**, 9: doi:10.1007/s11207-011-9751-4).
- No uncertainties in $B_{r\text{-}p}$

More recent data products:

- Synoptic maps of uncertainties
- Vector field (3 components)
- Composite maps (photospheric B_r)
- Pseudo-radial (chromospheric) B_r maps

I. Synoptic maps of uncertainties

CR2137



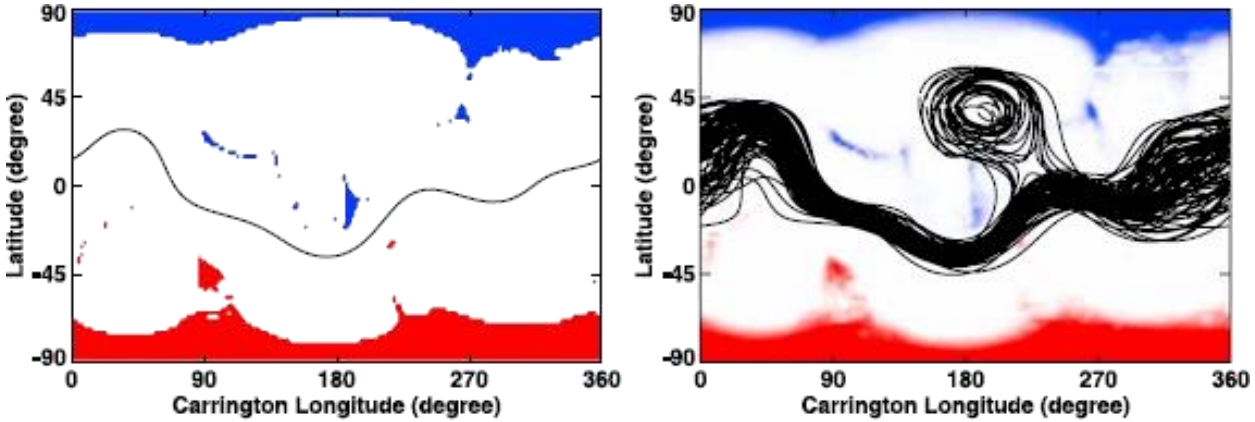
Magnetic flux ←

Uncertainties ←

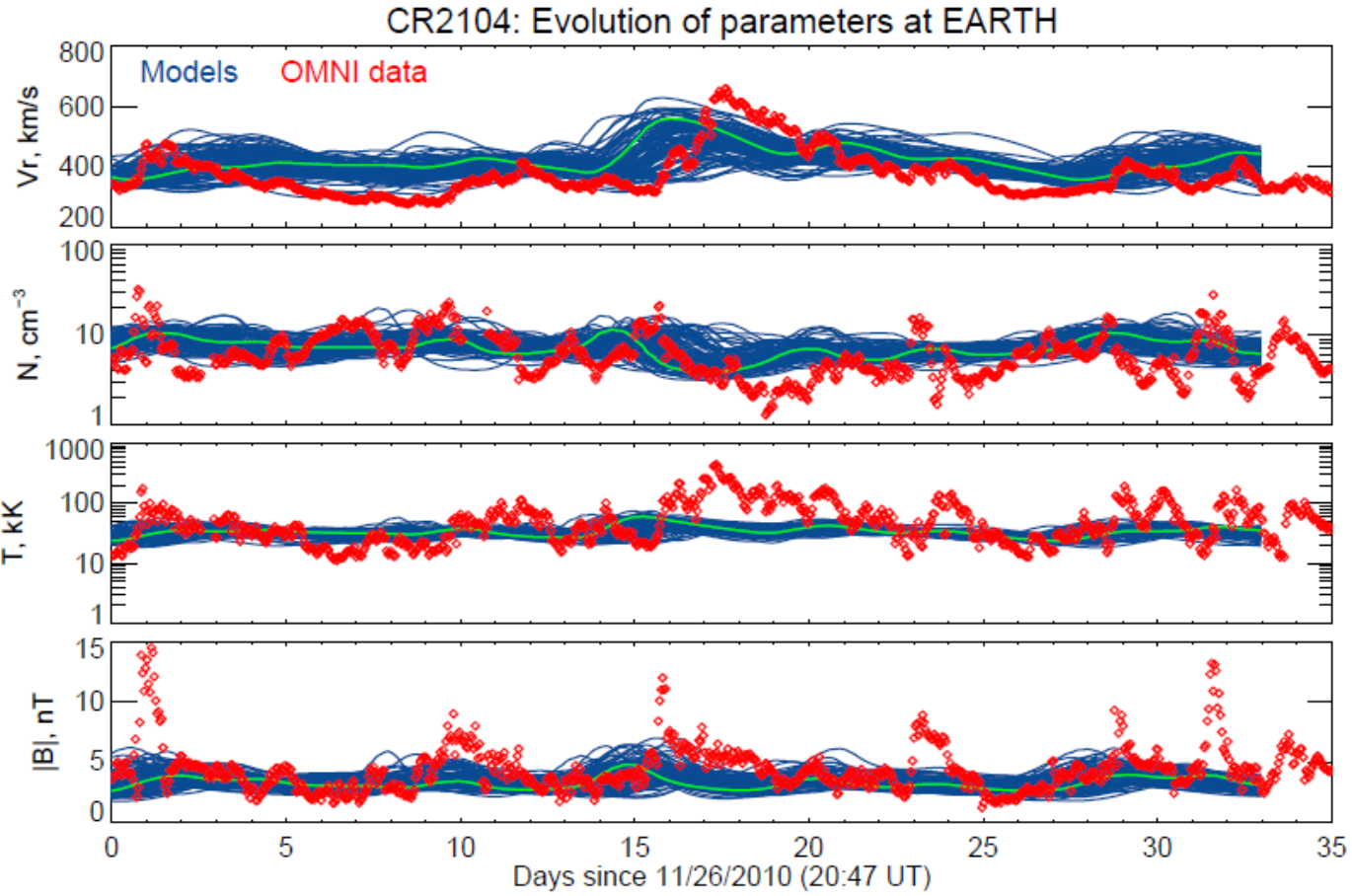
NSO: SOLIS/VSM and HMI (2010-2015)

Bertello et al (2014)

PFSS neutral line (thin black lines) and positive/negative open field footpoints (red/blue pixels) are shown for CR 2104.



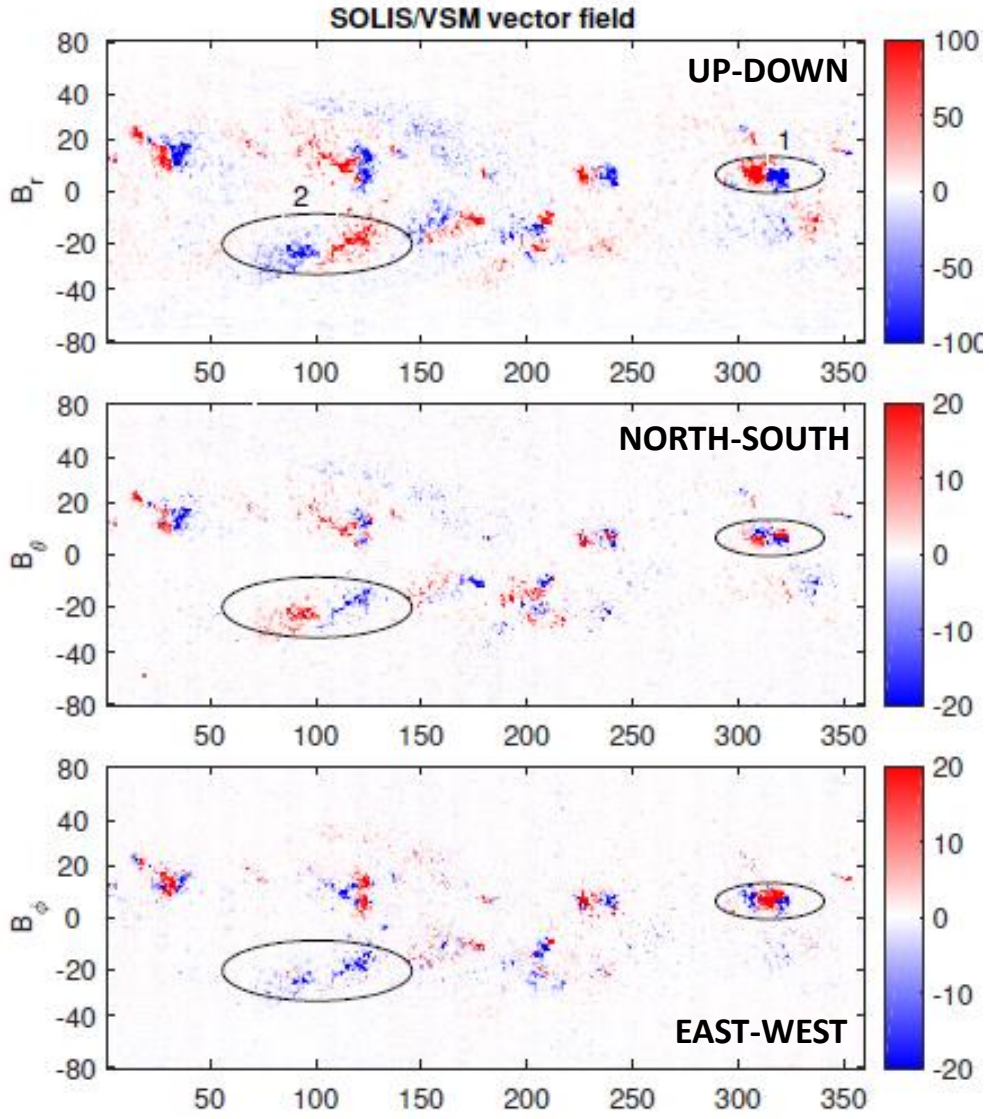
Bertello et al (2014)



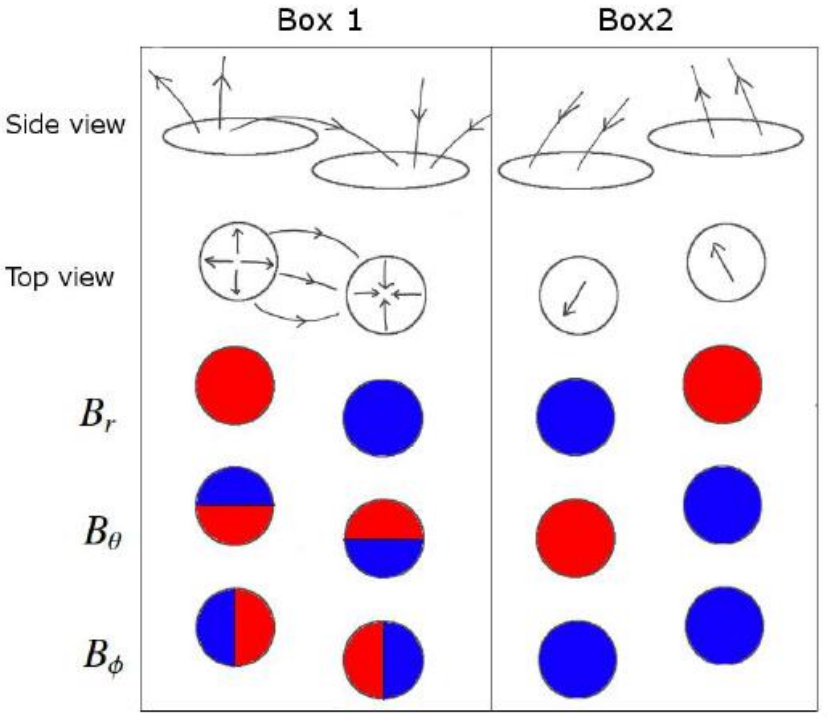
Period of lower sunspot activity: Blue – ensemble modeling, red – in situ observations.

Pevtsov et al (2015)

II. Vector Field Synoptic Maps

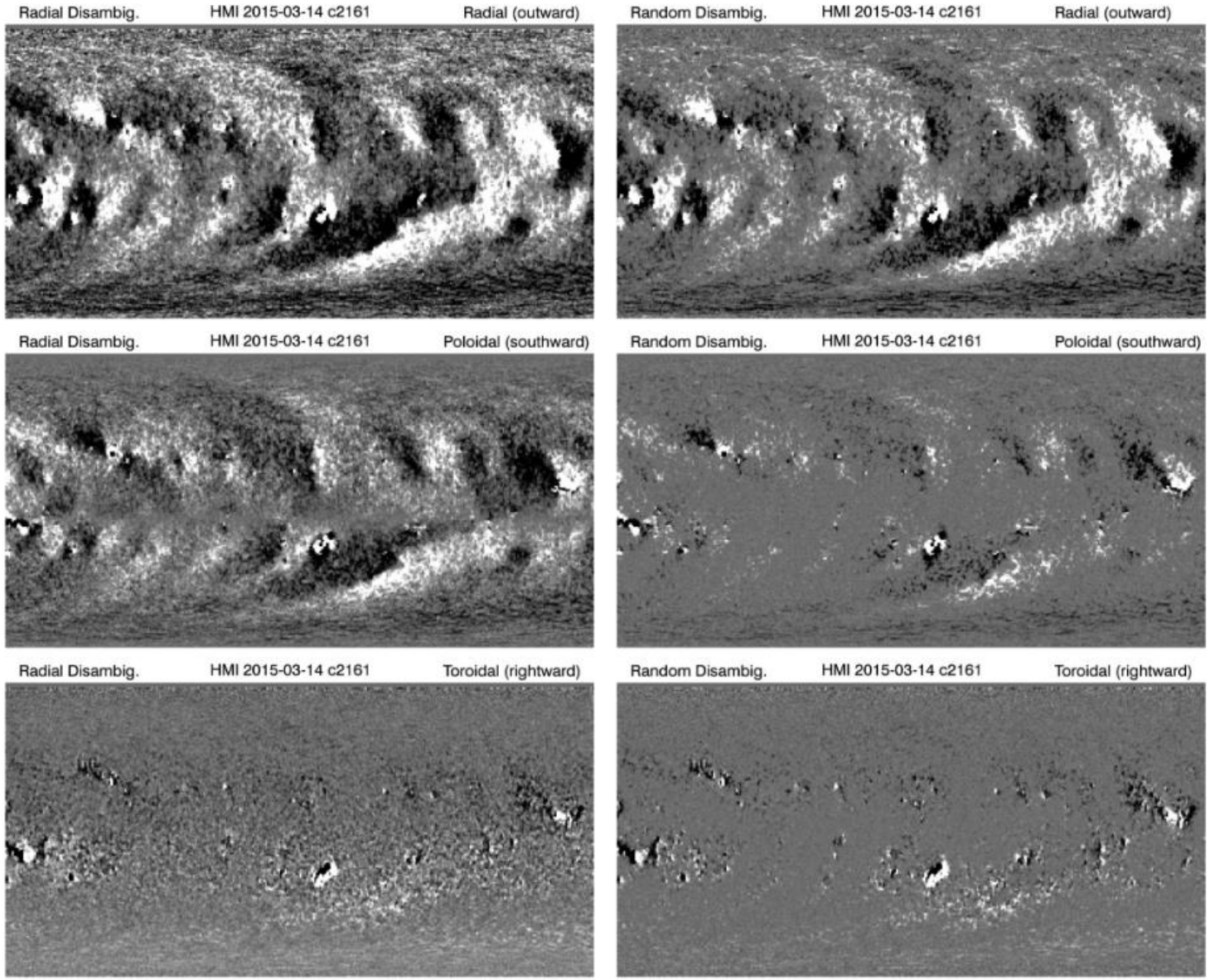


- Pole filling?
- 180-degree disambiguation?

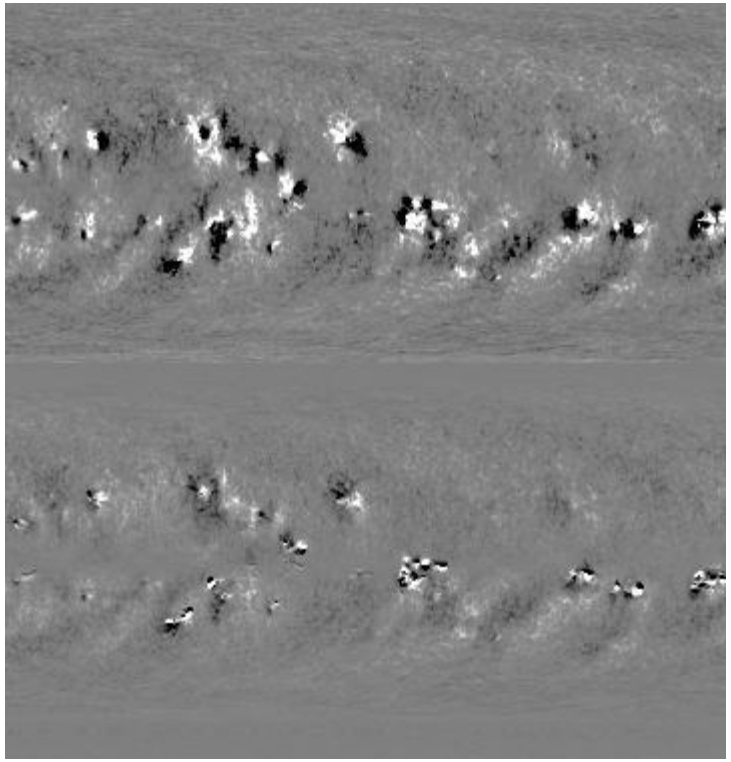


Virtanen et al (2018)

180-degree disambiguation

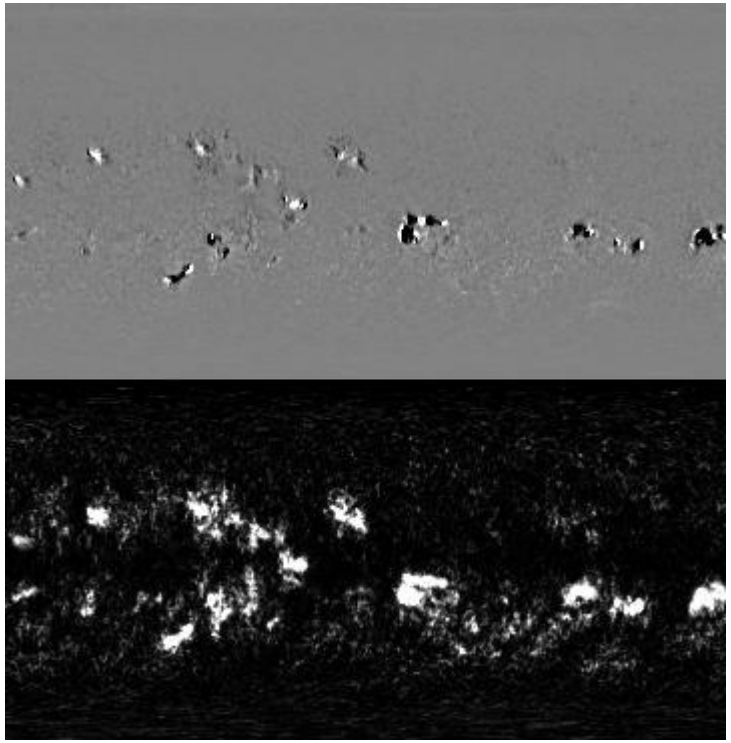


HMI vector synoptic maps by NSO



B_r

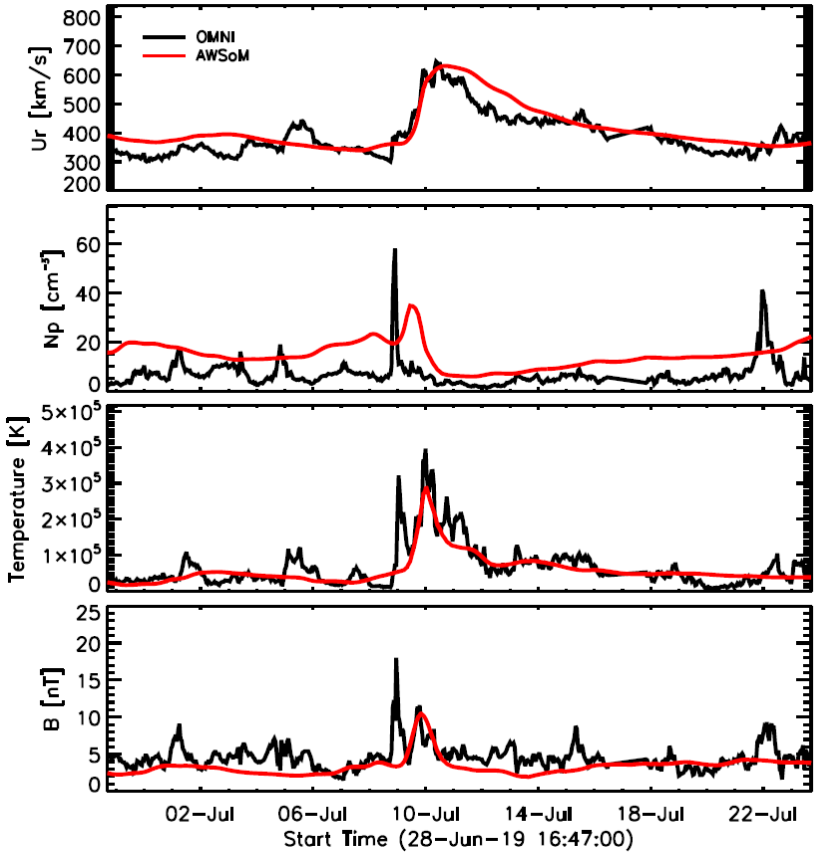
B_φ

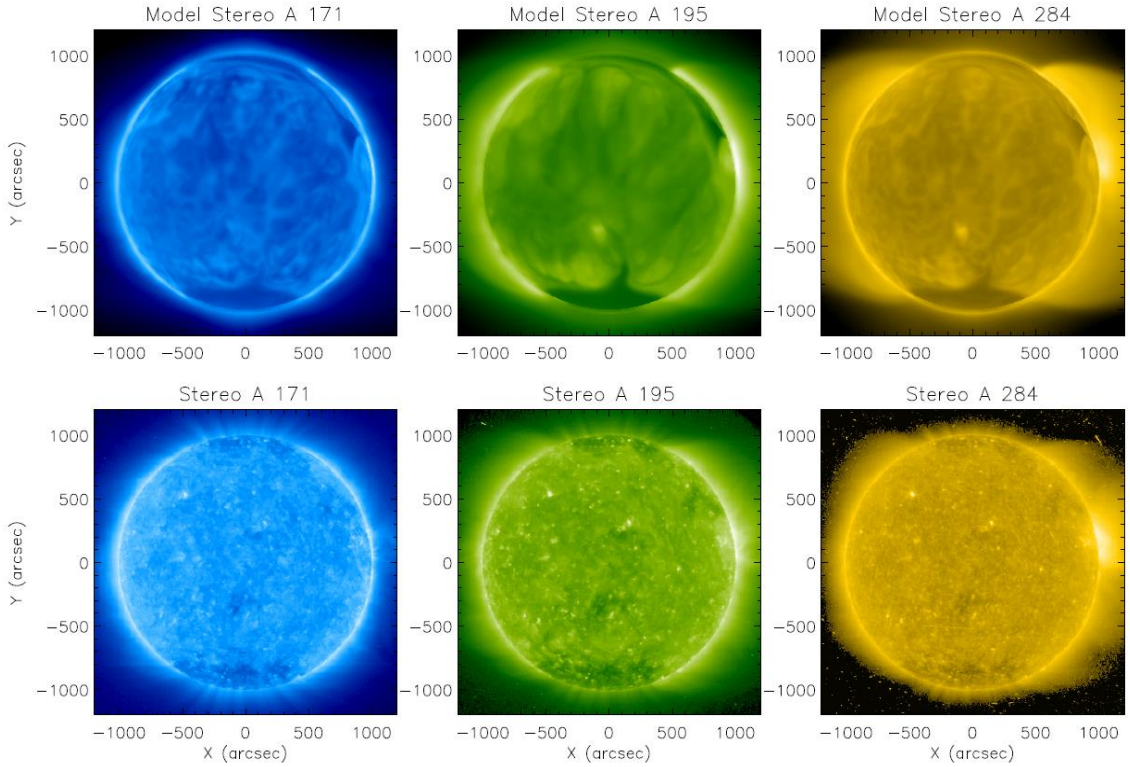


B_θ

mask

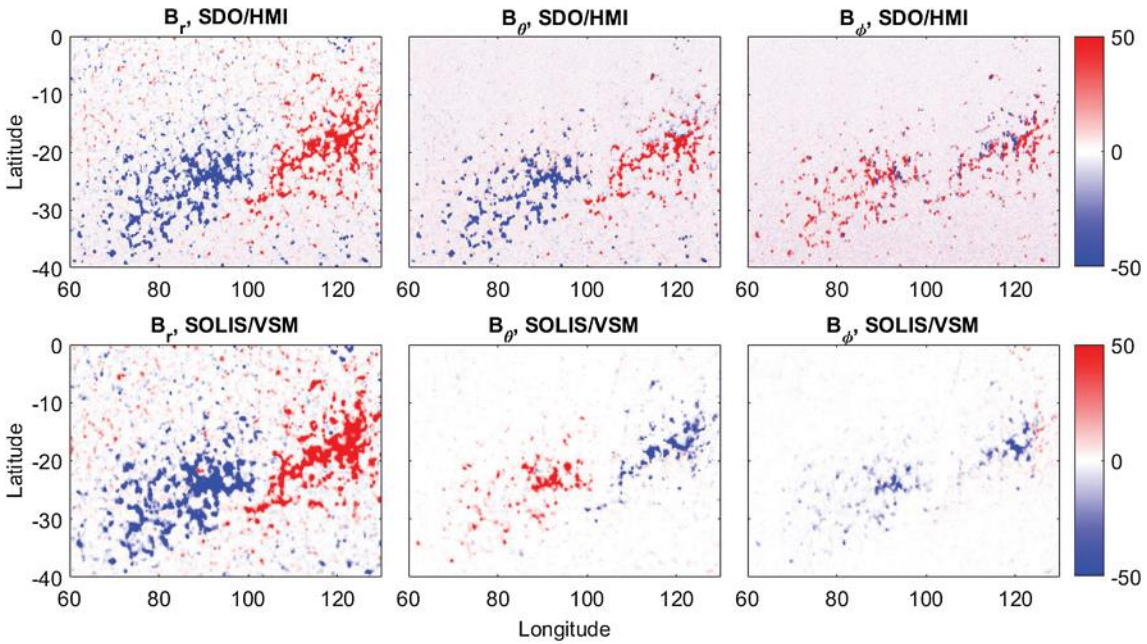
MHD simulations using vector data as input



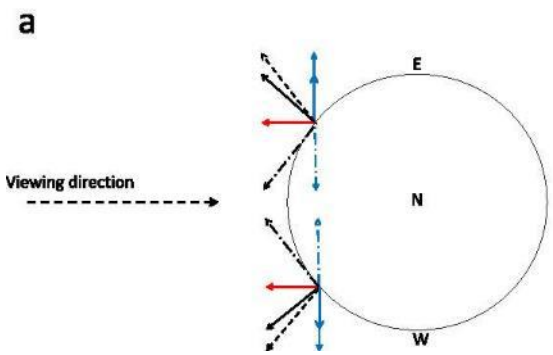


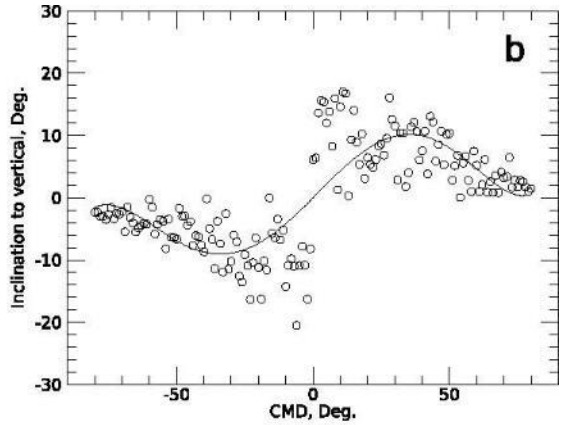
Tong Shi et al (2021)

Vector Field open questions



- Difference in noise?
- Fill factor?





Pevtsov et al, 2021, https://doi.org/10.1051/swsc/2021003

Vector Field open questions

$$B_{\parallel} \approx \frac{C_{\parallel}}{\alpha} \mathrm{V} \qquad (1)$$

$$B_{\perp} \approx \frac{C_{\perp}}{\sqrt{\alpha}} \sqrt[4]{Q^2 + U^2}. \qquad (2)$$

$$\begin{aligned} B_r &= B_{\parallel} \cos\phi \pm B_{\perp} \sin\phi \\ &= \frac{C_{\parallel}}{\alpha} V \cos\phi \pm \frac{C_{\perp}}{\sqrt{\alpha}} \sqrt[4]{Q^2 + U^2} \sin\phi \end{aligned} \qquad (3)$$

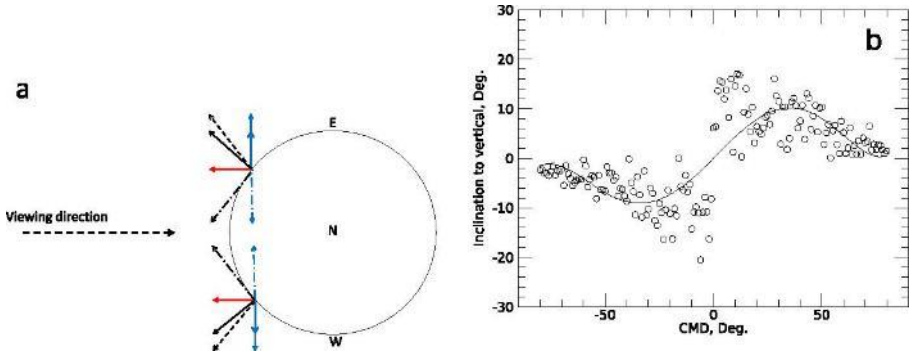
$$\begin{aligned} B_{\varphi} &= -B_{\parallel} \sin\phi \pm B_{\perp} \cos\phi \\ &= -\frac{C_{\parallel}}{\alpha} V \sin\phi \pm \frac{C_{\perp}}{\sqrt{\alpha}} \sqrt[4]{Q^2 + U^2} \cos\phi. \end{aligned} \qquad (4)$$

$$\left| \frac{-C_{\parallel} V}{\alpha} \right| \gg \frac{C_{\perp} \sqrt[4]{Q^2 + U^2}}{\sqrt{\alpha}}. \qquad (5)$$

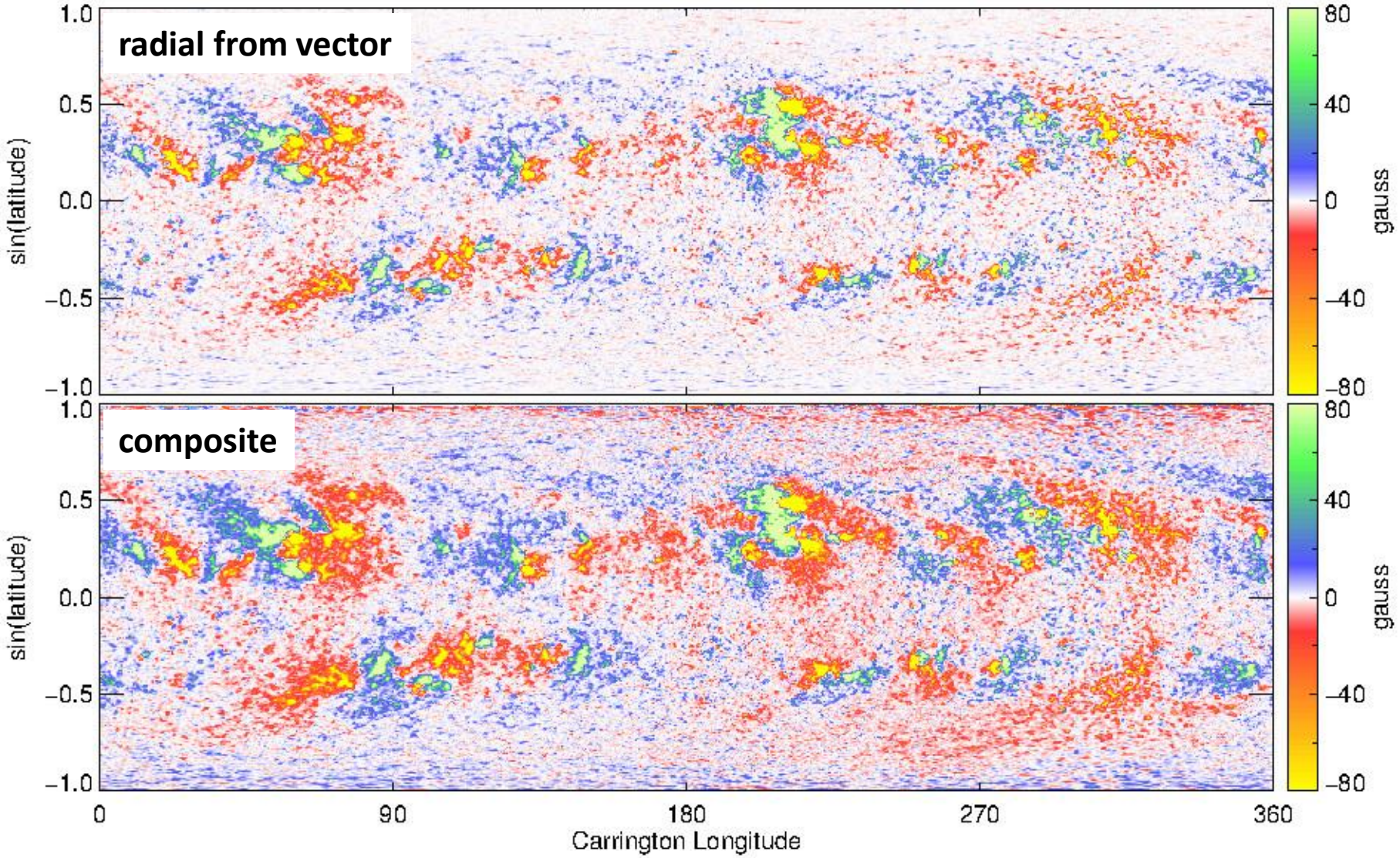
Field is mostly vertical

$$\left| \frac{-C_{\parallel} V}{\alpha} \right| \ll \frac{C_{\perp} \sqrt[4]{Q^2 + U^2}}{\sqrt{\alpha}}. \qquad (6)$$

Field is mostly horizontal

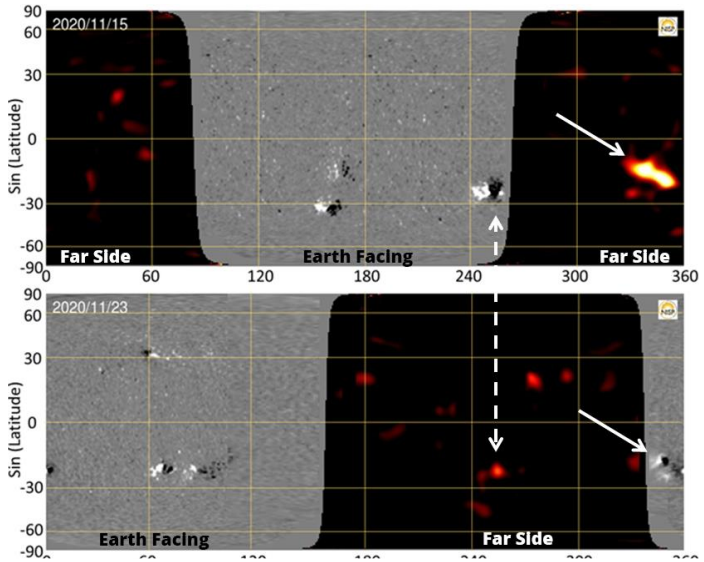


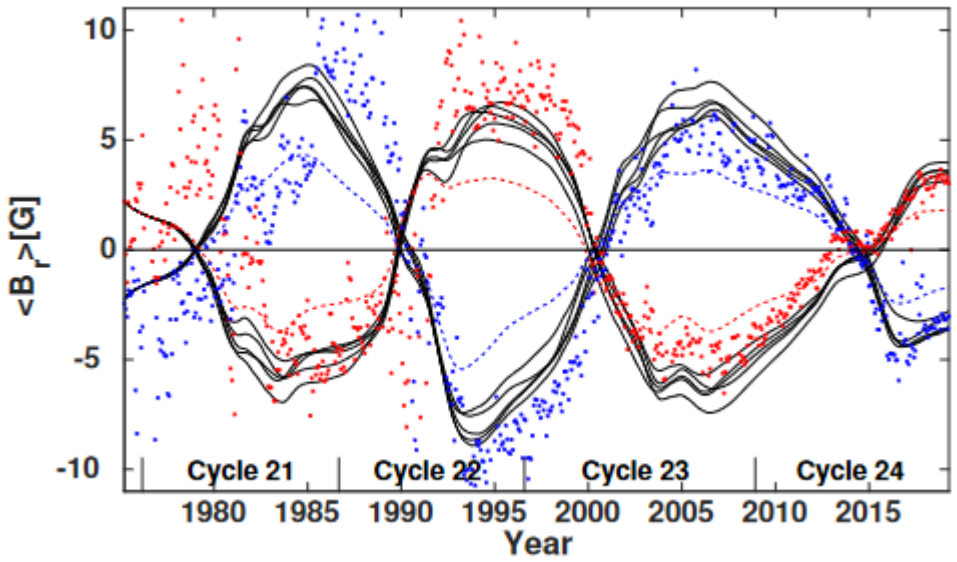
III. Composite (B_r + pseudo-B_r)maps



Synoptic maps shortcomings

- Polar field is not well represented (solutions: pole filling, using surface flux transport/SFT to fill poles), ADAPT model
- Missing flux (far side): SFT





Average strength of polar fields above 60° and below −60° latitude. Dashed – only observed active regions are included. Solid black lines - five realizations including additional far-side active regions with a lifetime limit of four days. Red and blue crosses - observed polar field.

Virtanen et al: 2021, A&A, doi: 10.1051/0004-6361/202140656

Summary

- Synoptic maps provide boundary conditions for modern modeling of solar corona, solar wind and the heliospheric magnetic field.
- Traditional maps are based on B-los magnetograms, but new data products are now available: (synoptic maps of) uncertainties, vector field, composite, and pseudo-radial chromospheric field.
- Pole filling for vector (and chromospheric) fields and disambiguation are open issues
- Vector data may have some limitations due to difference in noise between B-los and B-trans.