



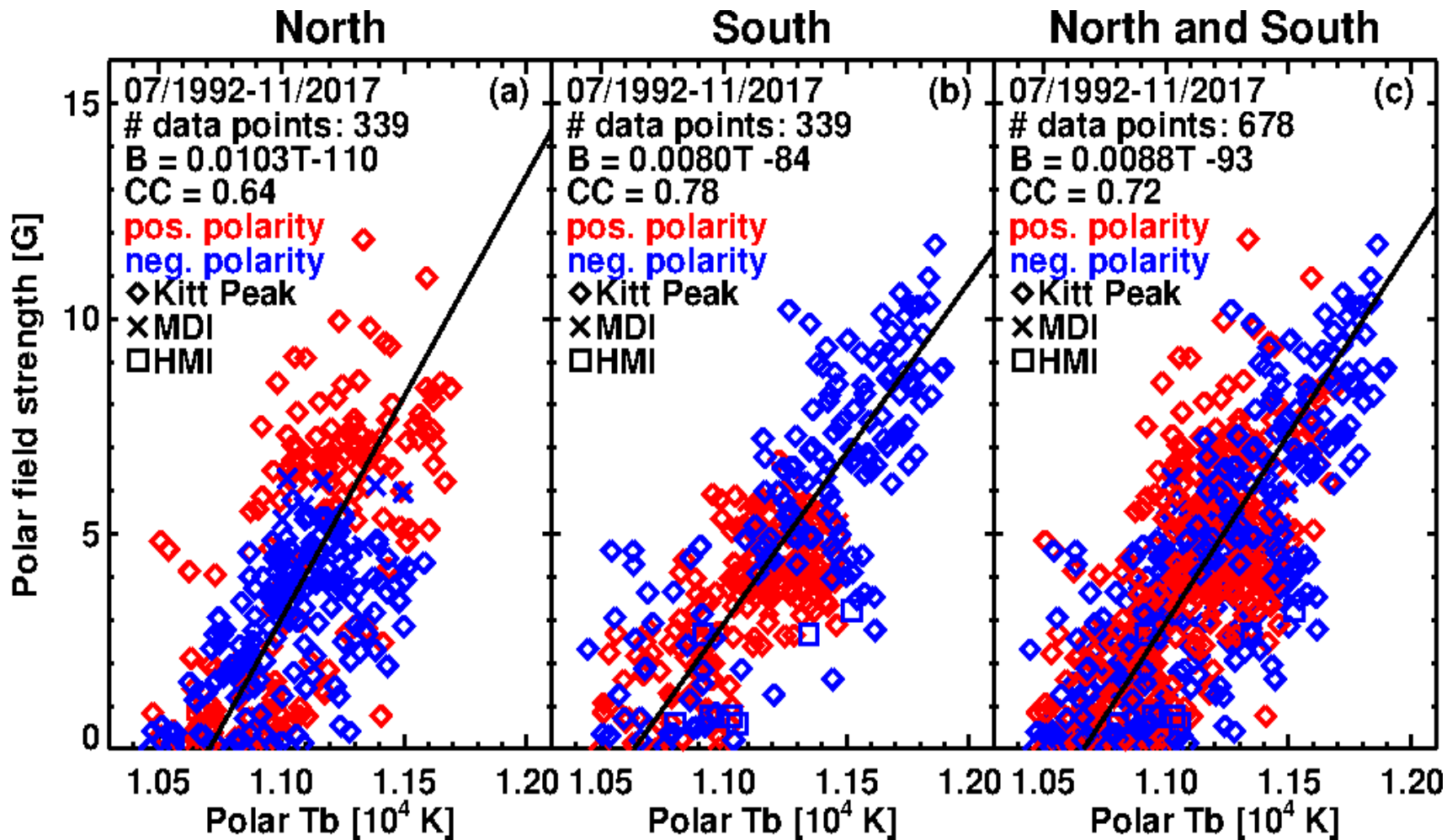
# Long-term Solar Activity Studies using Microwave Imaging Observations and Prediction for Cycle 25

N. Gopalswamy<sup>1\*</sup>, P. Mäkelä<sup>1,2</sup>, S. Yashiro<sup>1,2</sup>, S. Akiyama<sup>1,2</sup>

<sup>1</sup>NASA/GSFC, Greenbelt, MD, USA

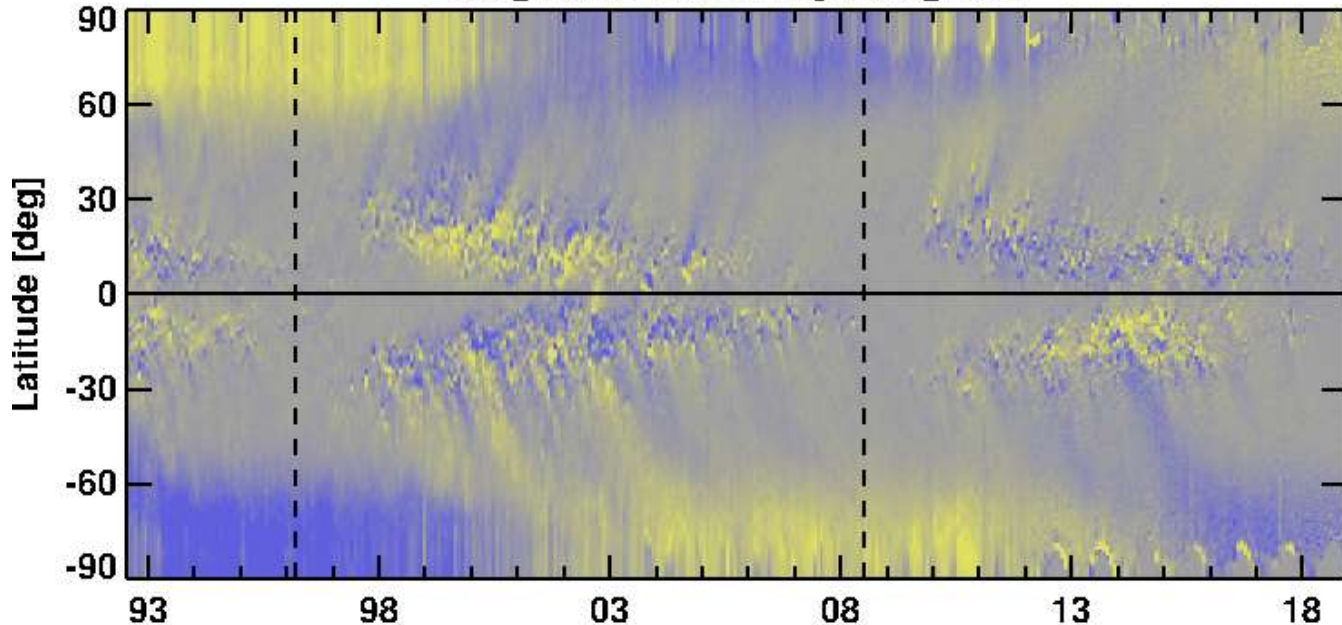
<sup>2</sup>Catholic University, Washington DC, USA

# Polar B and Microwave Tb are correlated

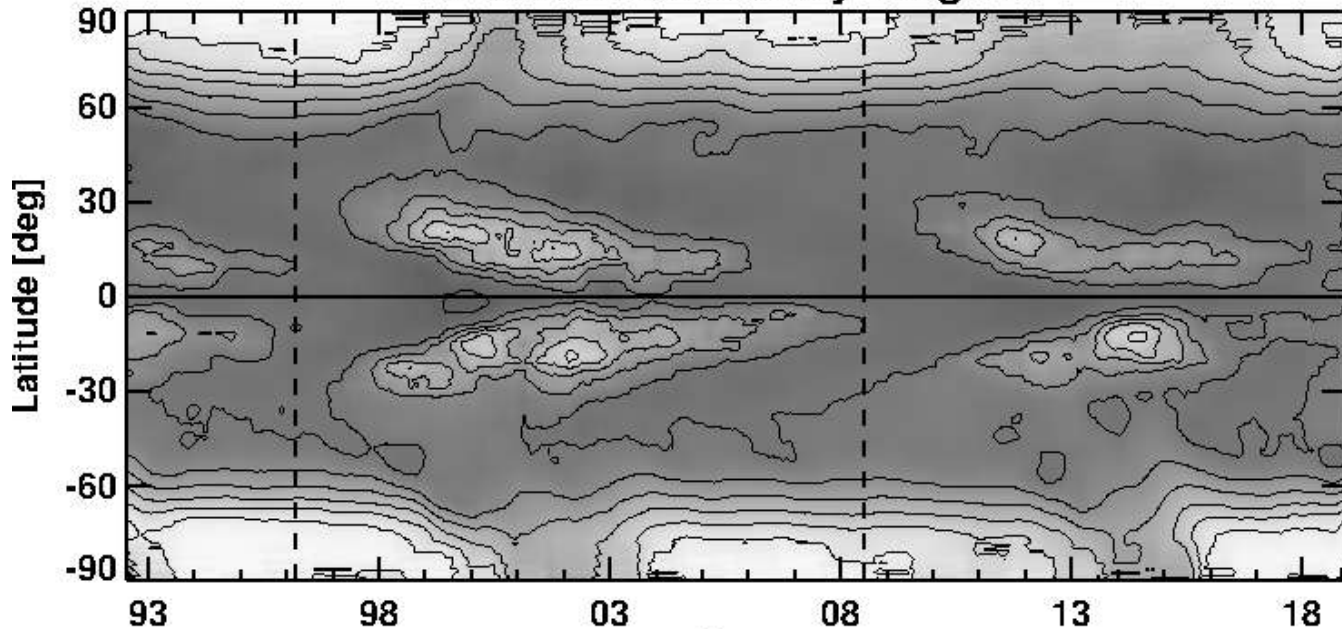


- Coronal holes are bright in microwaves
- Brightness enhancement is associated with enhanced unipolar B
- B and Tb are correlated in low-latitude and polar coronal holes (G et al 2000; 2012)
- For the interval 1992-2017:
- $B = 88 * T - 93$  G, T in  $10^4$  K

### Magnetic Butterfly Diagram

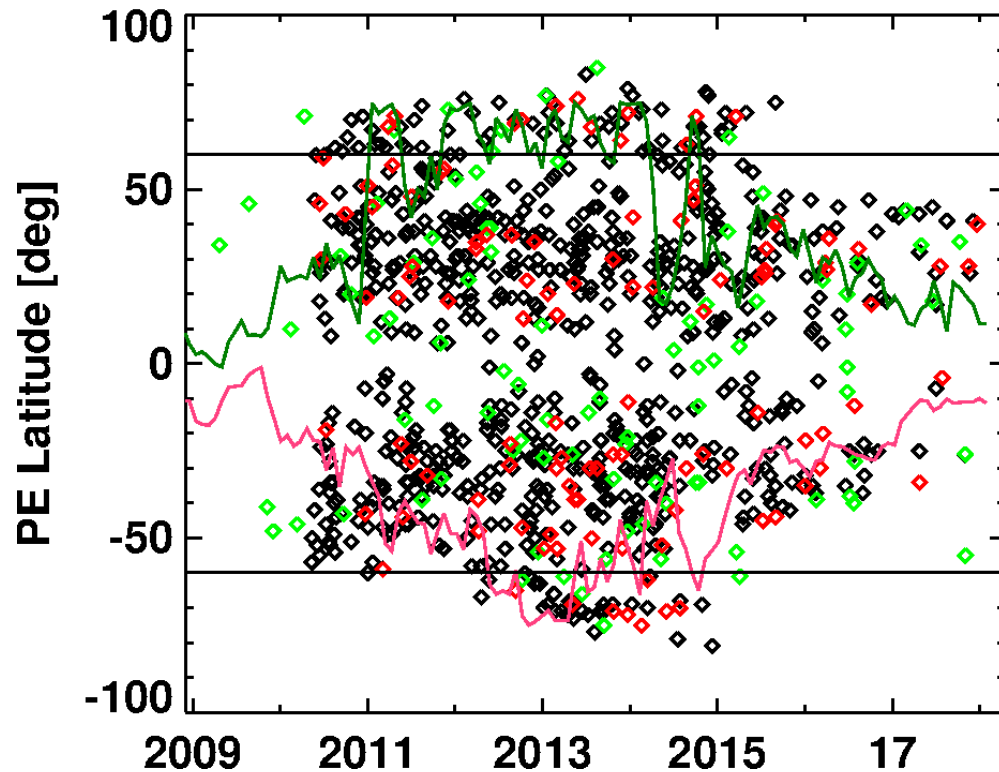


### Microwave Butterfly Diagram



- B – Tb correlation in butterfly diagrams
- Even plumes can be seen in Tb
- NS asymmetry in the polar field is obvious

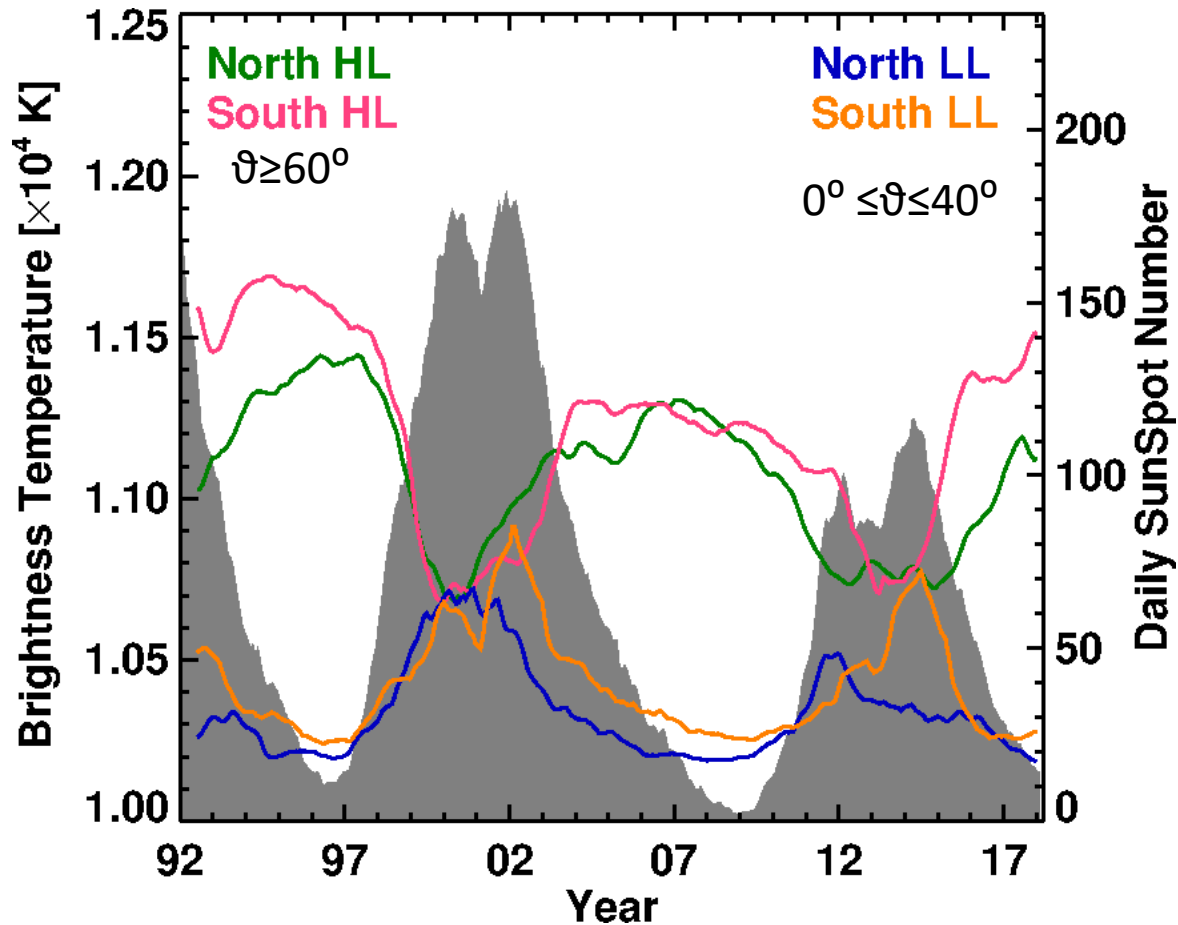
### AIA 304 / NoRH 17GHz



SDO only; SDO & NoRH; NoRH only

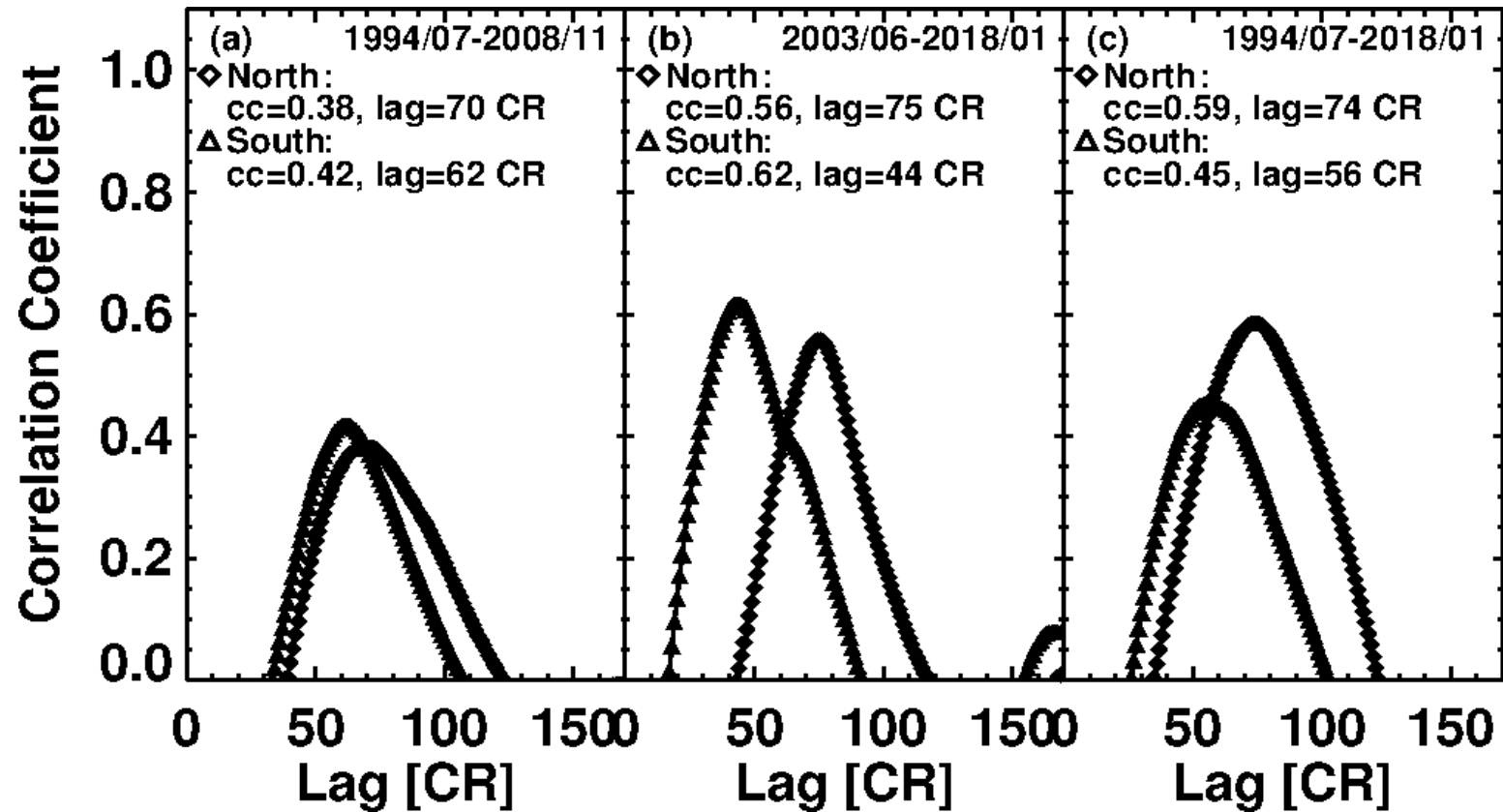
HL prominence eruptions during 2011-2015

# HL Tb and LL Tb



- Low-latitude Tb peaks at SSN maximum
- S and N hemispheres are different and contribute to the double peak and NS asymmetry
- High-latitude Tb peaks at SSN minimum
- High- and Low-latitude Tbs are anti-correlated
- HL Tb at the minimum of a cycle, is correlated with the LL Tb at the max of next cycle (similar to other proxies such as # polar faculae & SSN – Makarov & Makarova 1996)

# Cross Correlation between HL and LL Tb

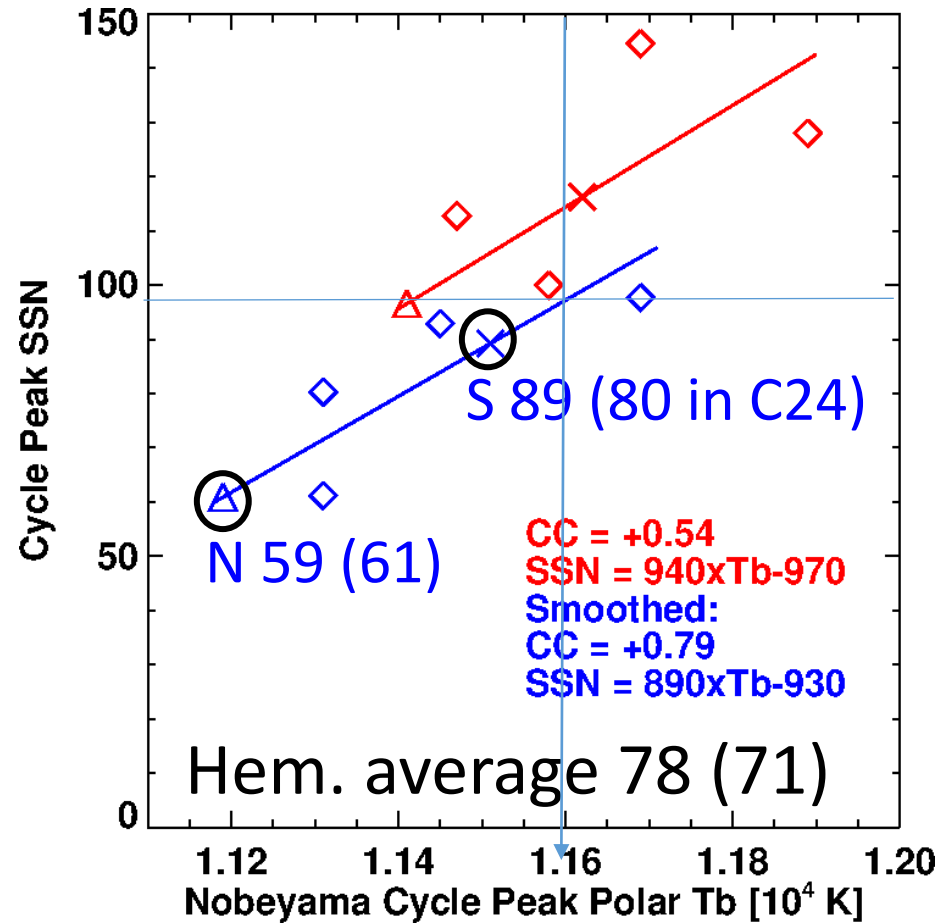


<S> 56 CR; <N> 74 CR  
4.5 years; 5.7 years

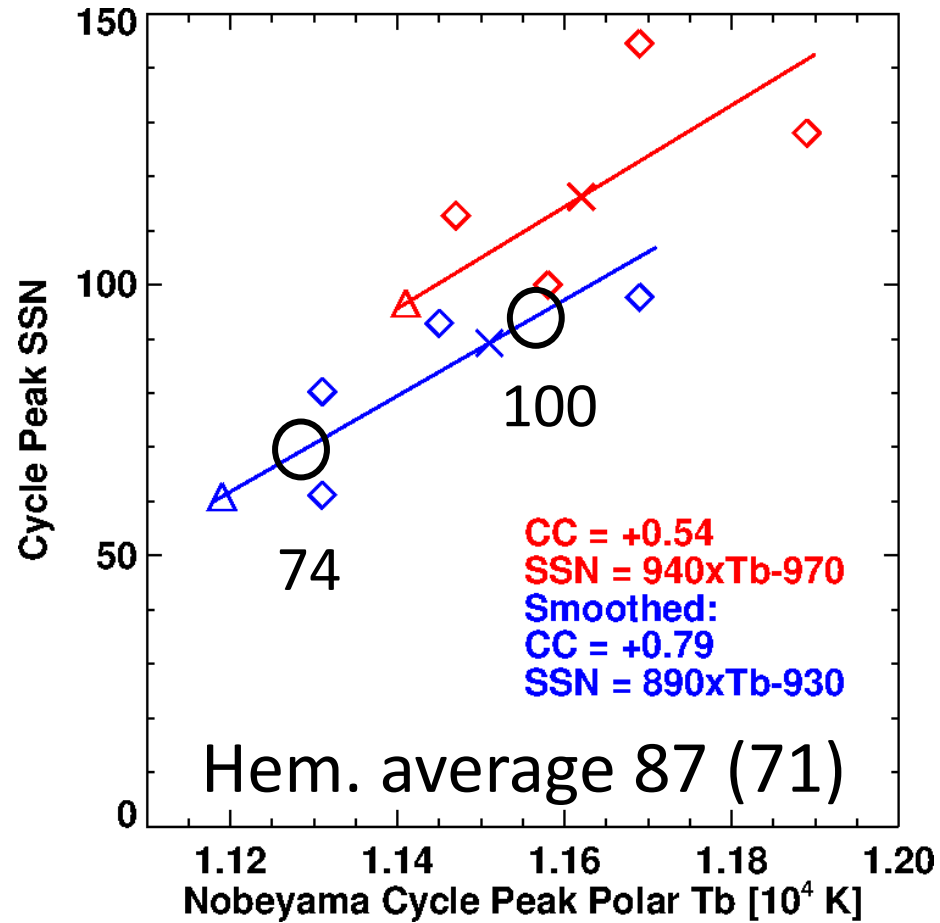
Makarov & Makarova (1996) obtained a lag of ~6 years  
between monthly #polar faculae & SSN

# Predicting Cycle 25 Strength

From Tb Value at the Poles

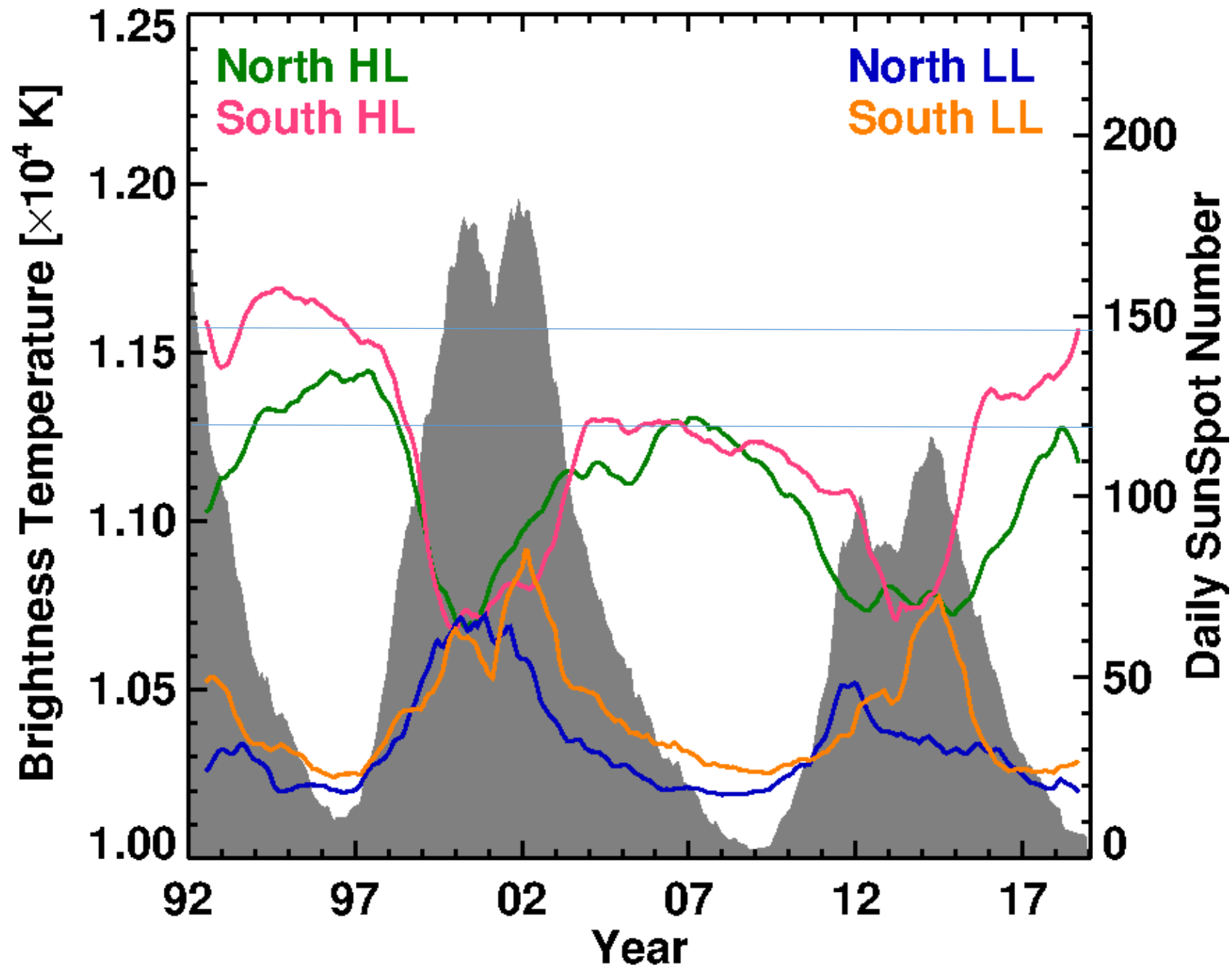


Updated



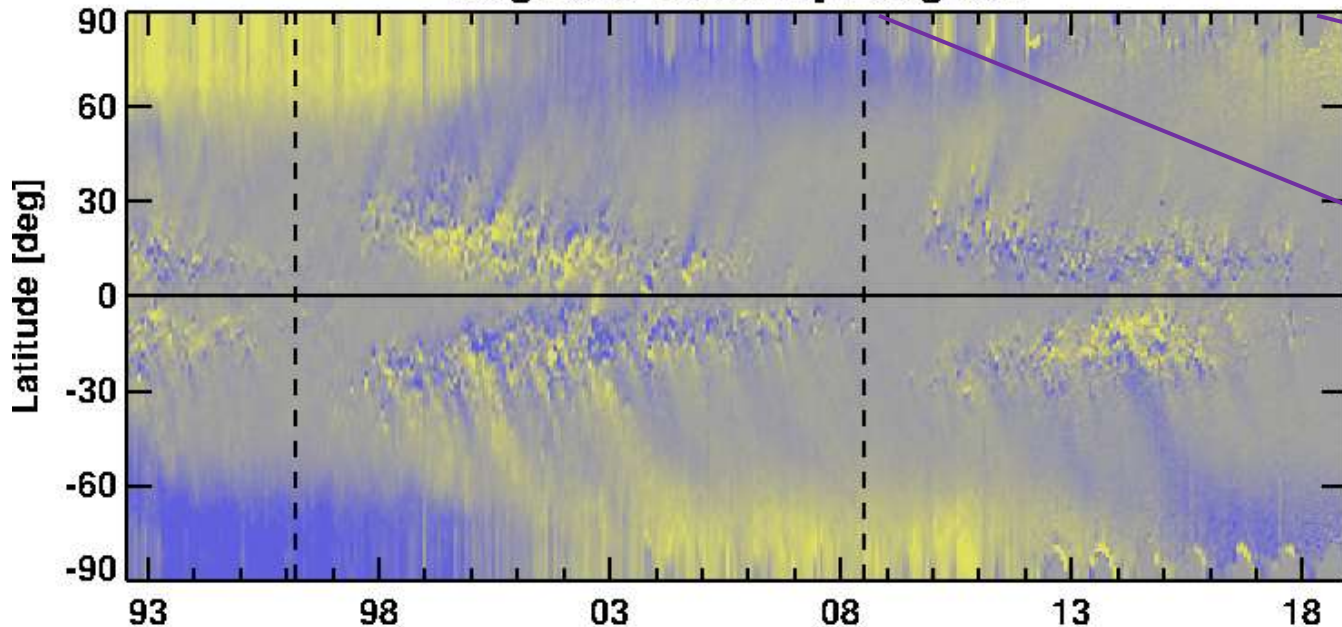
NS asymmetry  
will continue  
(south will be  
dominant again)

NOAA/NASA  
Panel:  
95 -140

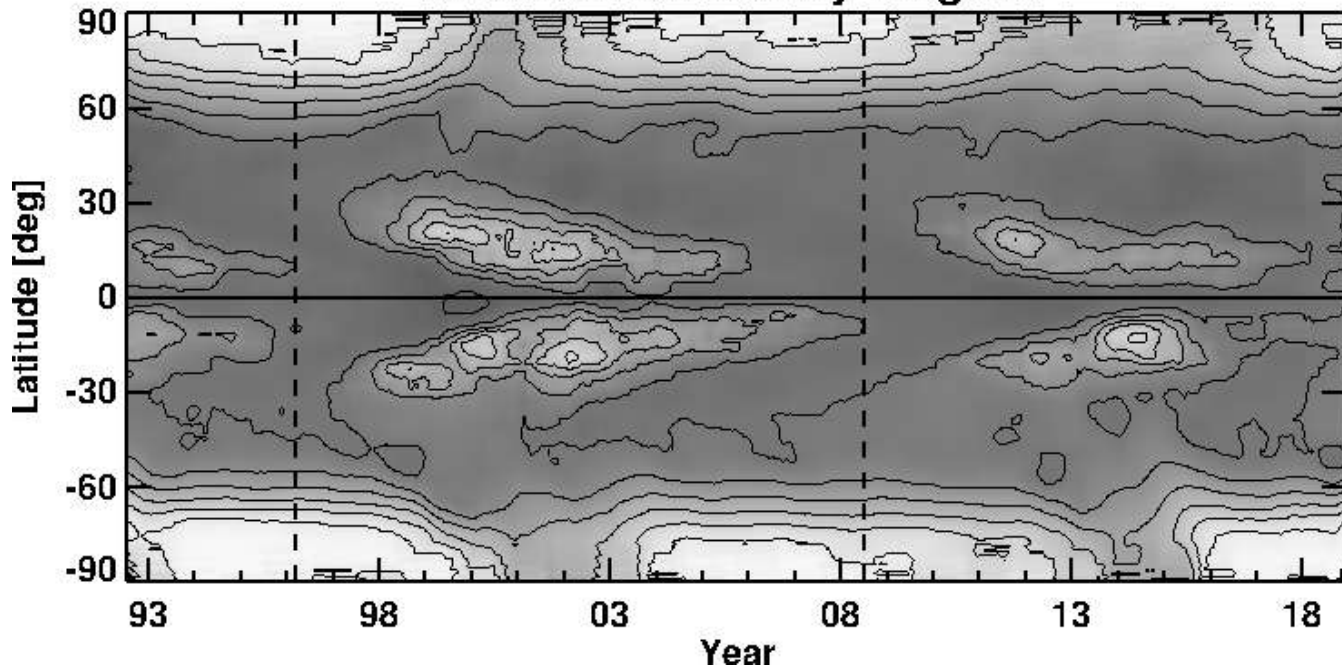




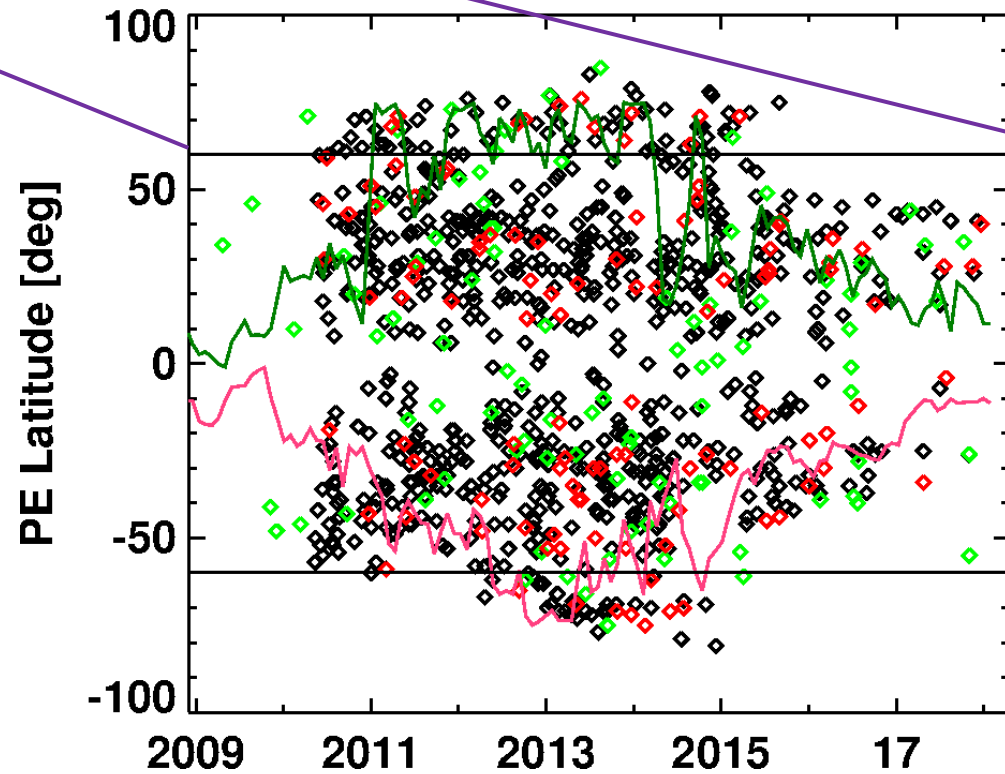
### Magnetic Butterfly Diagram



### Microwave Butterfly Diagram



### AIA 304 / NoRH 17GHz

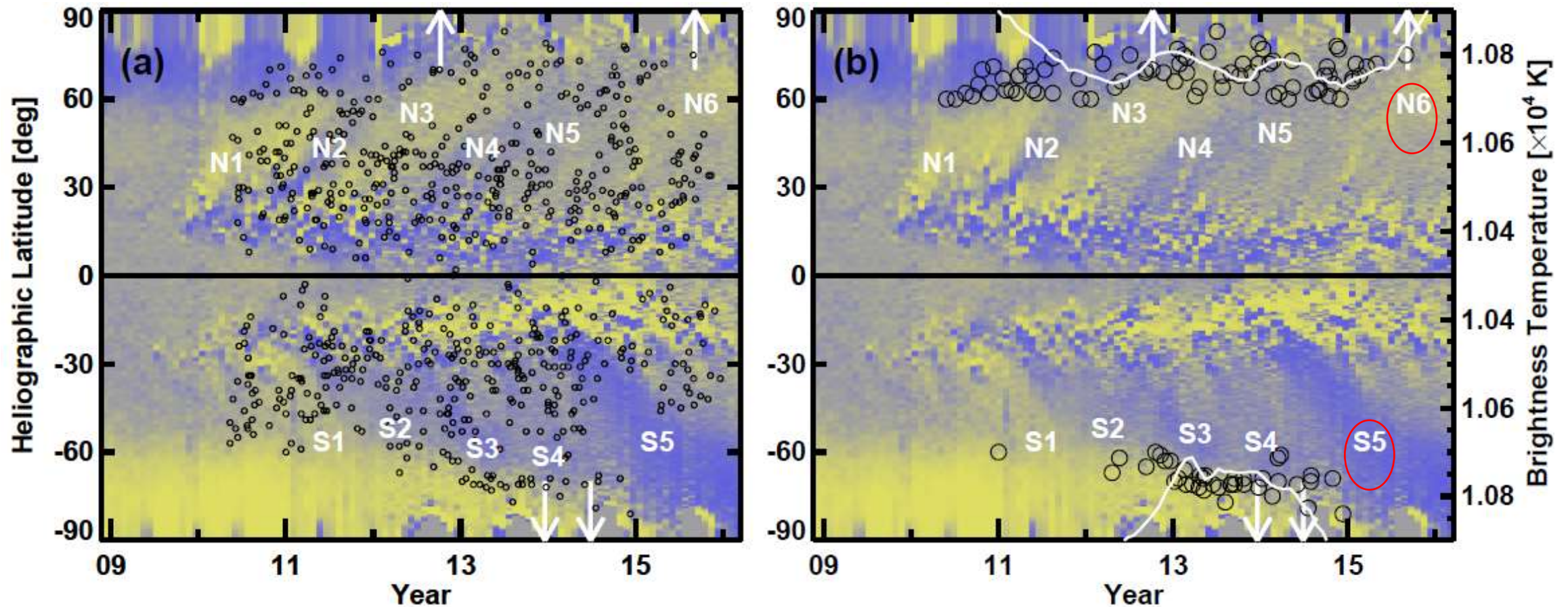


HL prominences during 2011-2015

- B – Tb correlation in butterfly diagrams
- Even plumes can be seen in Tb
- NS asymmetry in the polar field is obvious

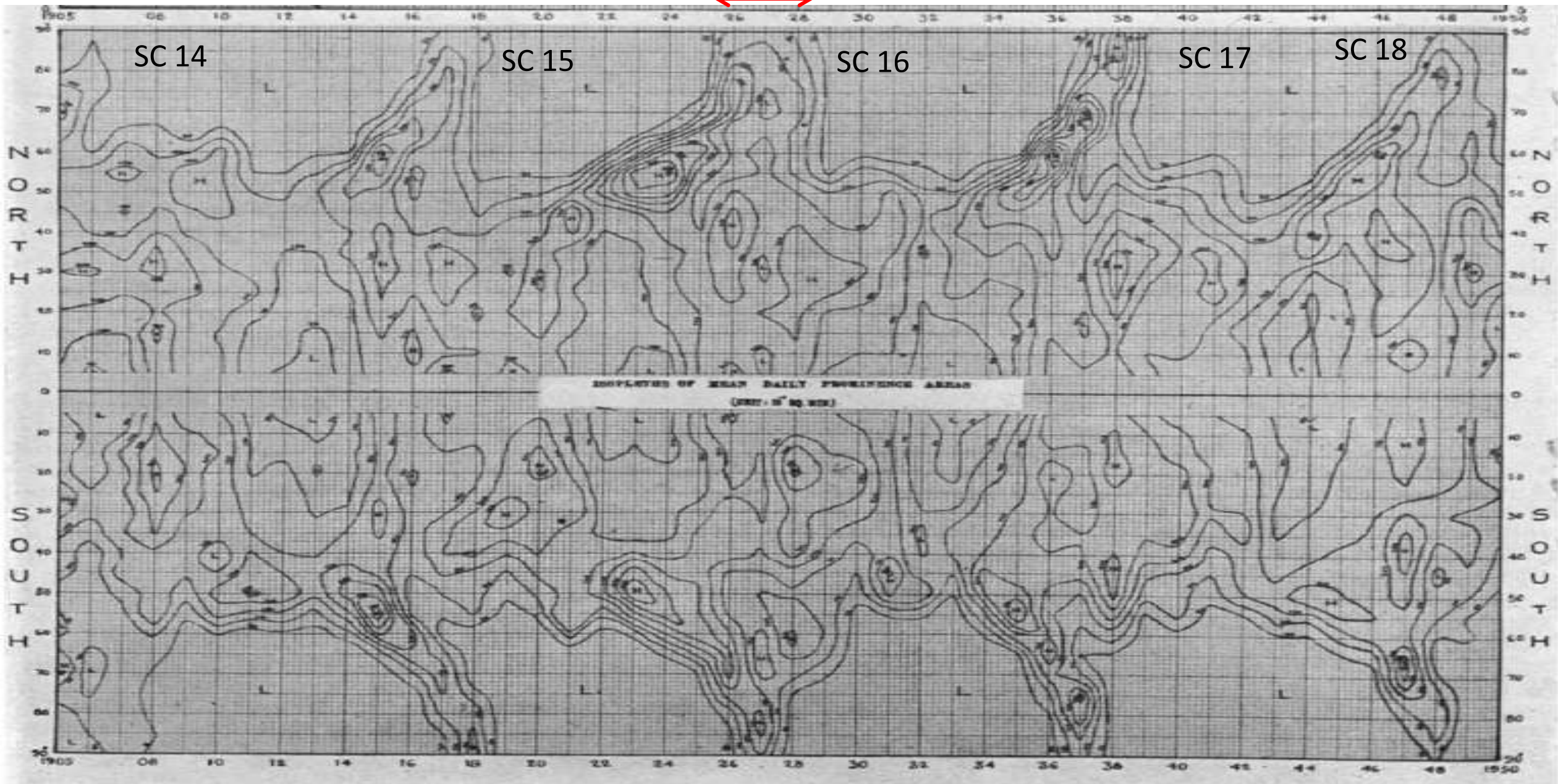


# Fight Between Incumbent and Insurgent Fluxes



- After reversal, no bipolar regions – No eruptions -- polar Tb increases above quiet Sun level (new polarity B)
- Delayed reversal: the surges of “wrong polarity” N2, N4, N5 (Cameron et al. 2013; Jiang et al. 2014; Sun et al. 2015)
- After sign reversal  $\rightarrow$  increase in HL Tb indicating buildup of new polarity field



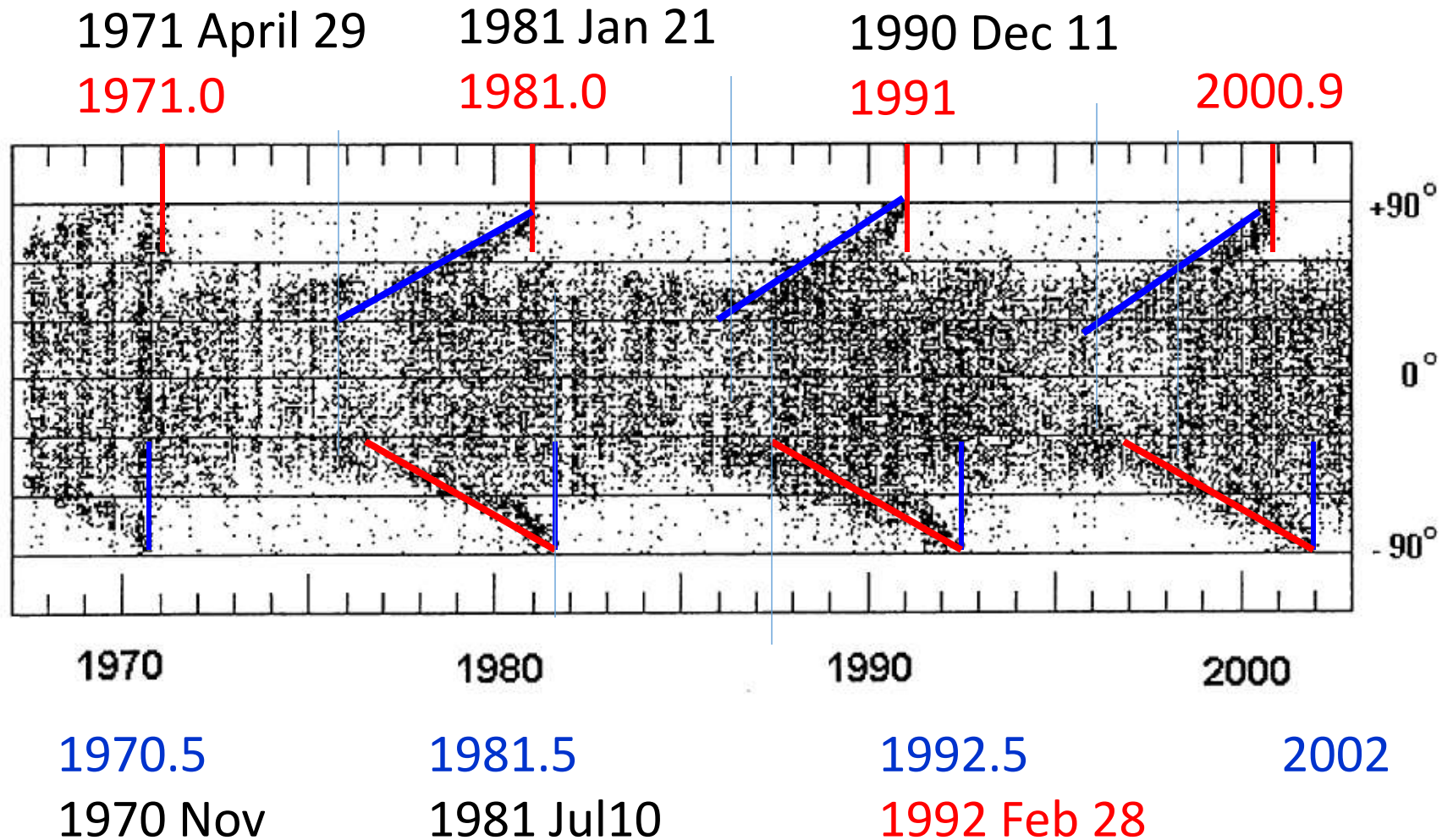


# Rush to the Poles (RTTP)

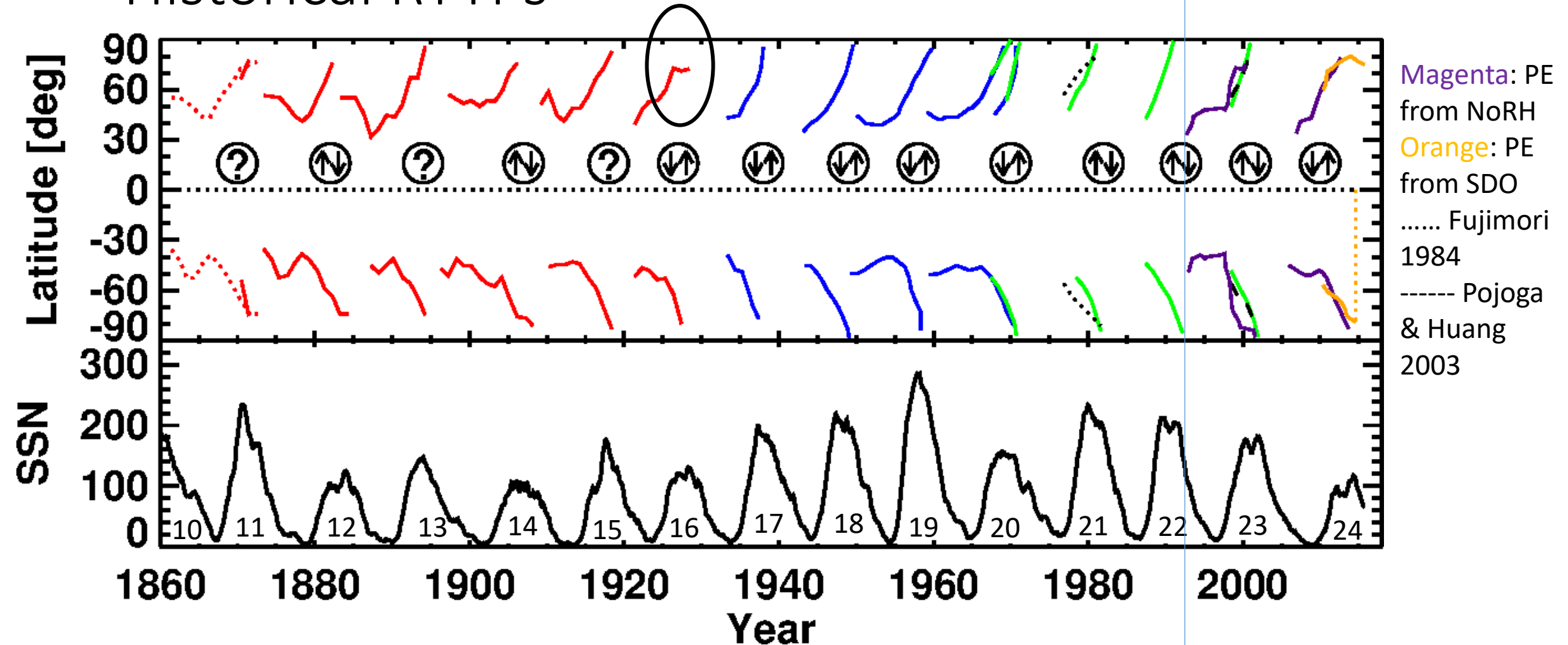
- High-latitude prominences/filaments and their poleward migration were discovered by Secchi in 1872
- RTTP refers to filament locations systematically moving toward the poles in both hemispheres (Lockyer 1931)
- “Dash to the poles” (Evershed and Evershed 1917) and “Rush to the poles” (Ananthakrishnan 1954)
- Synchronism between RTTP and the sign reversal at solar poles (Waldmeier 1960; Hyder 1965)
- Locations of prominence eruptions (PEs) as proxy to the locations of prominences/filaments (G. et al. 2003; 2012)



# Rush to the Poles of Filaments & Polarity Reversal



# Historical RTTPs



10-20: Stix (compiled from [Lockyer 1931](#); Kiepenhauer 1953; Waldmier 1968; 1973)

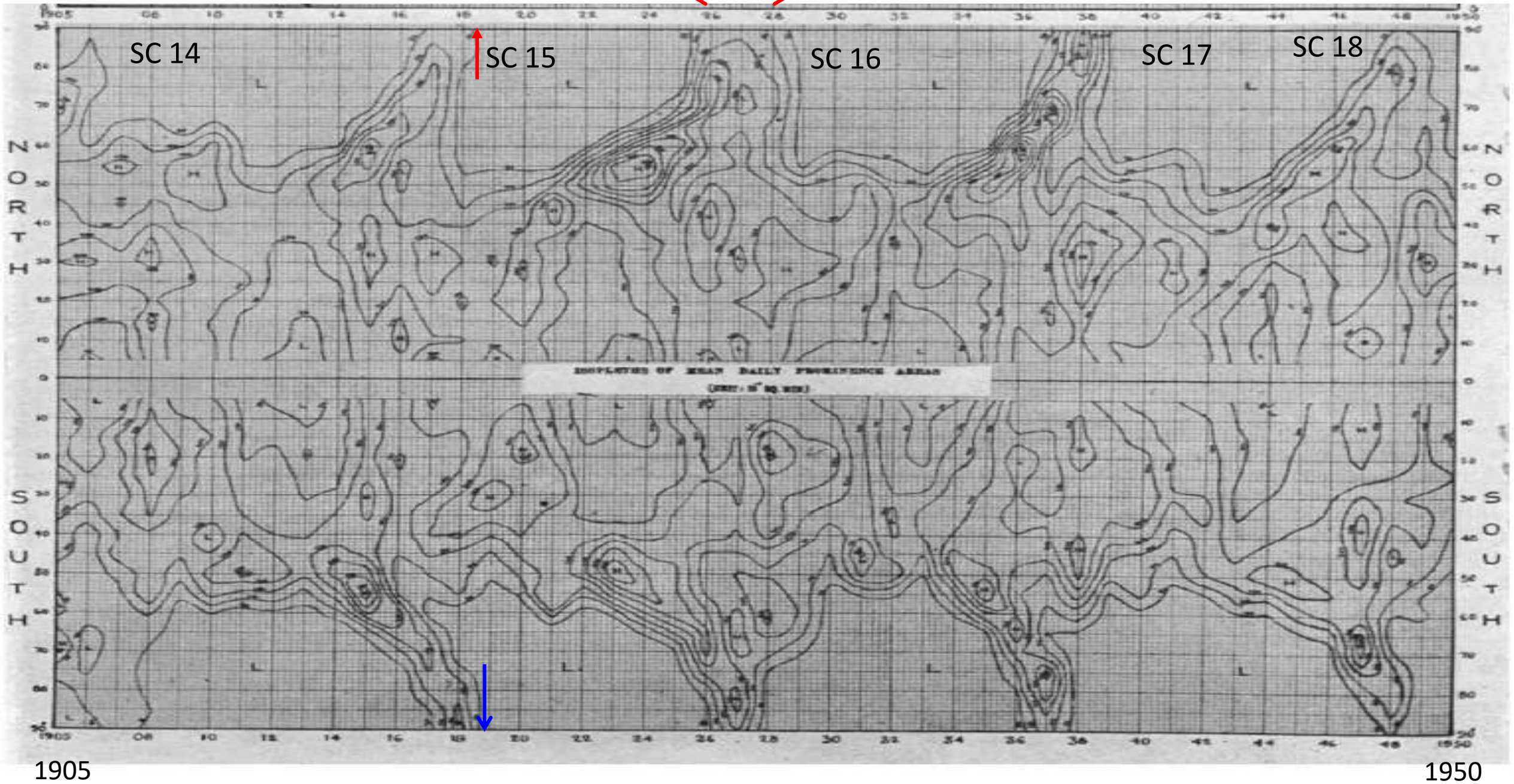
20-23: [Lorenc et al. \(2003\)](#)

23-24 [Gopalswamy et al. 2003; 2012; 2016](#)

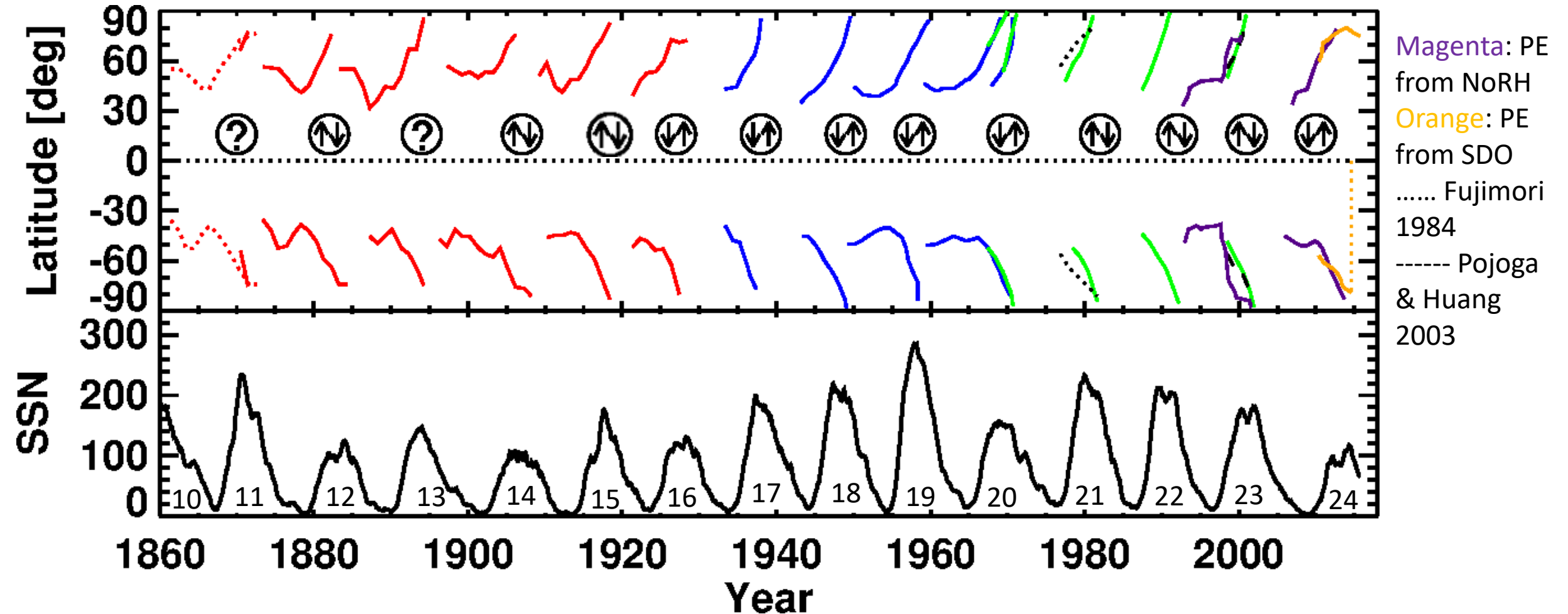
[Gopalswamy et al. 2018 JASTP](#)

Cycle 16 has similar RTTP behavior as cycle 24; the reversal asymmetry also changes





# Historical RTTPs



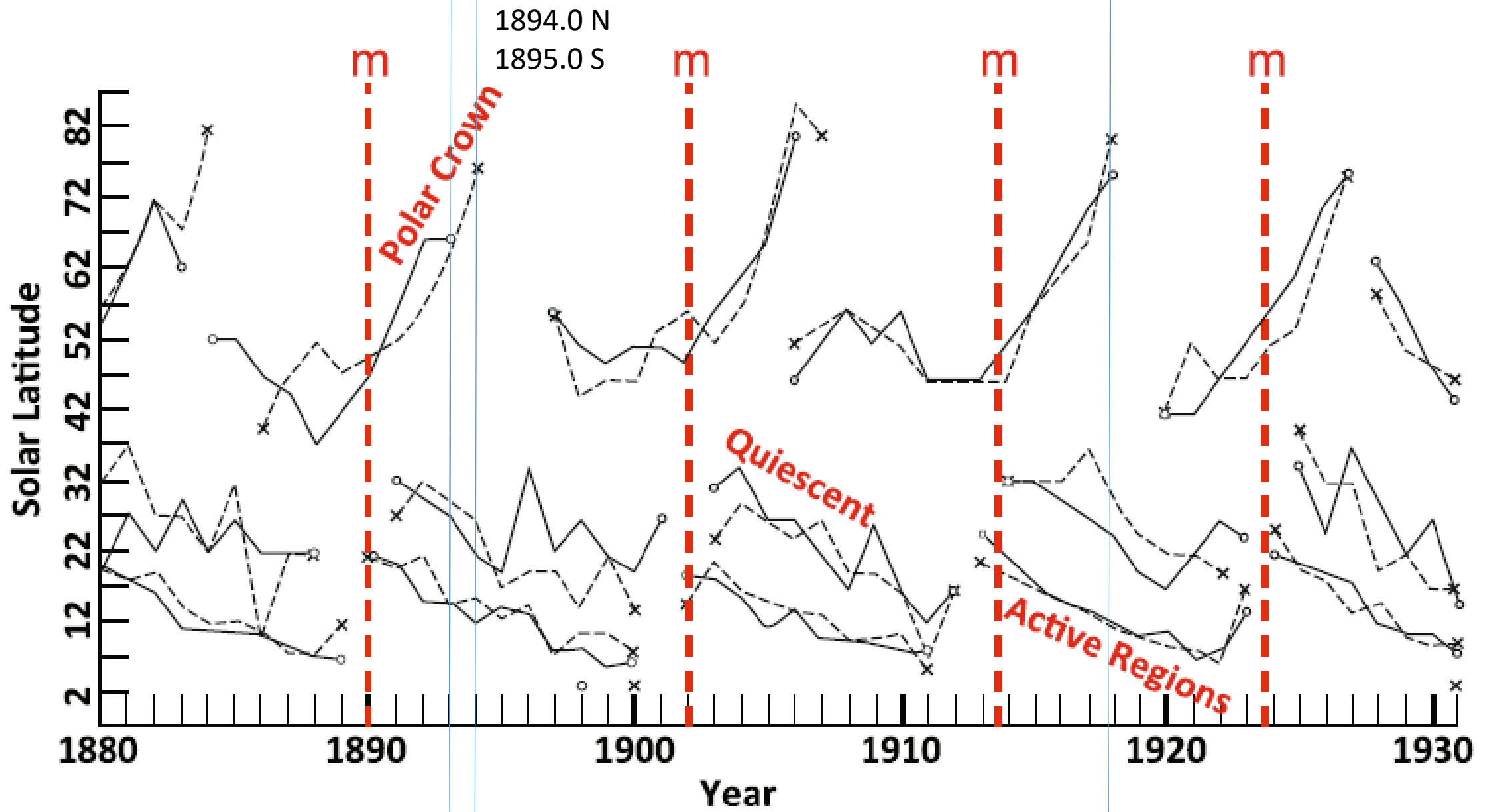
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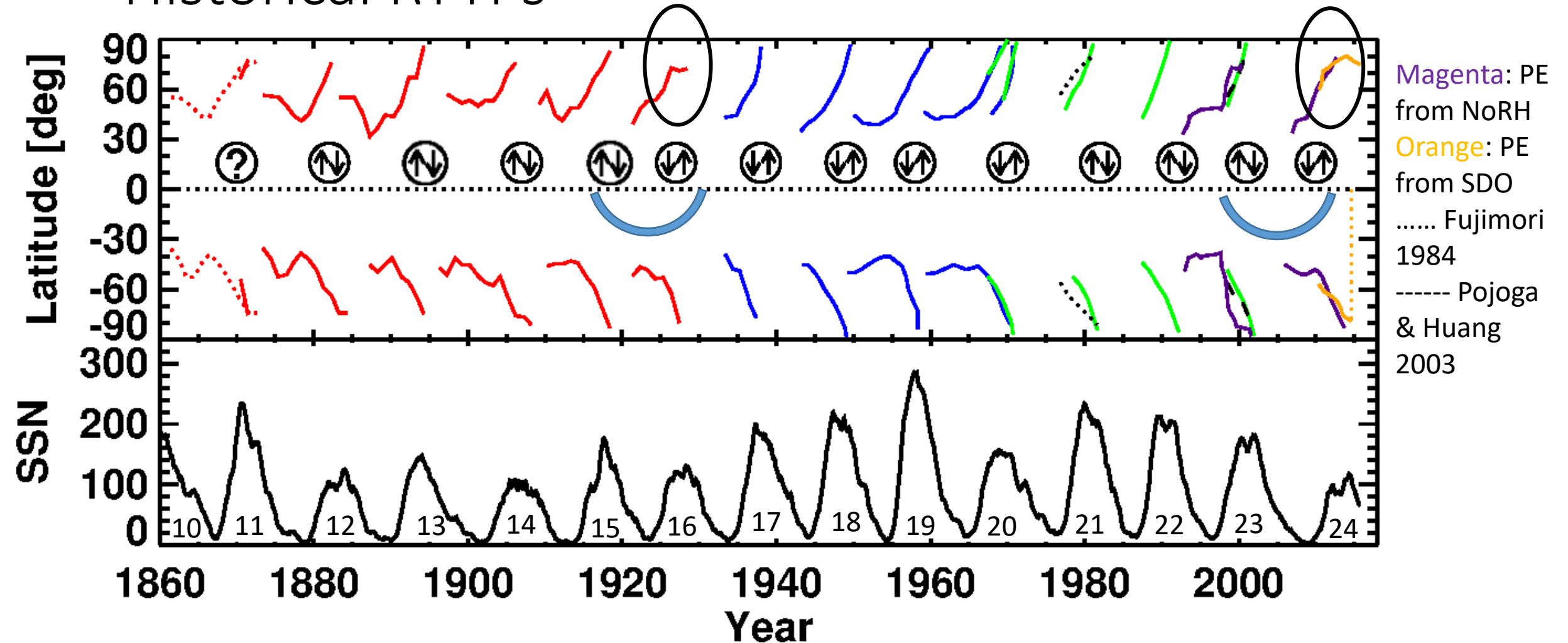
Cycle 16 has similar RTTP behavior as cycle 24; the reversal asymmetry also changes



Bocchino 1933 in Cliver 2014; also Evershed & Evershed 1917 (Kodaikanal)

# Historical RTTPs

Reversal asymmetry changes every 3-5 cycles  
 Extended period of HL Prominences in cycle 16, 20 maxima



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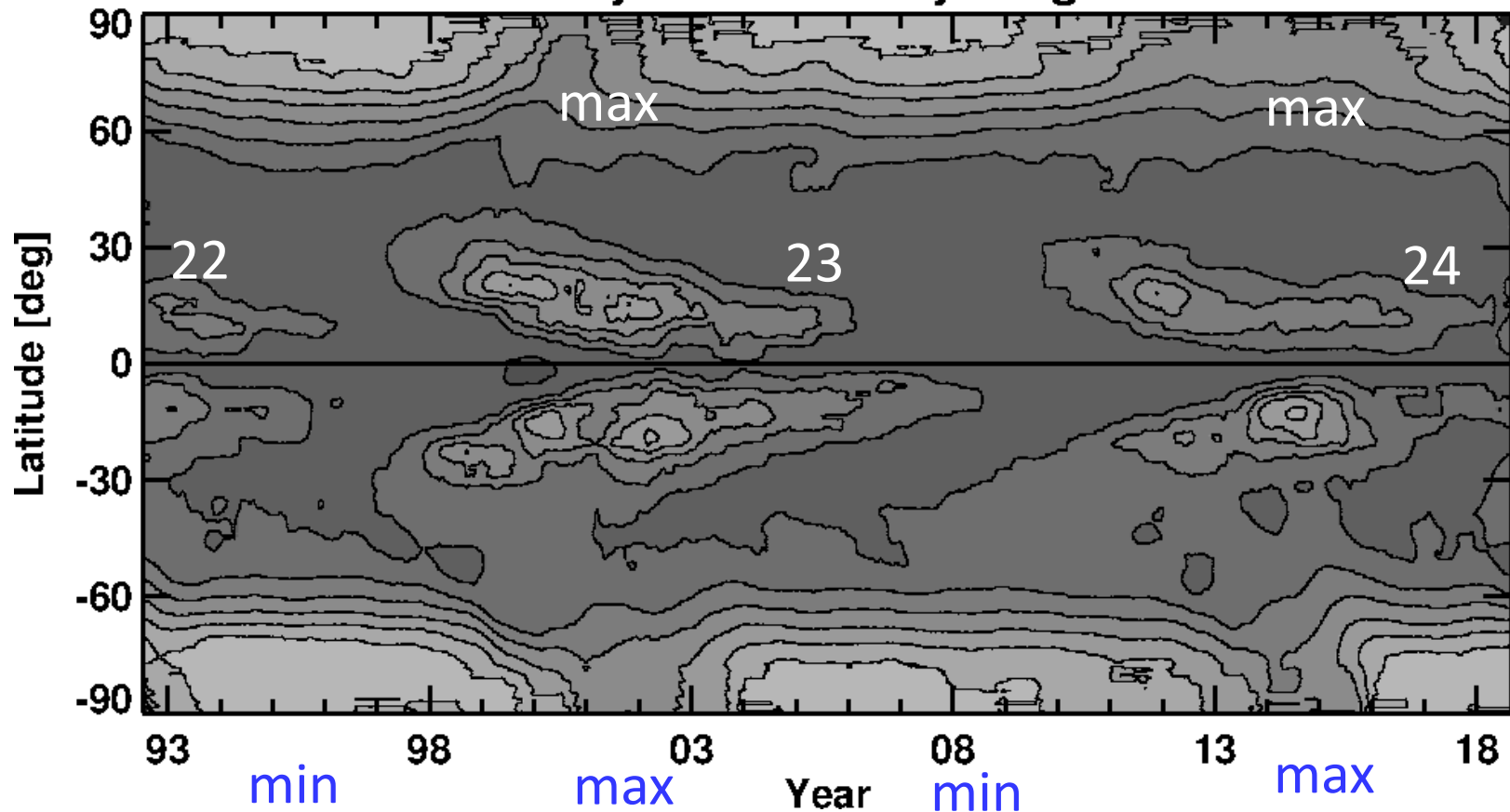
[Gopalswamy et al. 2018 JASTP](#)

Cycle 16 has similar RTTP behavior as cycle 24; the reversal asymmetry also changes



# Microwave Tb is also a measure of solar activity

## Nobeyama Butterfly Diagram



The prolonged zero-field conditions in the north pole will delay the onset of cycle 25 in the northern hemisphere

SC 24 is already weak, so it may not add too much new flux to north polar region  
**caveat: a huge active region can still emerge in the declining phase and build the polar field**

In the south the maximum was normal.  
The cycle is likely to start around 2021.0

Reversal precedence switched between the poles

Reversal asymmetry: solar activity modulated by the tilt angle distribution

- Reversal asymmetry to follow sunspot hemispheric asymmetry Svalgaard and Kamide (2013)
- Large scatter in the distribution of tilt  $\rightarrow$  large variability in the polar B  $\rightarrow$  the variability in the amplitude and phase of the new cycle (e.g. Nagy et al. 2017)



# Summary

- Unusual polar conditions prevailed in the north polar region of the Sun until recently (extended PE, low polar Tb,  $B \sim 0$ )
- A similar situation prevailed in cycle 16
- In cycles 24 and 16, the reversal asymmetry switched from NS to SN
- In 14 cycles, there were three switches, indicating a 3-5 cycle periodicity
- The extended PE activity is due to plumes of wrong polarity heading to the poles (due to wrong tilt angles) and contributes to prediction uncertainty
- Using microwave polar Tb, we predict SC 25 will be similar to SC 24, may be slightly larger, but a huge hemispheric asymmetry is expected.