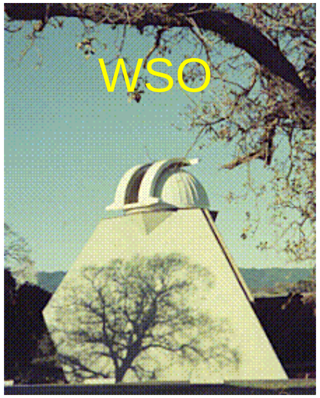
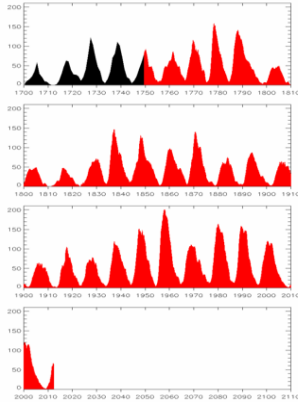
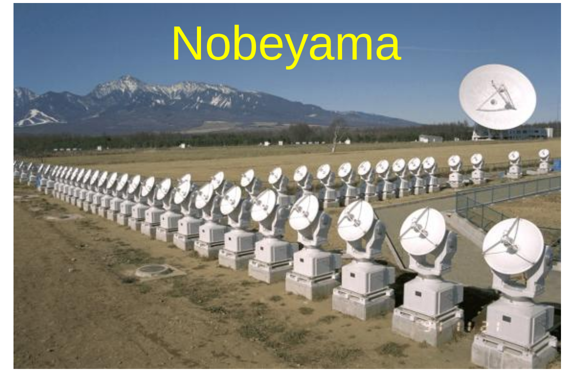






Solar Predictions Using Nobeyama Data

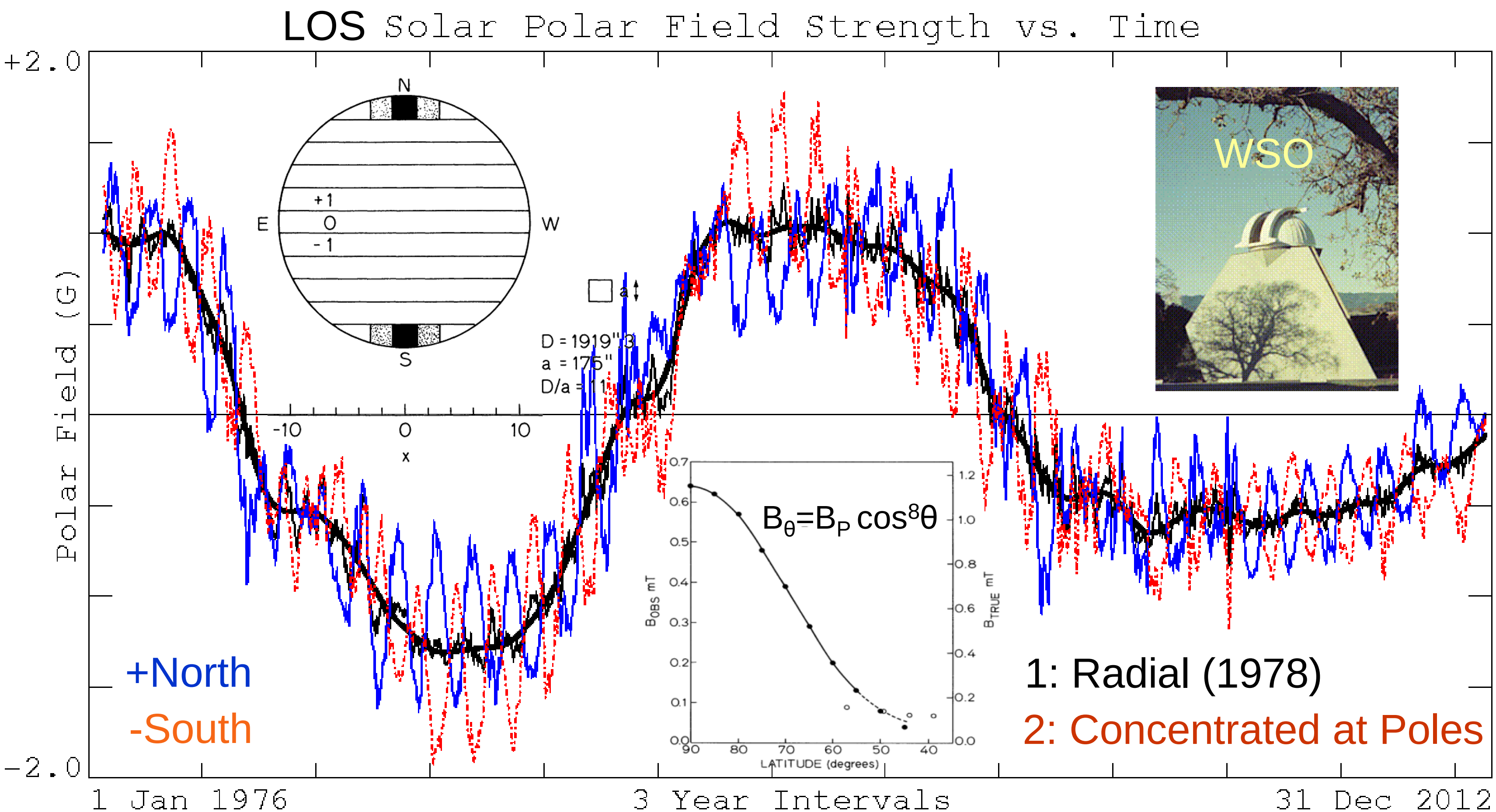
L. Svalgaard (Stanford University)
Y. Kamide (Nagoya University)

SPRO2012, Nagoya University, 22 November 2012

Outline

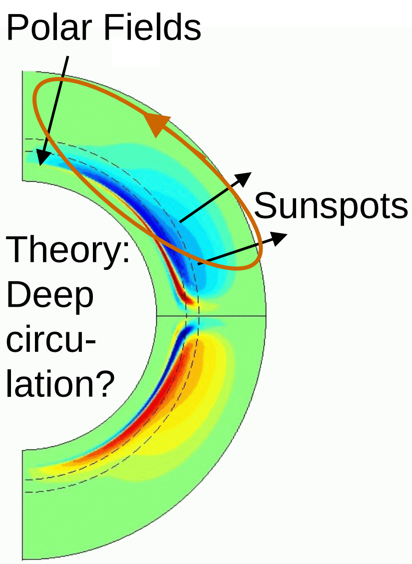
- The hard-to-measure solar polar fields
- Polar brightness seen in Nobeyama 17 GHz
- Correlation with polar magnetic fields
- Importance of polar fields for solar wind
- Polar field and activity asymmetry
- Full-disk radiometry
- Too few sunspots forming
- A Grand Minimum looming?

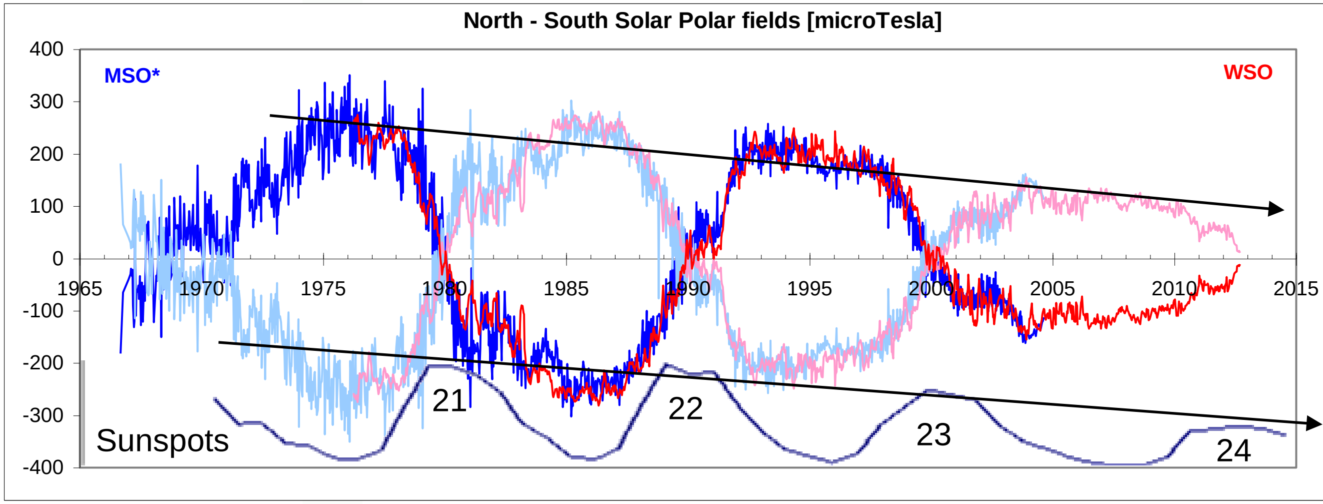
Observing the Polar Magnetic Flux

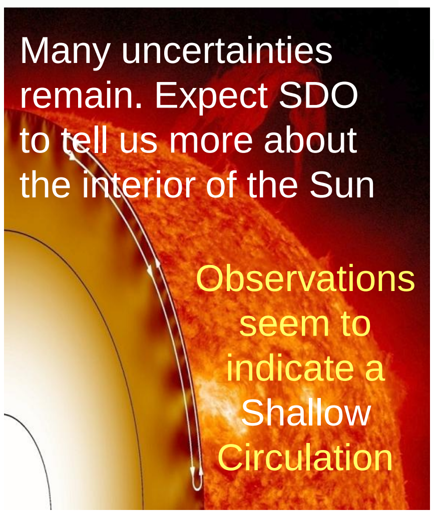


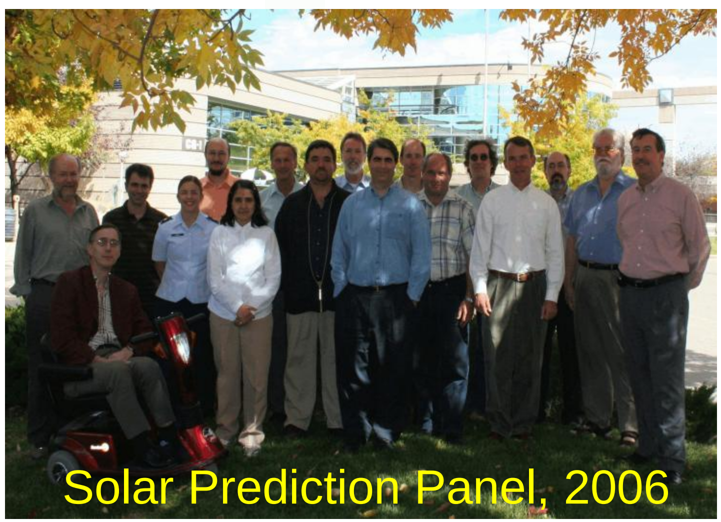
Strong annual Bo variation [by factor of two]

Can we predict Solar Activity?







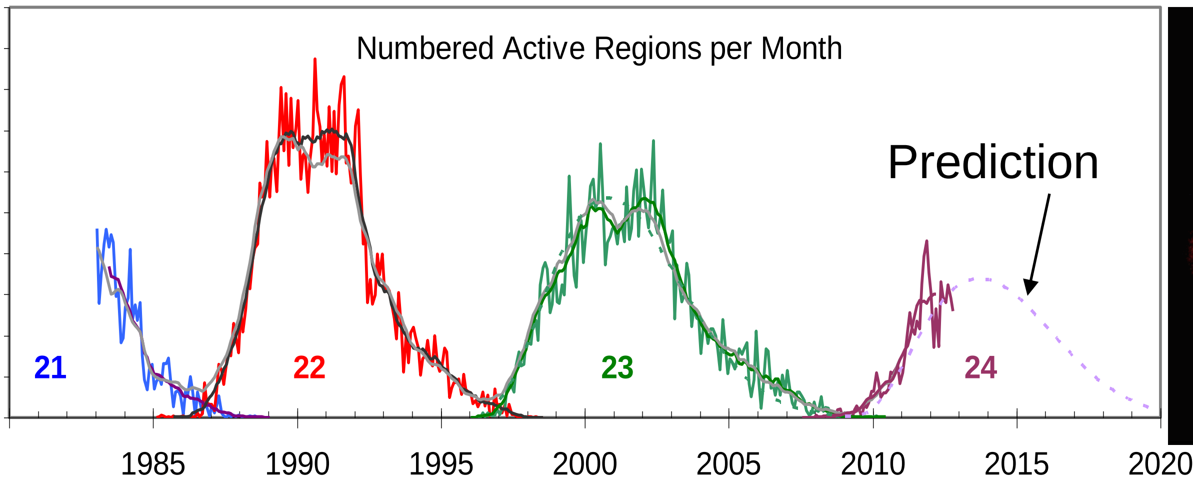

Solar Prediction Panel, 2006

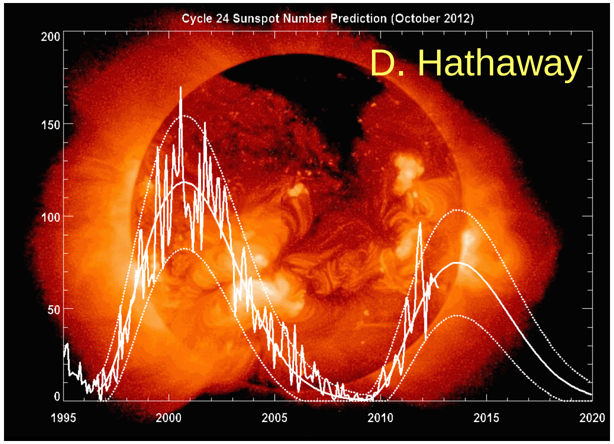
Observations and theory suggest that the magnetic field at the poles of the Sun at solar minimum is a good predictor of the next solar cycle.

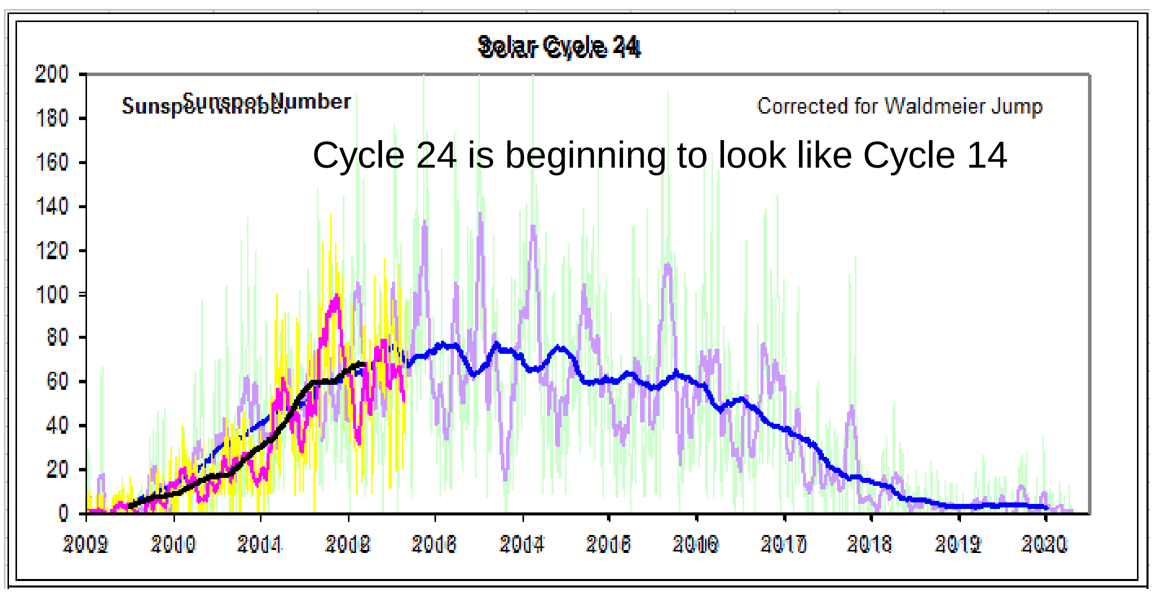
The low polar fields at the recent solar minimum predicted a small cycle 24

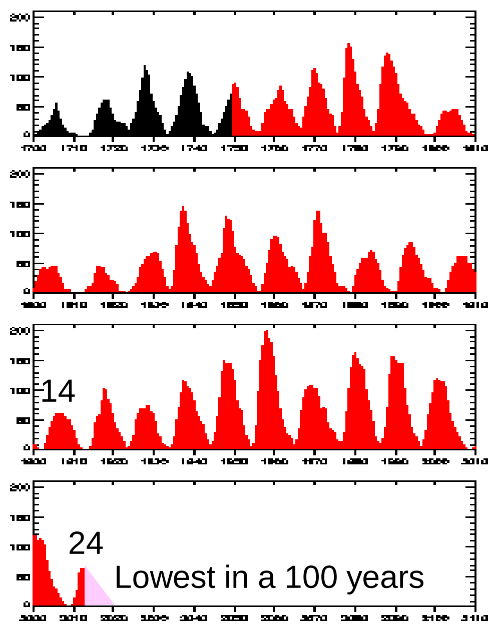
How is Cycle 24 Evolving? As Predicted!
So, the polar field precursor method seems to work

Active Region Count

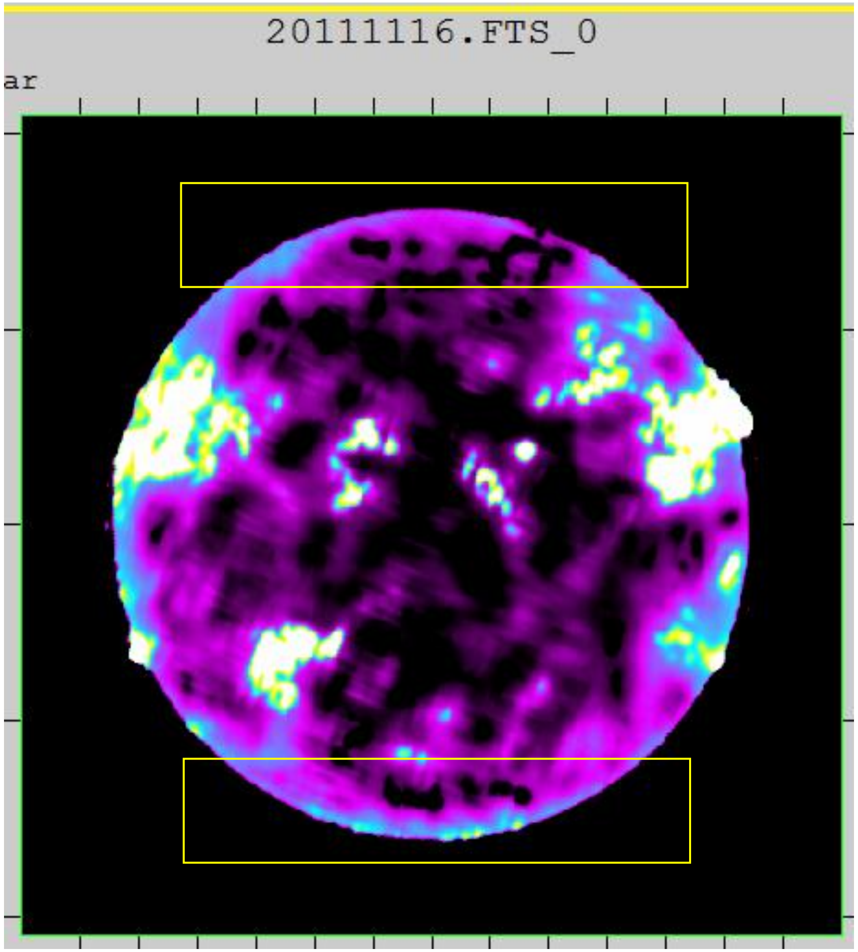








A different view of polar fields (?): Nobeyama Image of 17GHz Emission



ν17 GHz = λ1.76 cm

v_e = B (Tesla) · 28 GHz

17 GHz is 3rd harmonic v_e for 2000 G

Beam width 10”

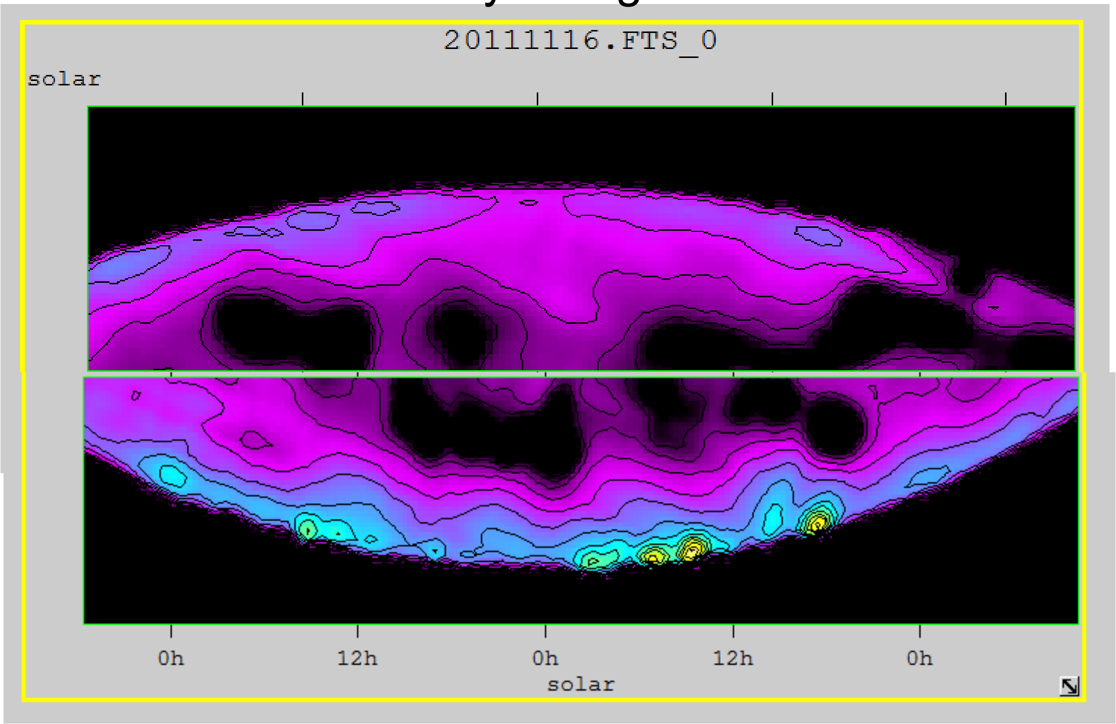
1. General Limb brightening
2. Active regions bright

A. Gyro-resonance is thought (?) to result as 3rd harmonic of 2000 G

B. Also Bremsstralung from hot atmosphere [10,000 – 13,000 K]

Bright Patches in Polar Regions

A year ago…



Polar regions at brightness temperature 10,000 and 13,000 K. (333 K between contour lines).

Bright Patches Mark Strong Magnetic Fields (?)

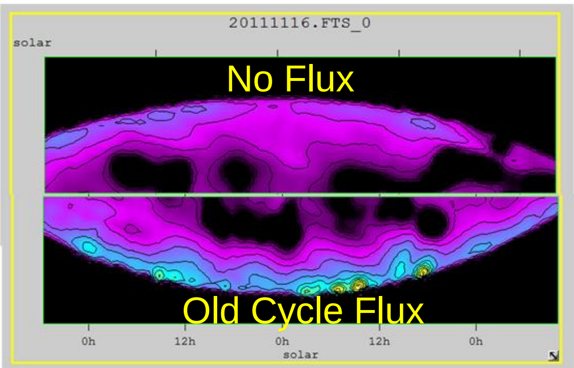
"One still **unresolved puzzle** about the chromosphere is why at some frequencies (at least 10-100 GHz) the polar coronal holes appear brighter than the rest of the quiet Sun. There is some evidence that all coronal holes, even those not at the poles, are brighter"

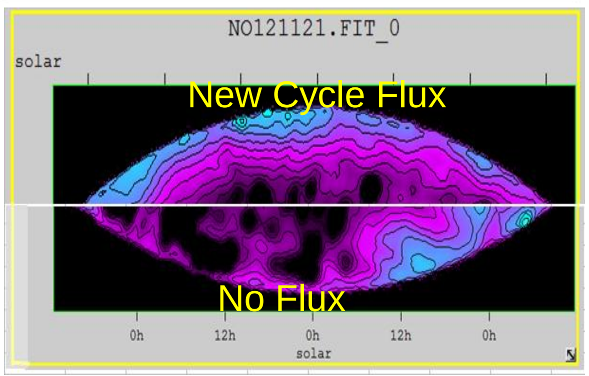
http://web.njit.edu/~gary/728/
Lectures 10 & 11

"still-mysterious polar brightenings" *Bastian et al.* (1998, FASR)

Magnetic Flux in the Polar Caps

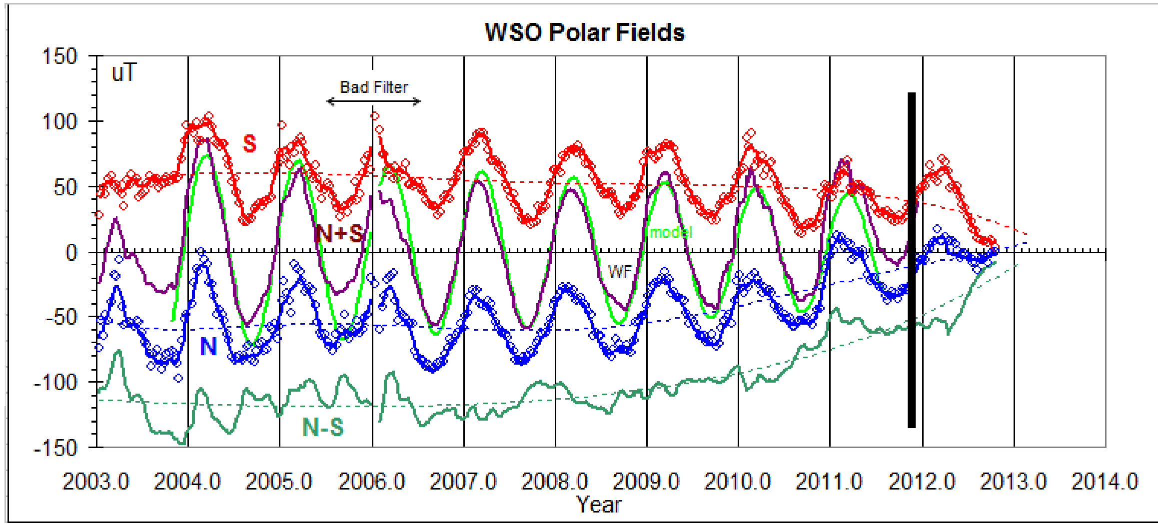
A year ago…

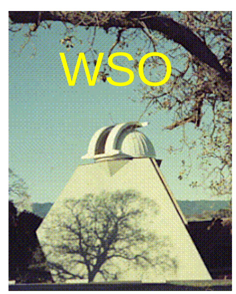


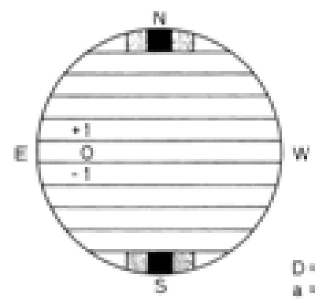


Yesterday…

Answer: There is no flux judging from the 17GHz images



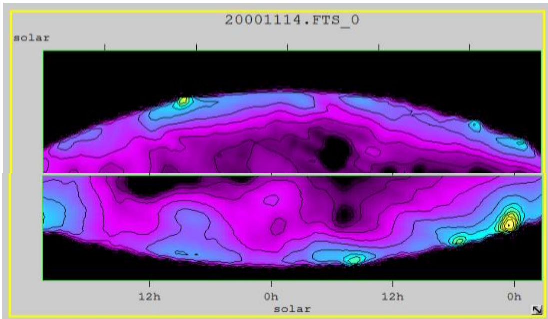


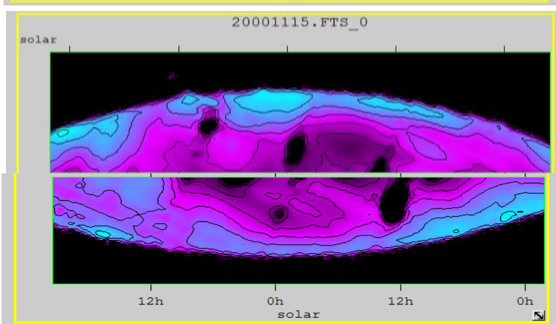


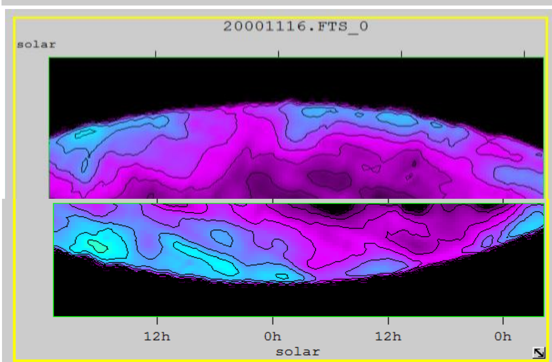
Average flux above 55°: First North reversing, now the South…

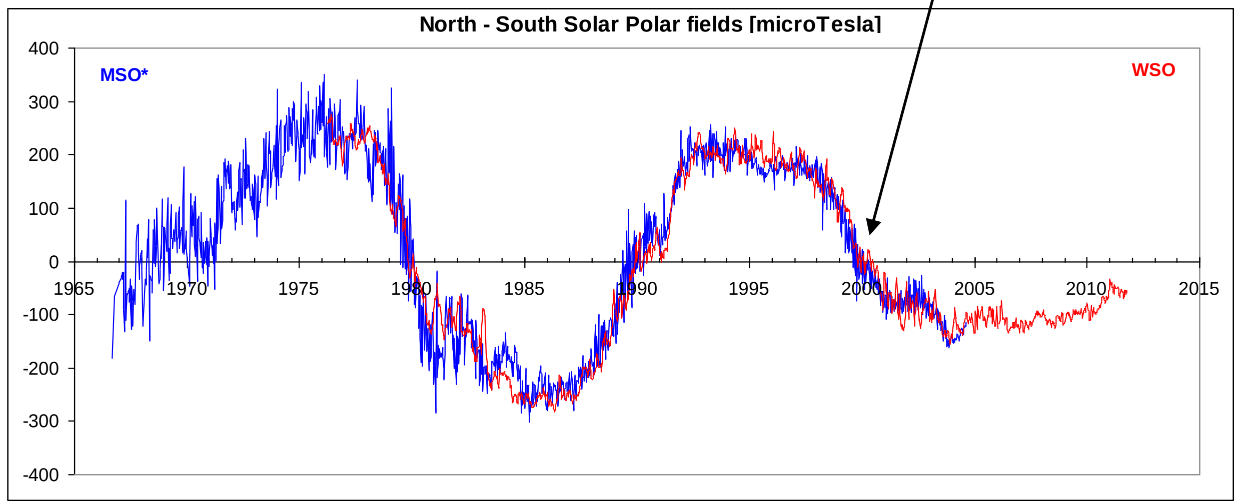
Question: At solar maximum, are the polar caps, when reversing field, covered with equal amounts of opposite polarity magnetic fluxes or isn't there any flux?

Few or Weak Bright Patches at Solar Maximum, 2000







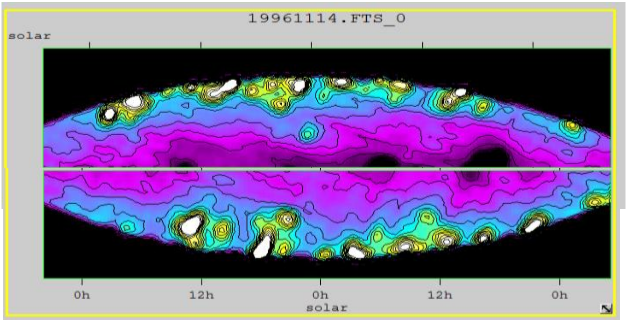


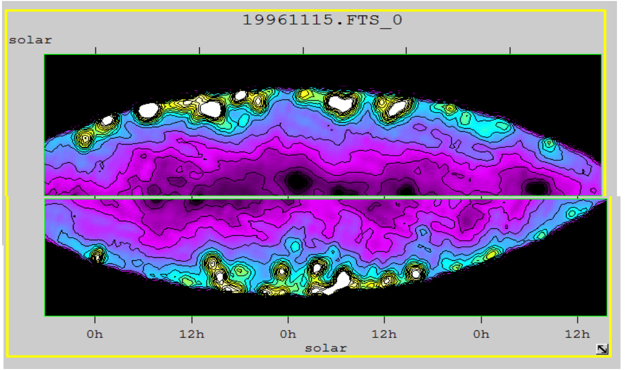
Only a few scatted, weak patches. So no magnetic flux of the kind that makes patches [~2000 G], thus the polar fields are not an equal mixture of opposite polarities. There aren’t any.

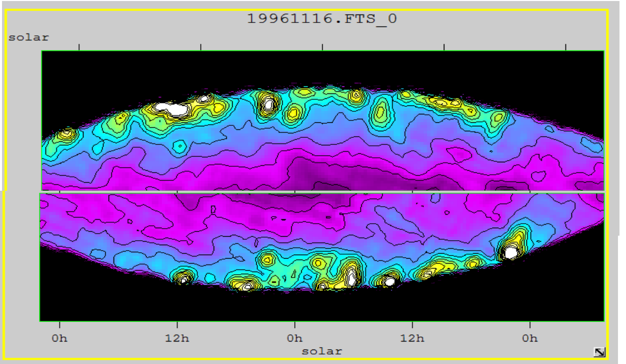
What does WSO measure? Not the ‘pepper and salt’

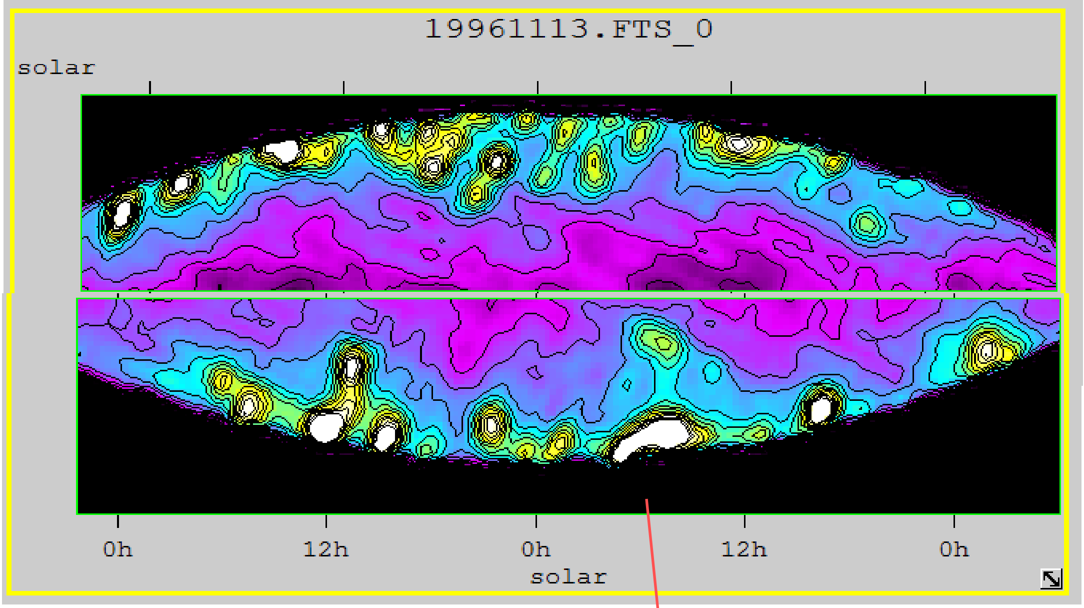
But at Solar Minimum, Oh Boy!

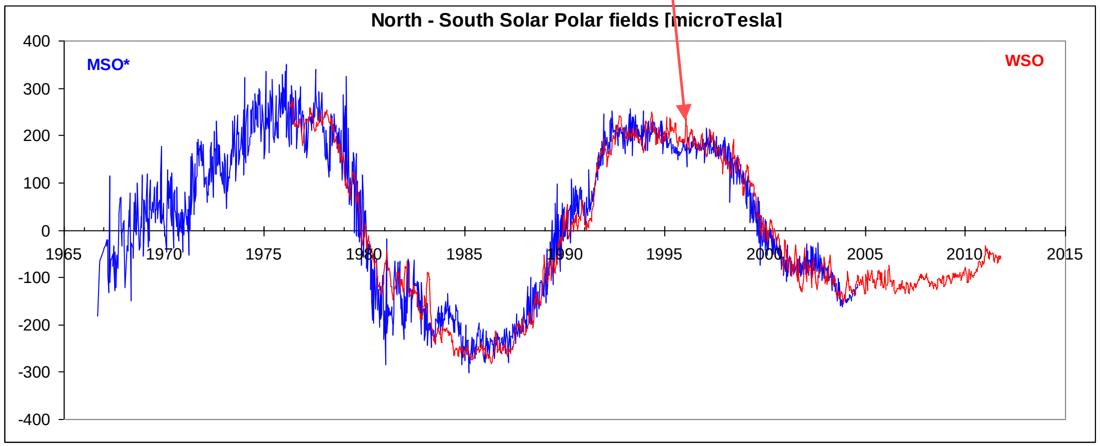
Rotate and long-lived



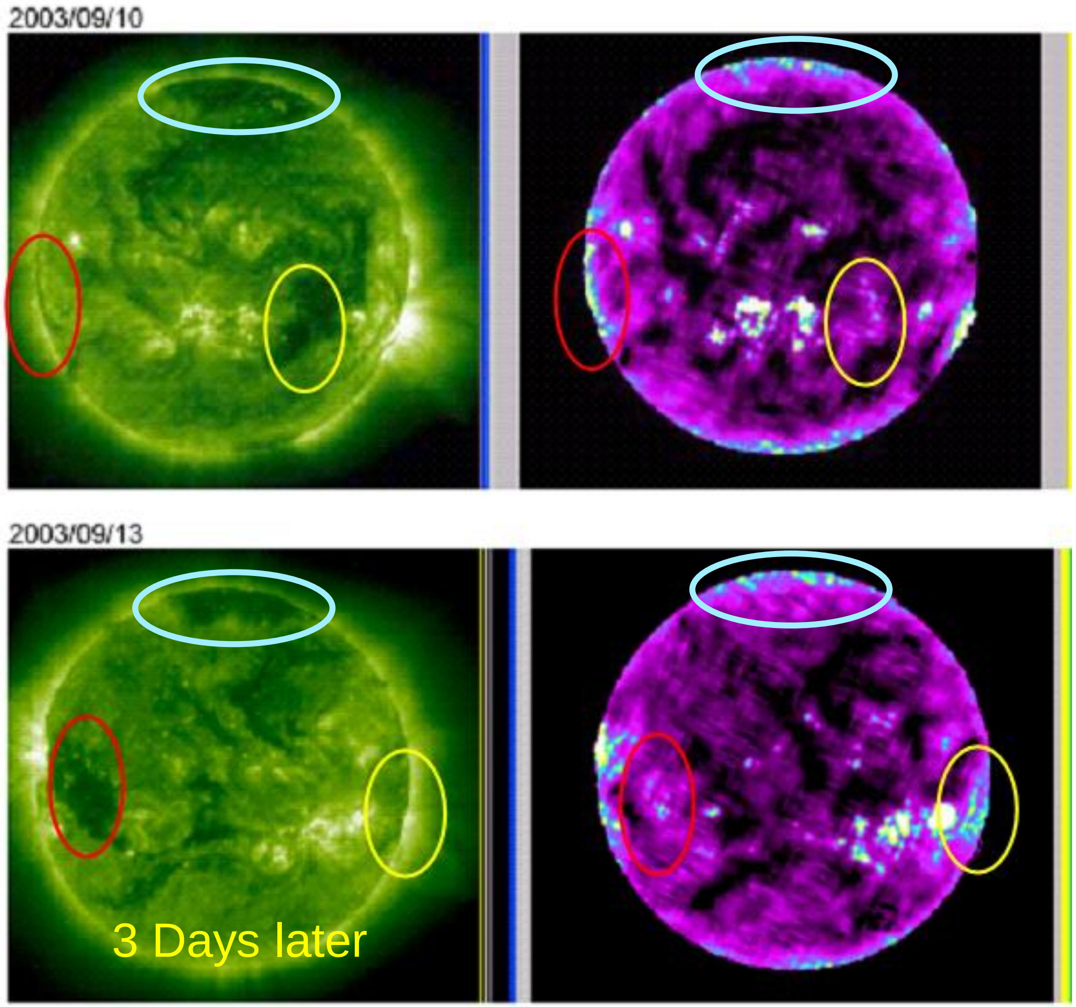








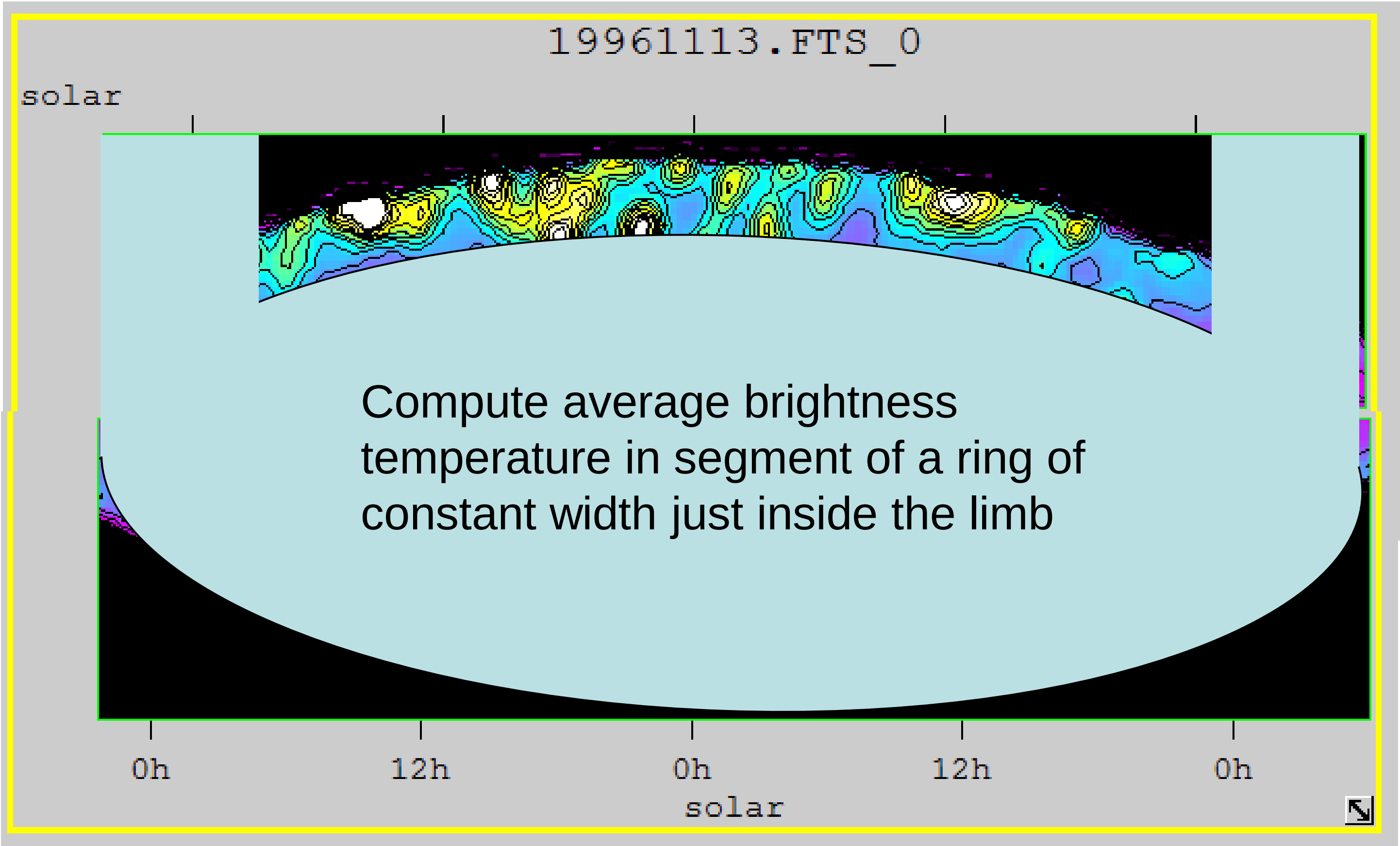
Coronal Holes everywhere show same behavior as the polar holes



When a coronal hole is at the limb, the bright 17GHz patches appear, otherwise not

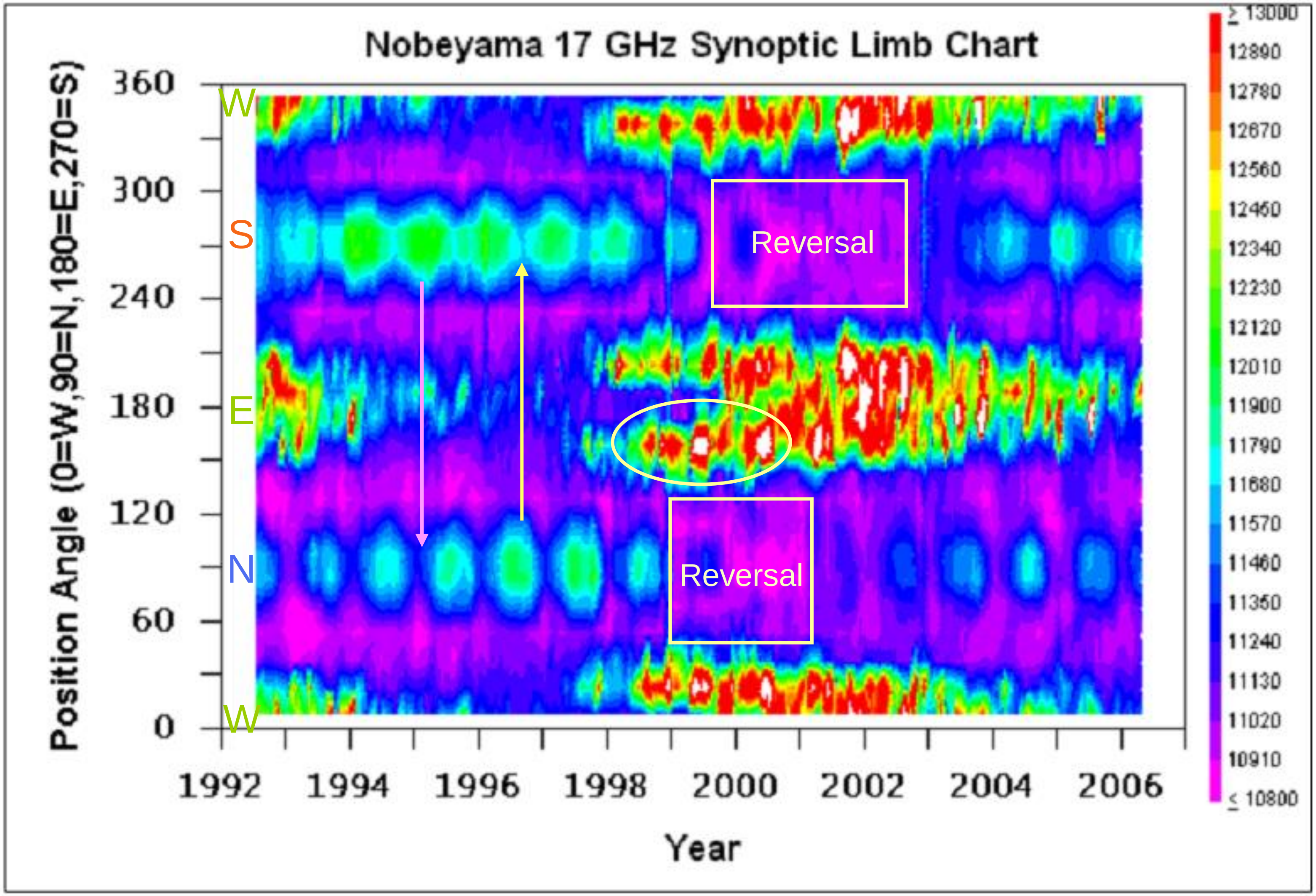
Suggesting that the 'patches' are the integrated effect of several individual sources along the line of sight. Matching the polar patches to other features has not been successful.

Quantifying the Brightening

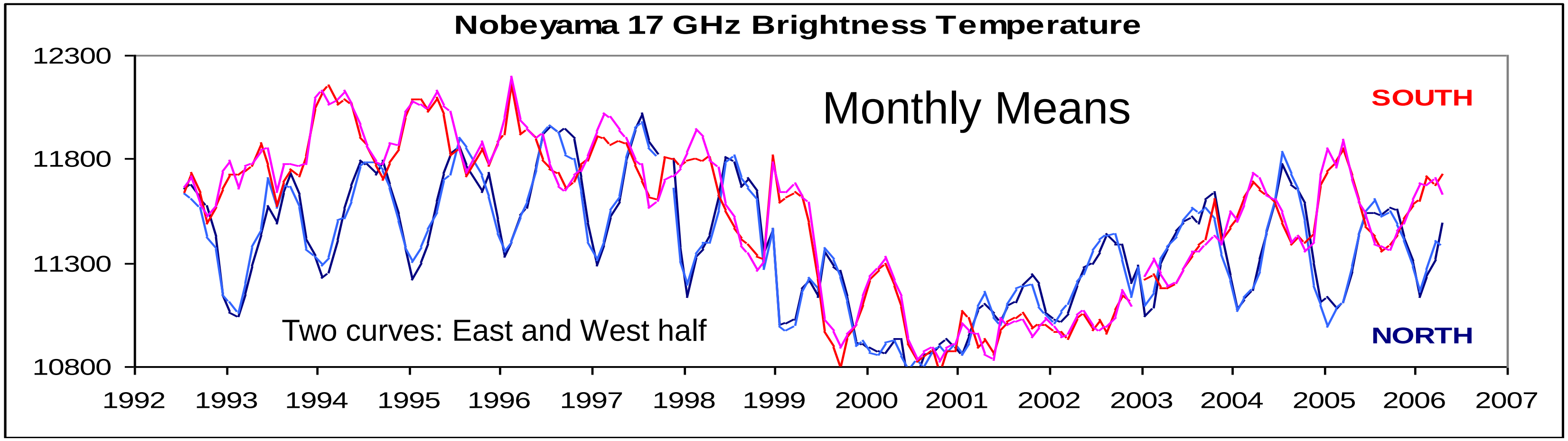


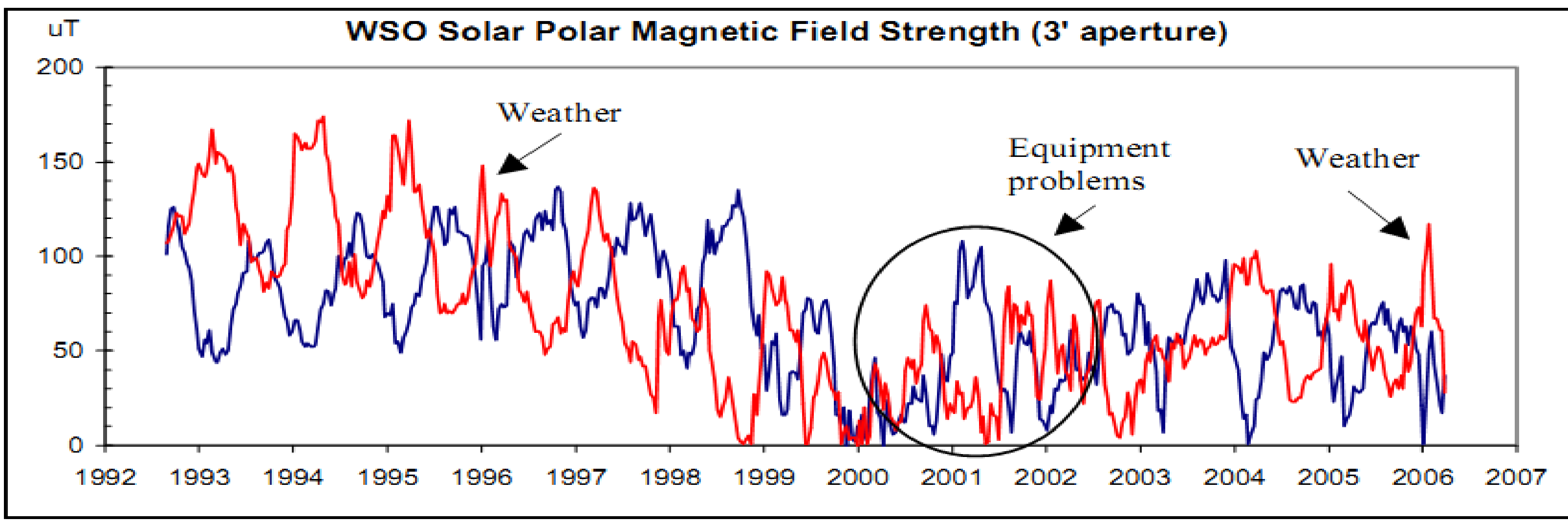
Compute average brightness temperature in segment of a ring of constant width just inside the limb

Evolution of Patches over the Cycle



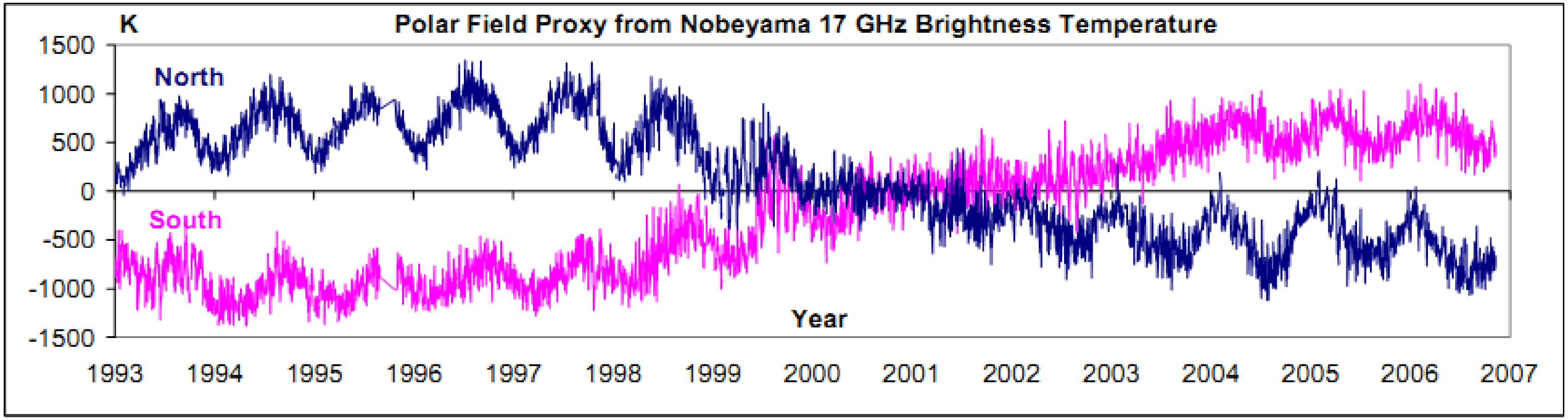
Annual [B_0] Modulation

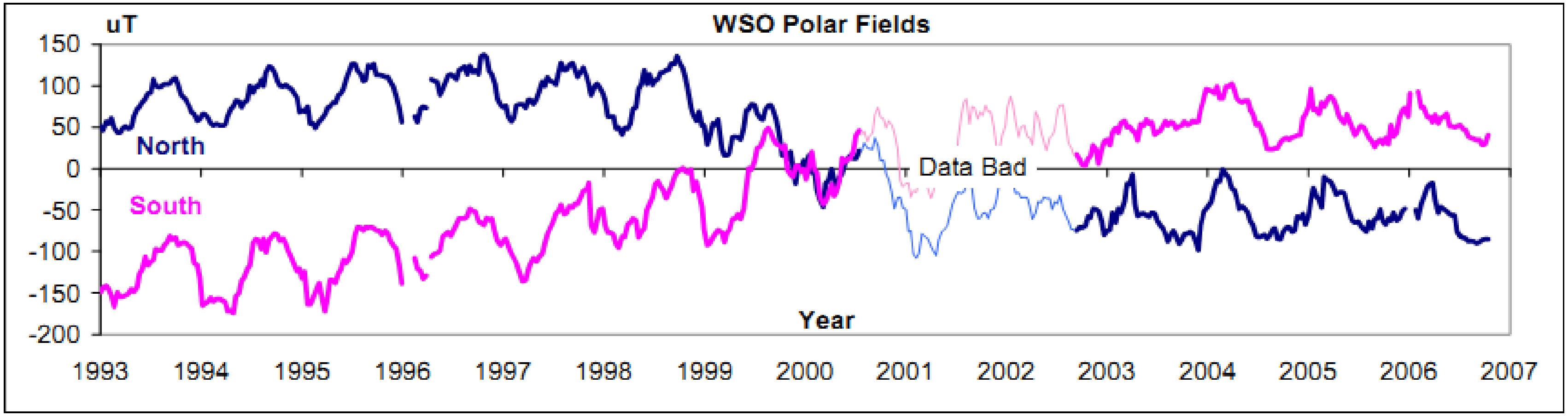




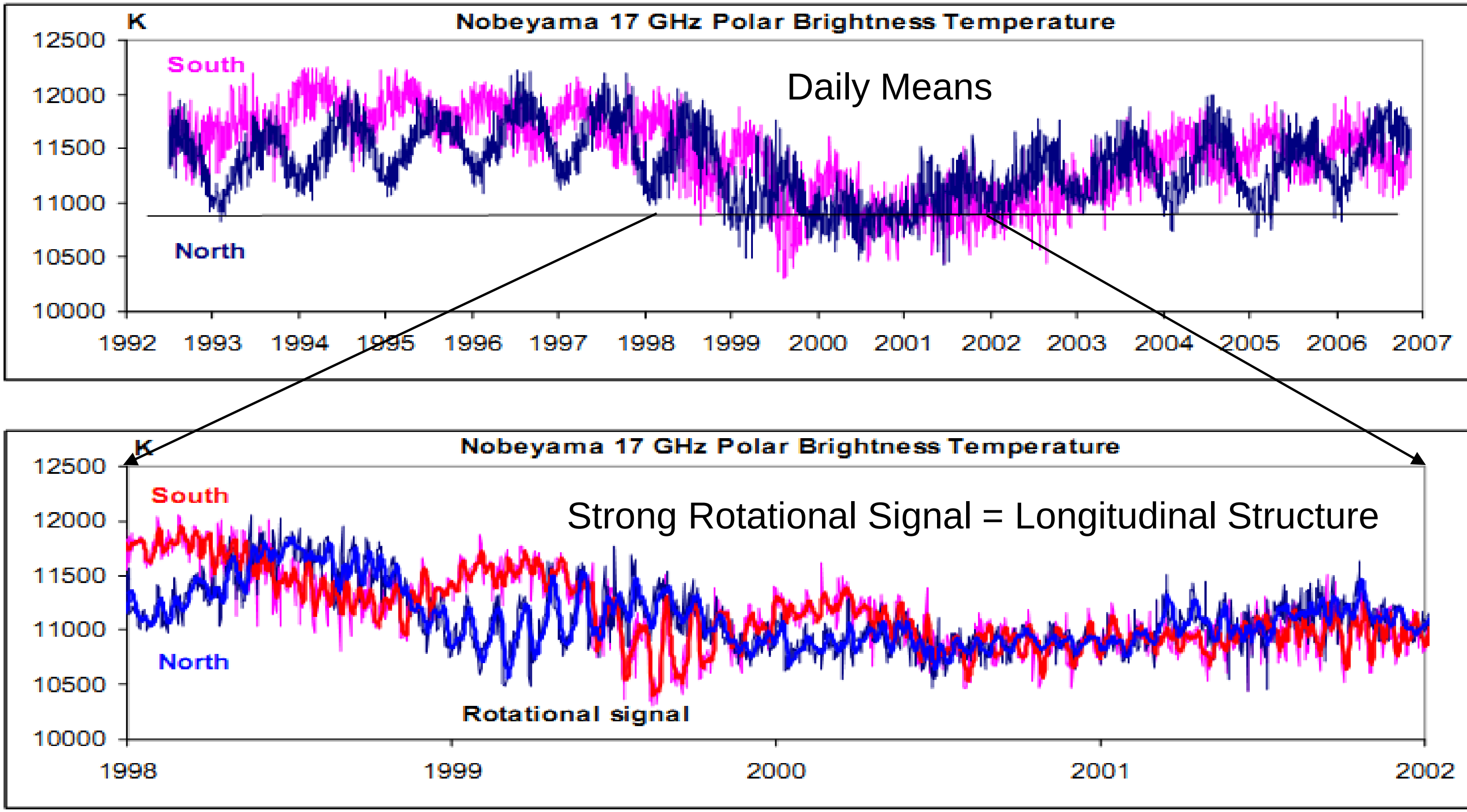
This shows that the brightening is not just general limb brightening, but is concentrated at the pole just as the polar magnetic field (is thus due to the field?)

Excess T_b over 10,800K, signed according to WSO polar field sign

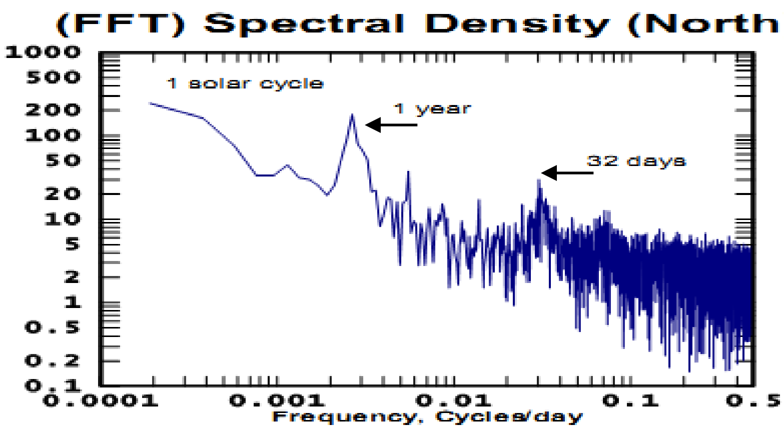


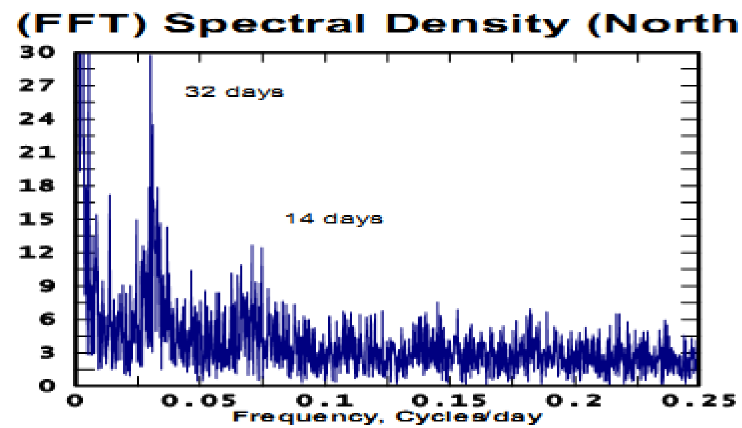


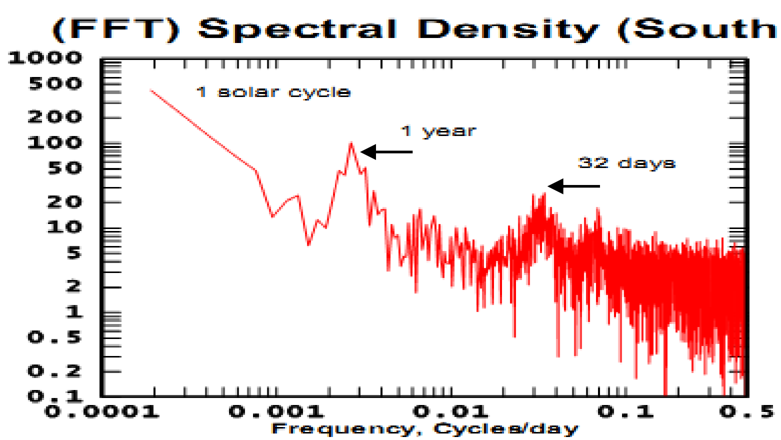
Strong Rotational Modulation

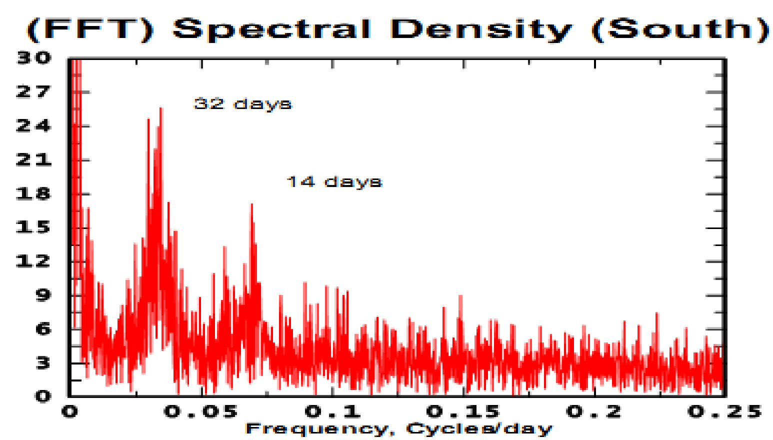


Rotational Period and 14-day Signal



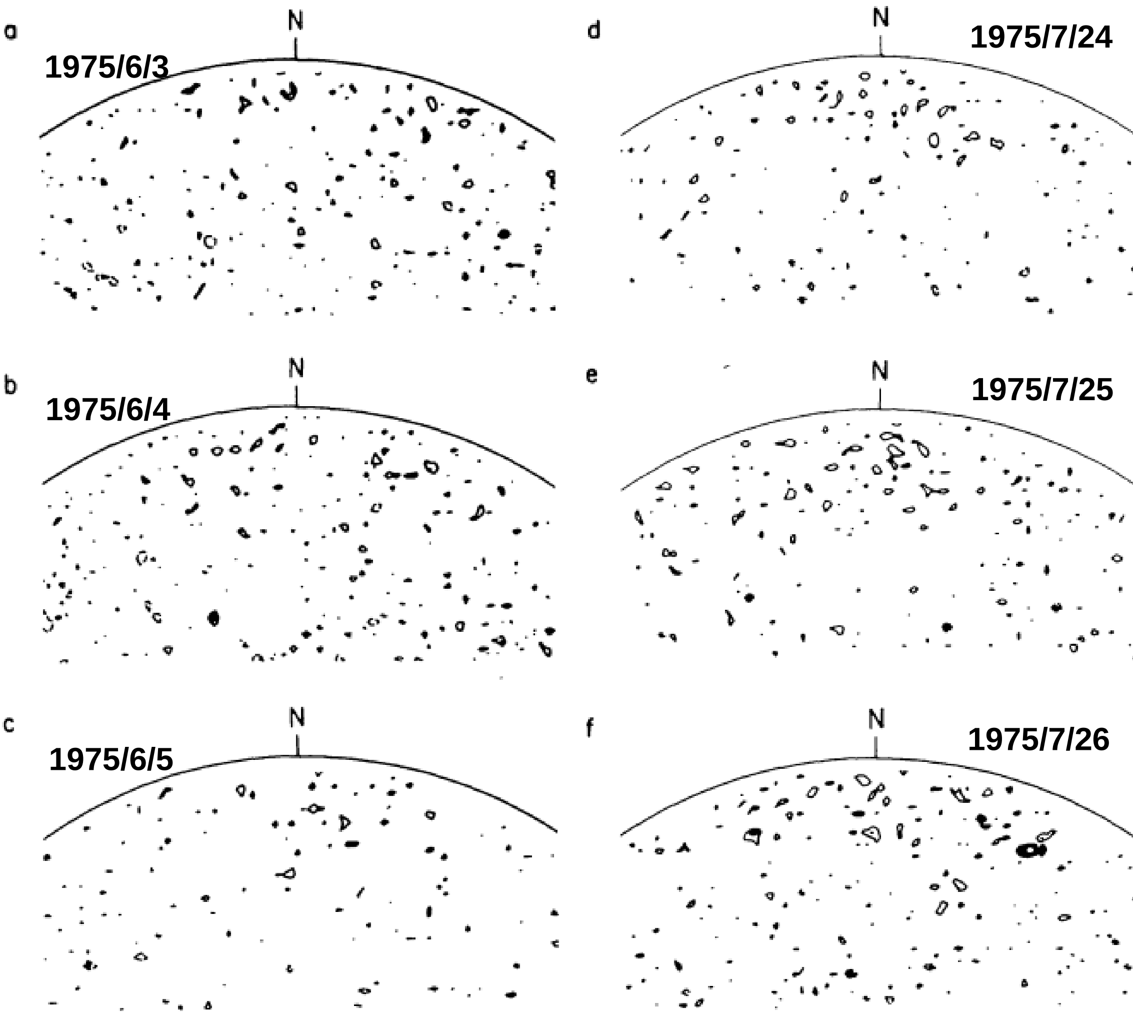




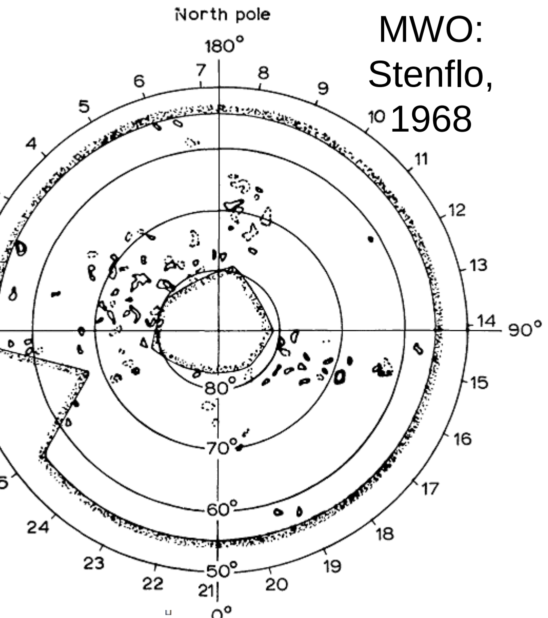


Structure of the Polar Fields

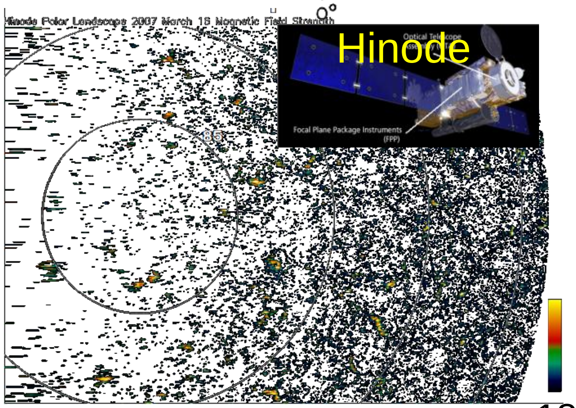
Scattered strong elements concentrating at pole



MWO: Howard, R., Solar Physics, 59, 243 (1978)

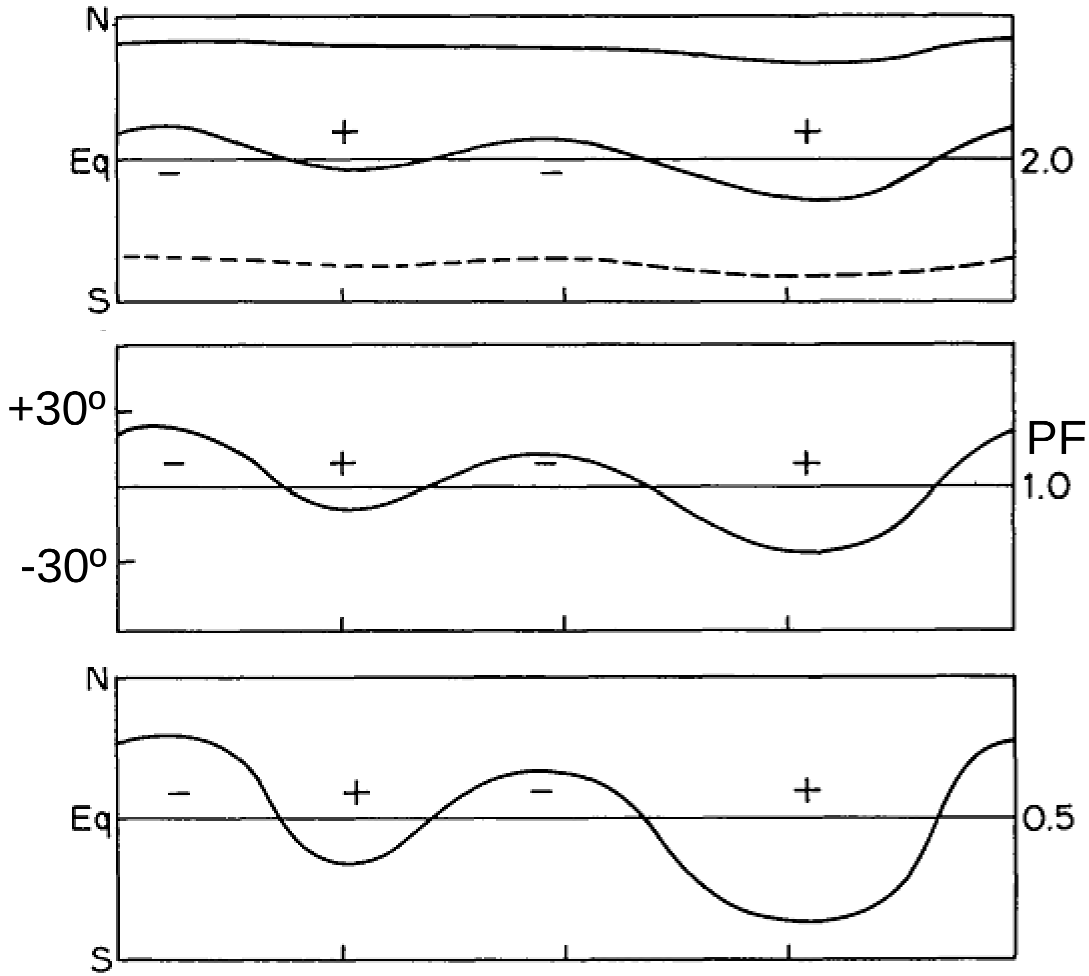


MWO: Stenflo, 1968



Tsuneta et al. ApJ, 2008

The Polar Fields are Crucial for correct Modeling of the Source Surface Neutral Line

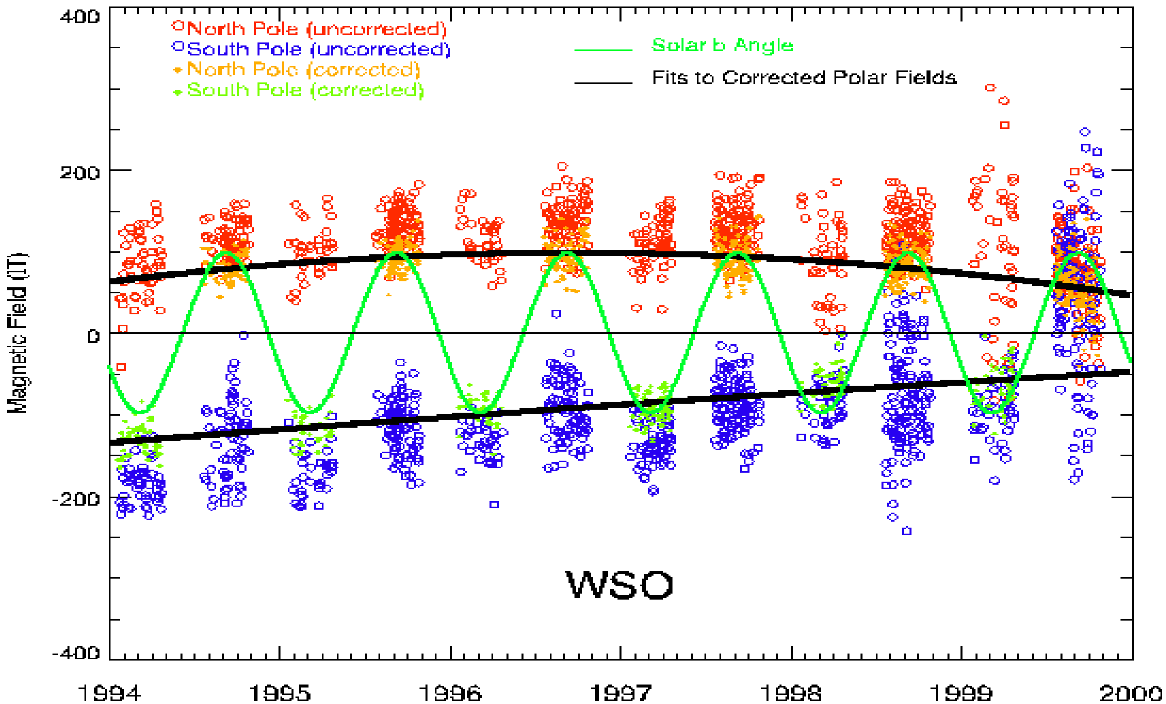


Svalgaard & Wilcox, 1978 Review

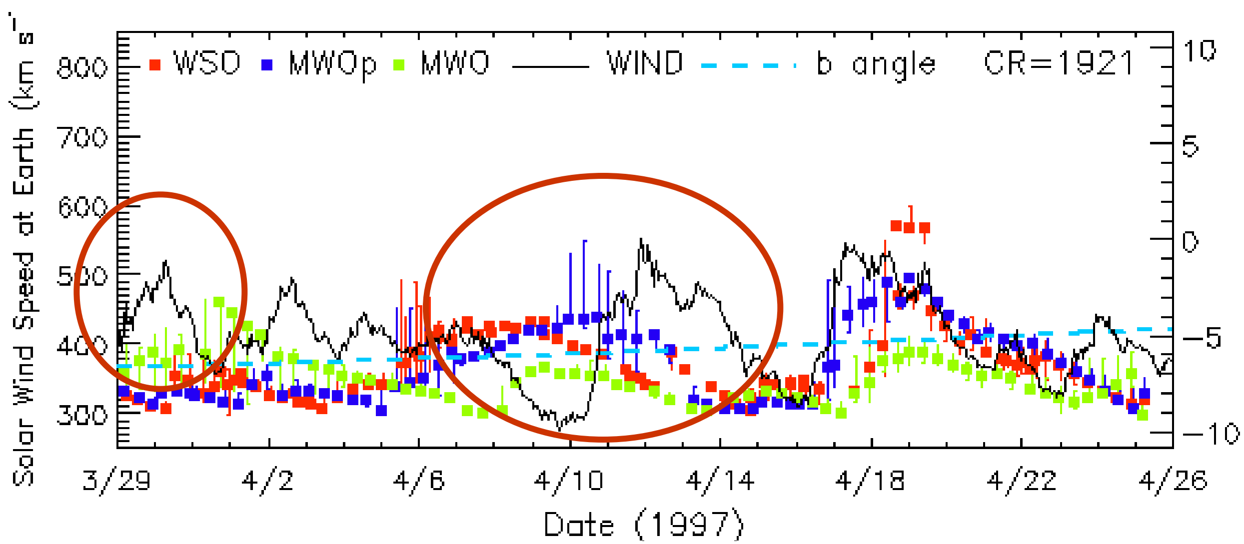
This is true both for the Potential Field Models and even more so for MHD models

Current practice interpolates or ‘fills in’ polar fields from one measurement point per year [at large B_o]

Instead, Real Time Data from Nobeyama could be helpful

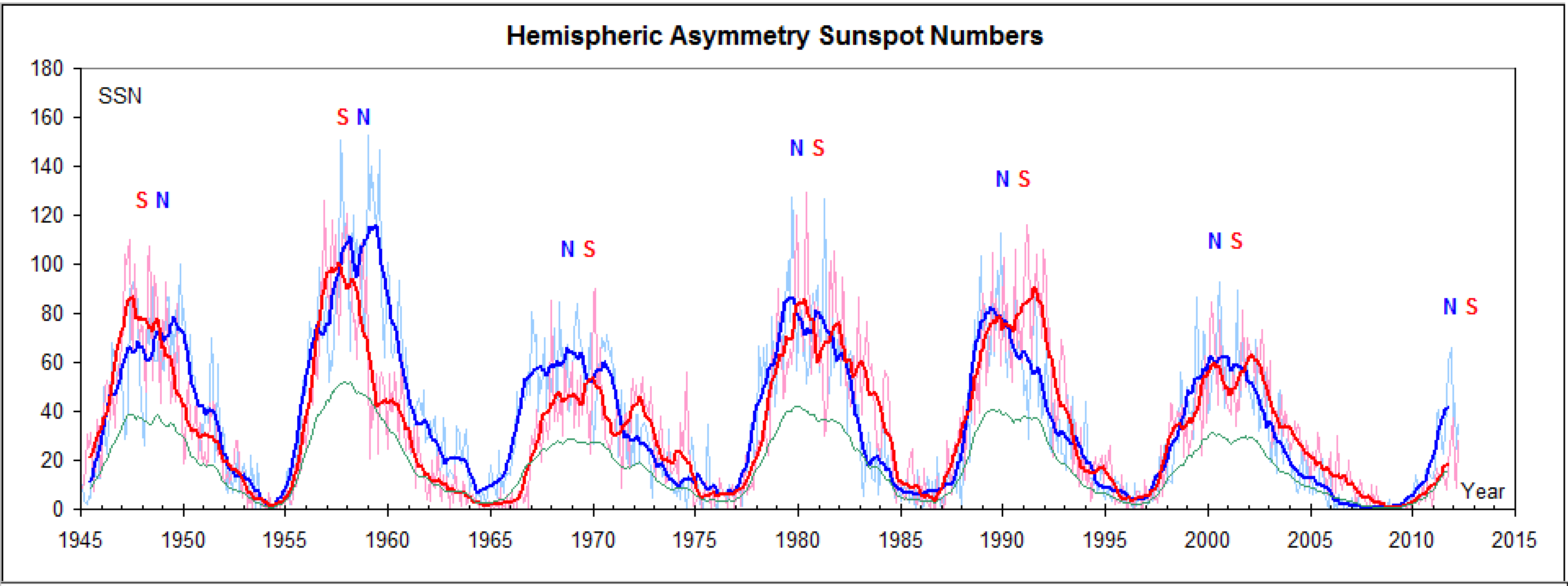


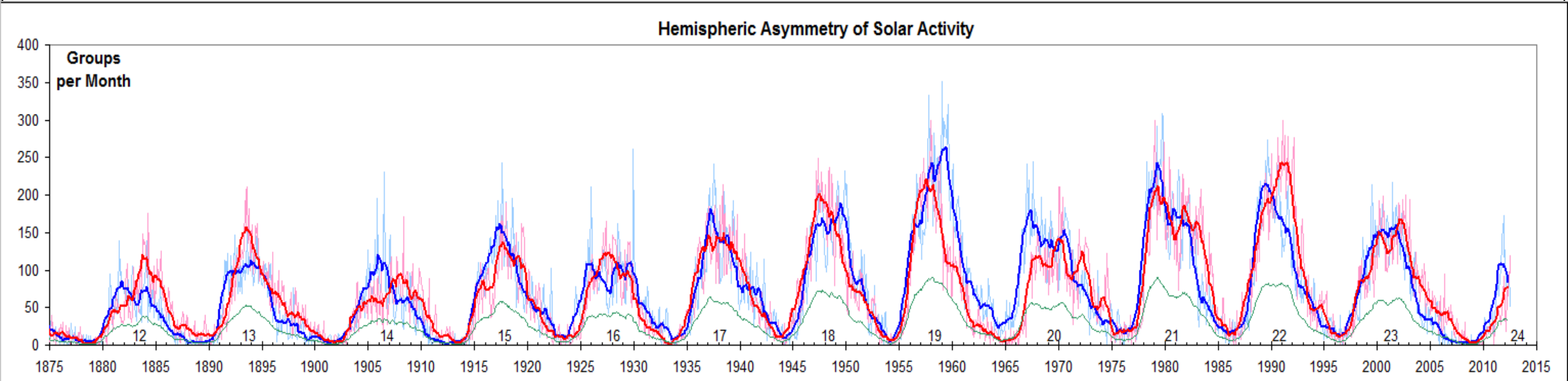
"Corrected and Fitted Polar Fields"



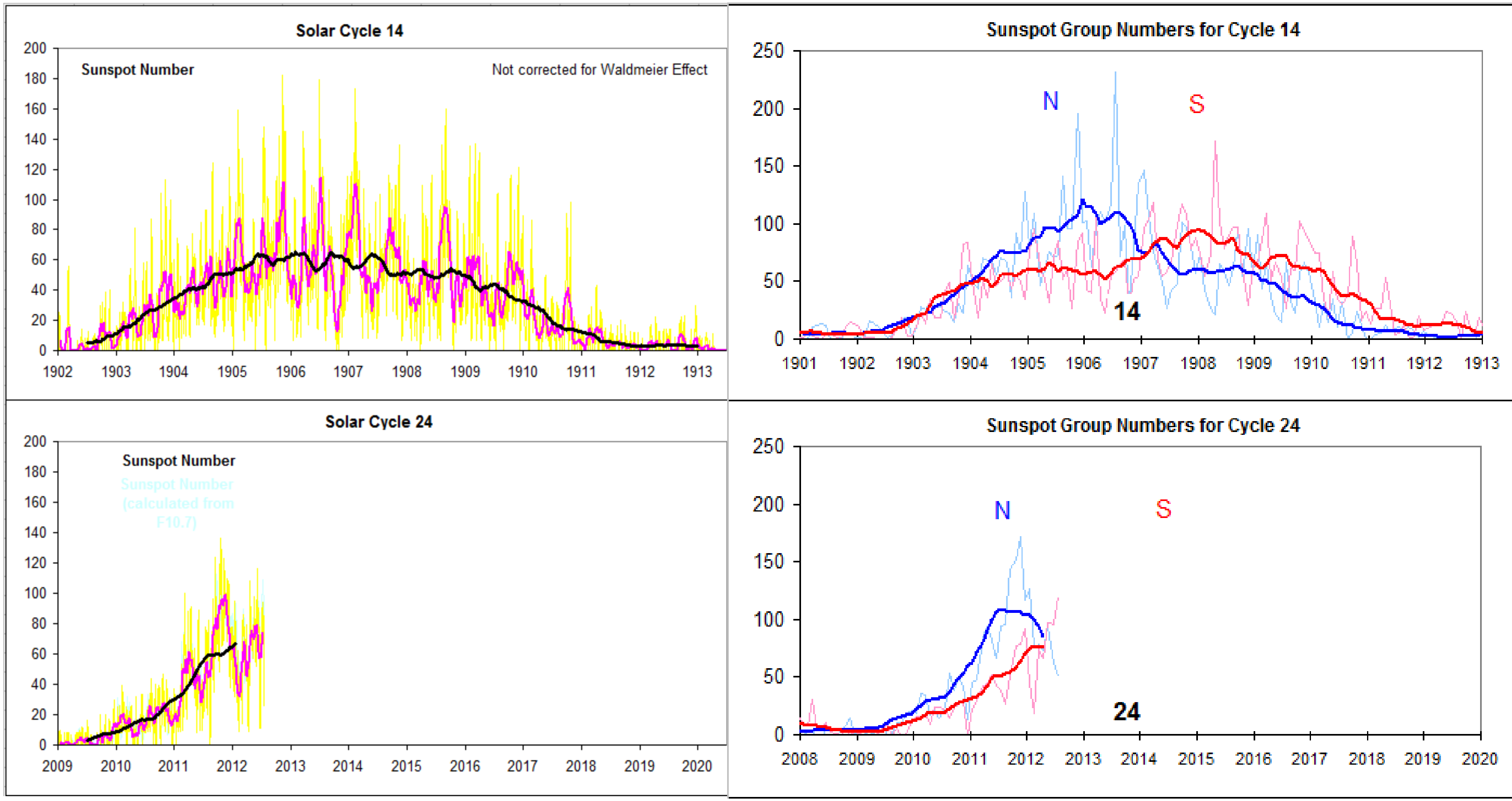
If you don't get the polar fields right you may miss a coronal hole and its high-speed stream

Asymmetric Solar Activity



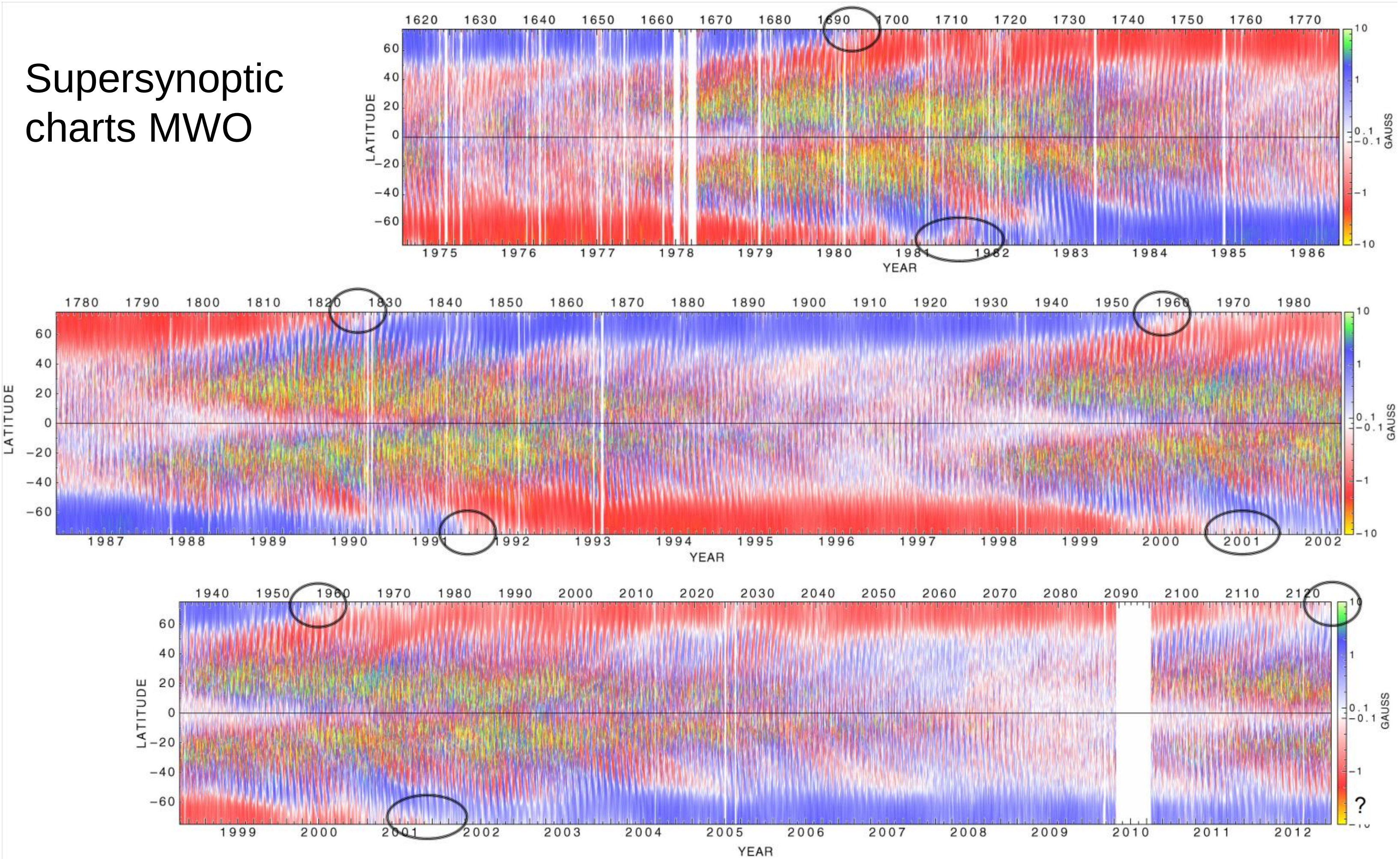


Comparing Cycles 14 and 24



Observed Polar Field Reversals

Supersynoptic charts MWO



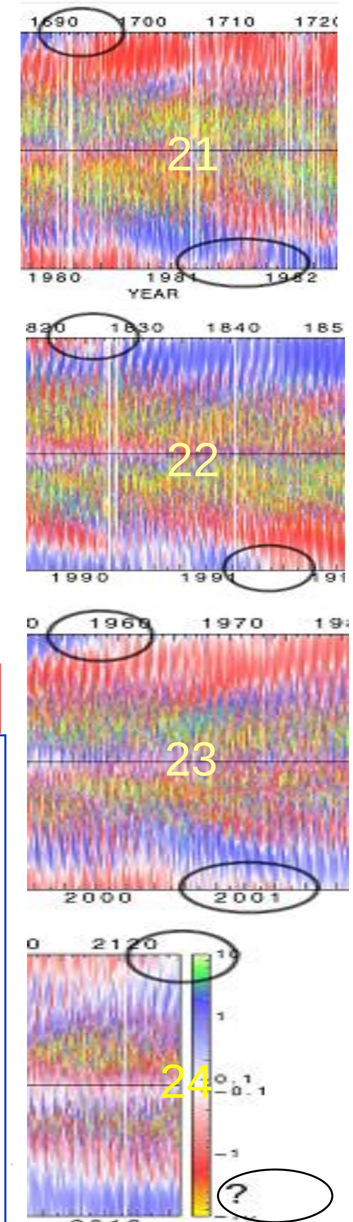
MWO: Roger Ulrich, 2012

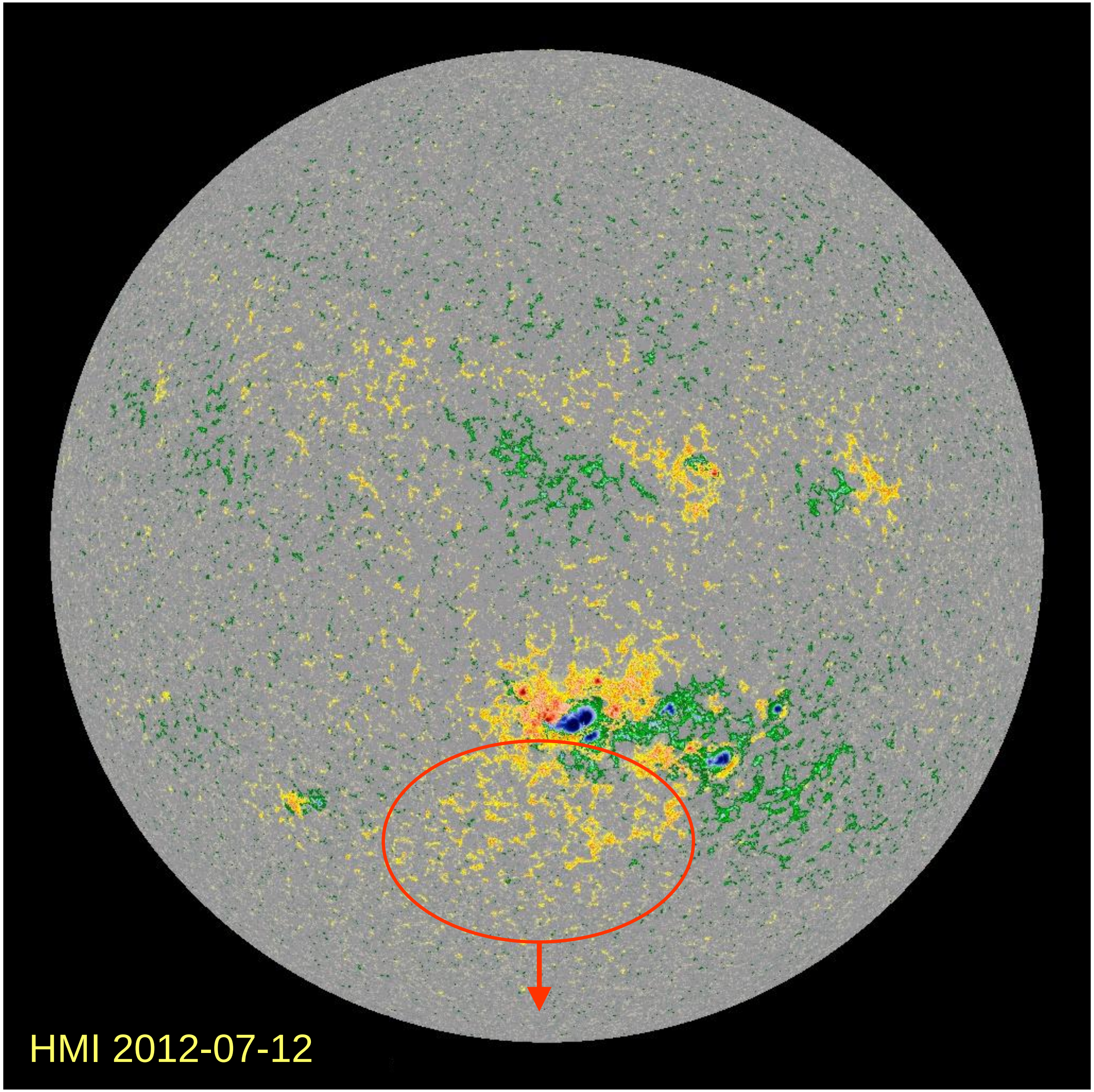
Reversals due to Migration of Fields are no News

Large-Scale Patterns of the Solar Magnetic Field. V. Bumba, *Astronomical Institute of the Czechoslovak Academy of Sciences*, Robert Howard, *Mount Wilson and Palomar Observatories*, and Sara F. Smith, *Lockheed Solar Observatory.*

Astronomical Journal, Vol. 69, p. 535 (1964)

The main direction of motion of the migrating fields is eastward and poleward. The following polarity in each hemisphere usually predominates in the poleward drift of fields. The polar magnetic field measurements record this quantized migration of fields (Undoubtedly, as has already been pointed out, this drift of following polarities was responsible for the reversal in polarity observed in the polar fields during the last maximum.)





“This just in:”

Large (-) Flux Injection Heading for the South Pole

Todd Hoeksema, 2012: “It wouldn't surprise me if this is the region that eventually moves poleward to reverse the stalled southern pole”

Full-disk Microwave Flux

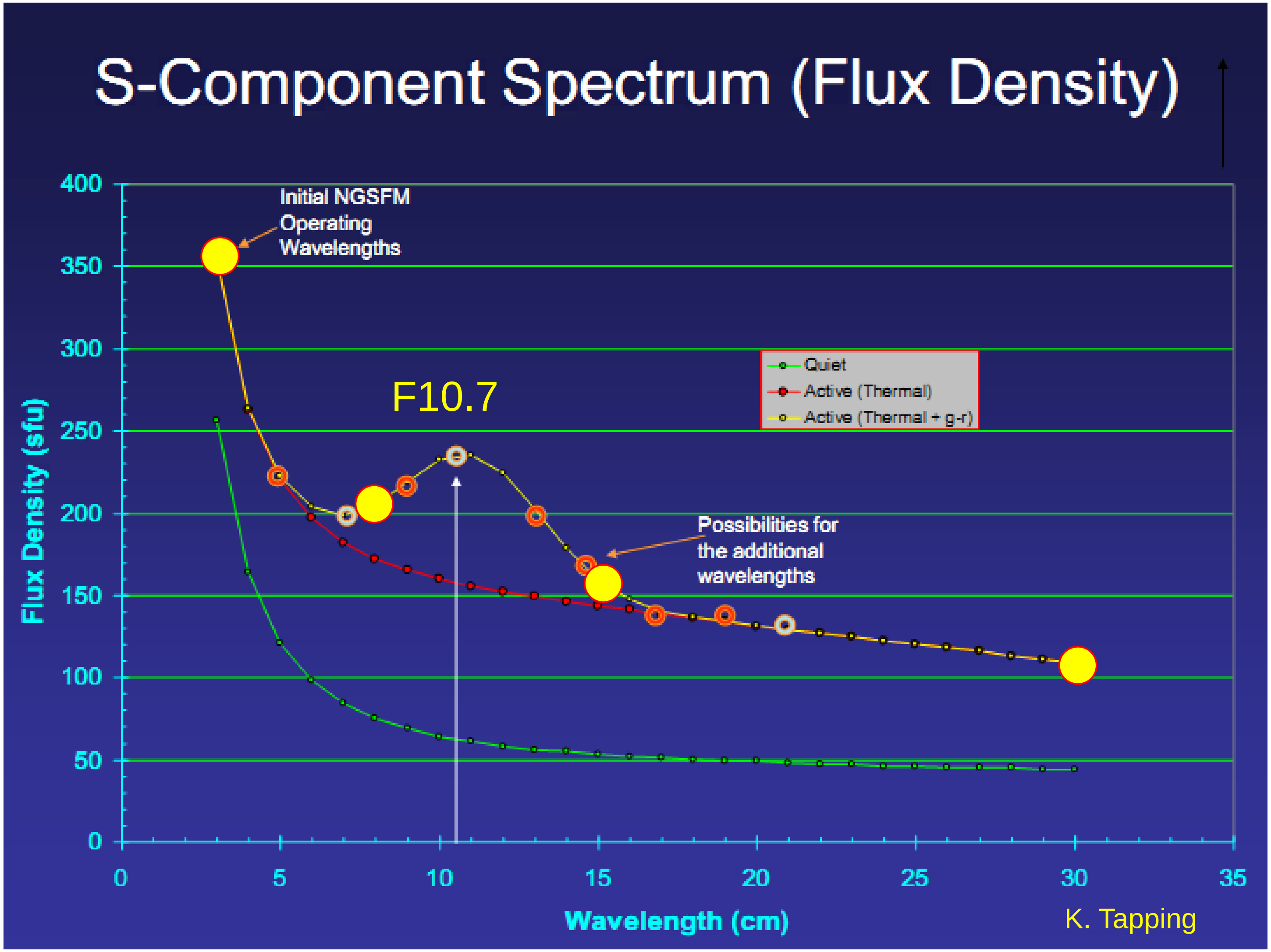
Nobeyama 1.0, 2.0, 3.75, 9.4 GHz

Toyokawa 1950s – 1994.5

Penticton 2.8 GHz

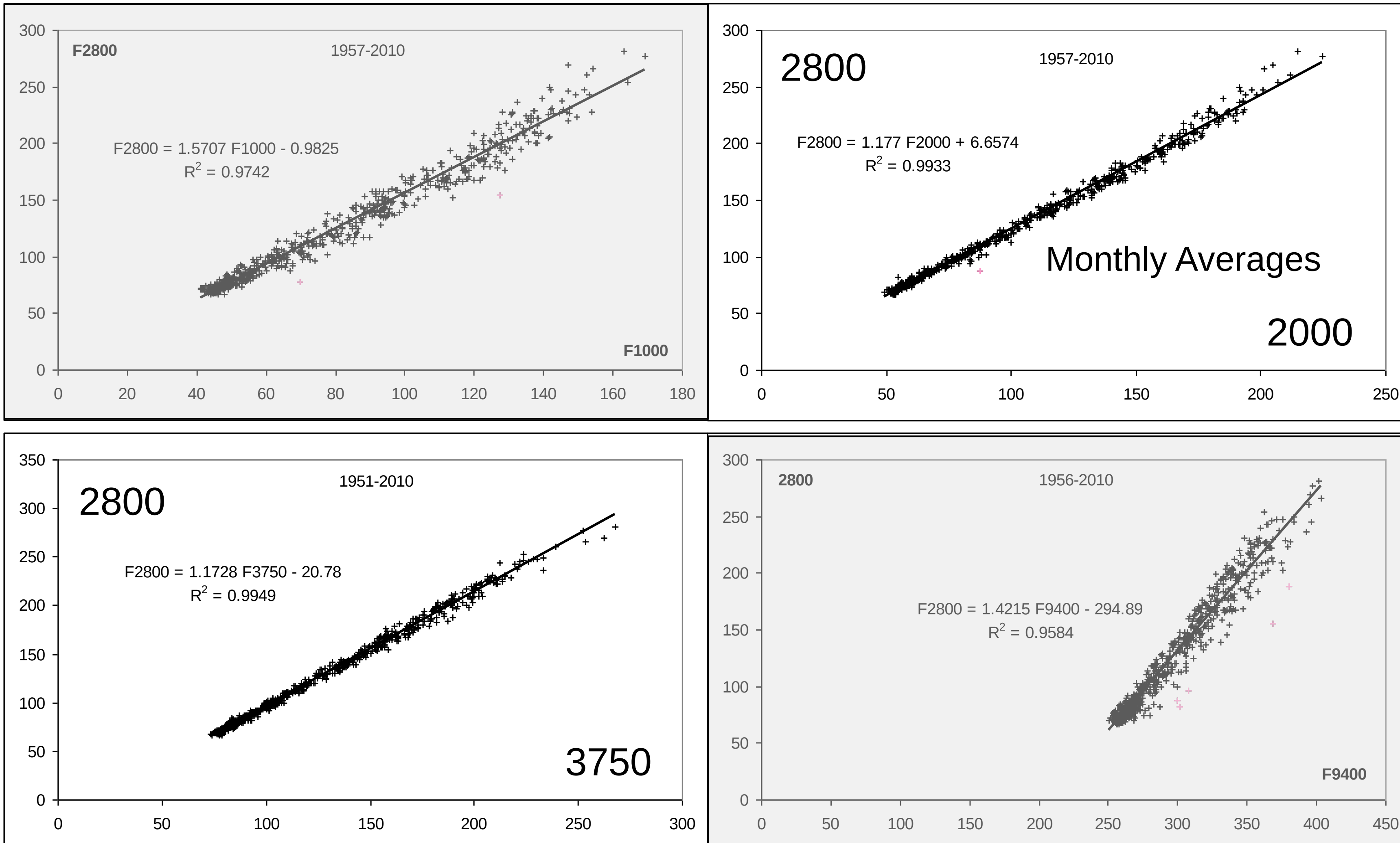
Ottawa 1947.2 – 1991.5

Nobeyama Measurements

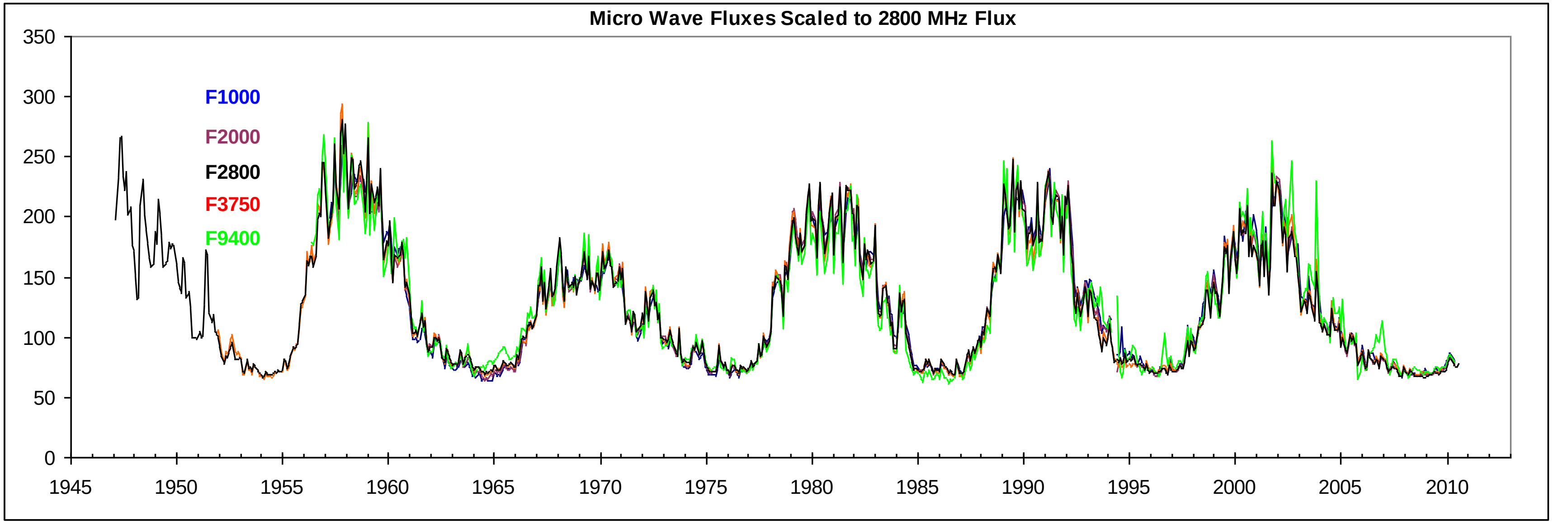


On both sides of 'F10.7'

All observations are highly correlated, especially the ones [2000, 3750] flanking 2800 MHz

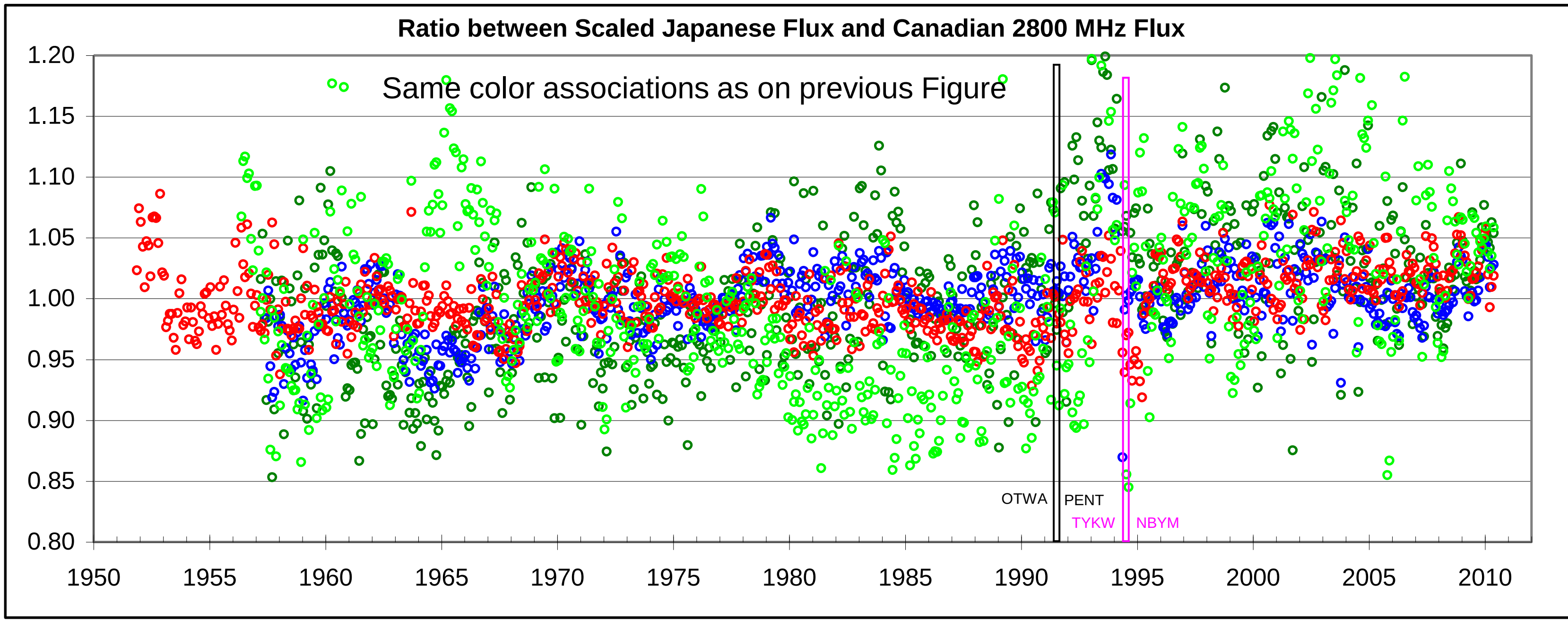


This allows us to scale all observations to 2800 MHz



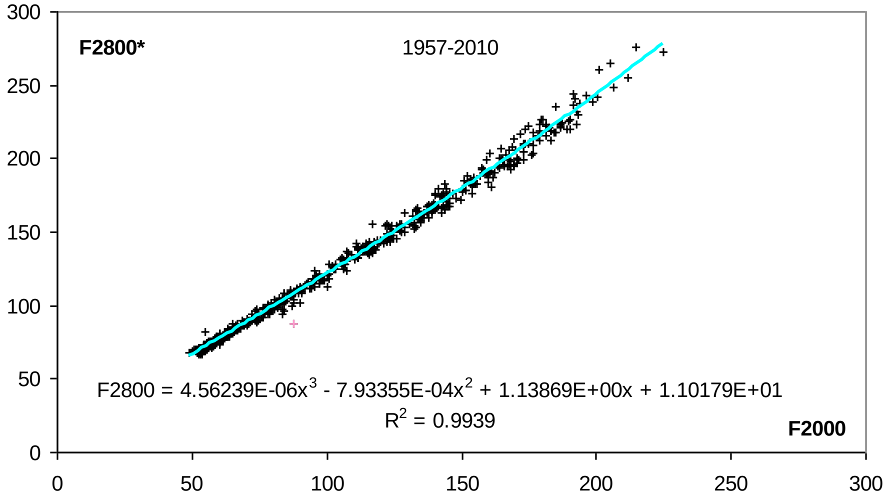
The scaled values match each other very well, except 9400 MHz where the solar activity component is rather noisy.

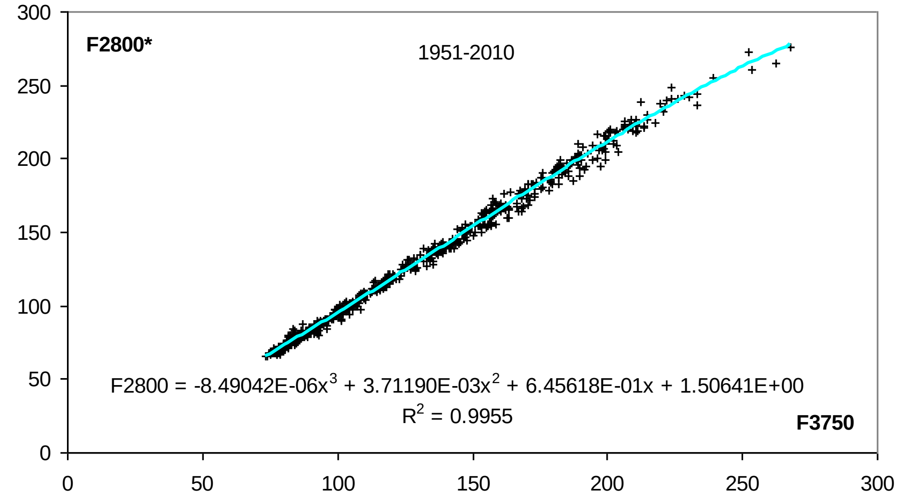
If the calibrations of the data have not changed over time, the ratios between the scaled fluxes and the 2800 MHz flux should be constant = 1

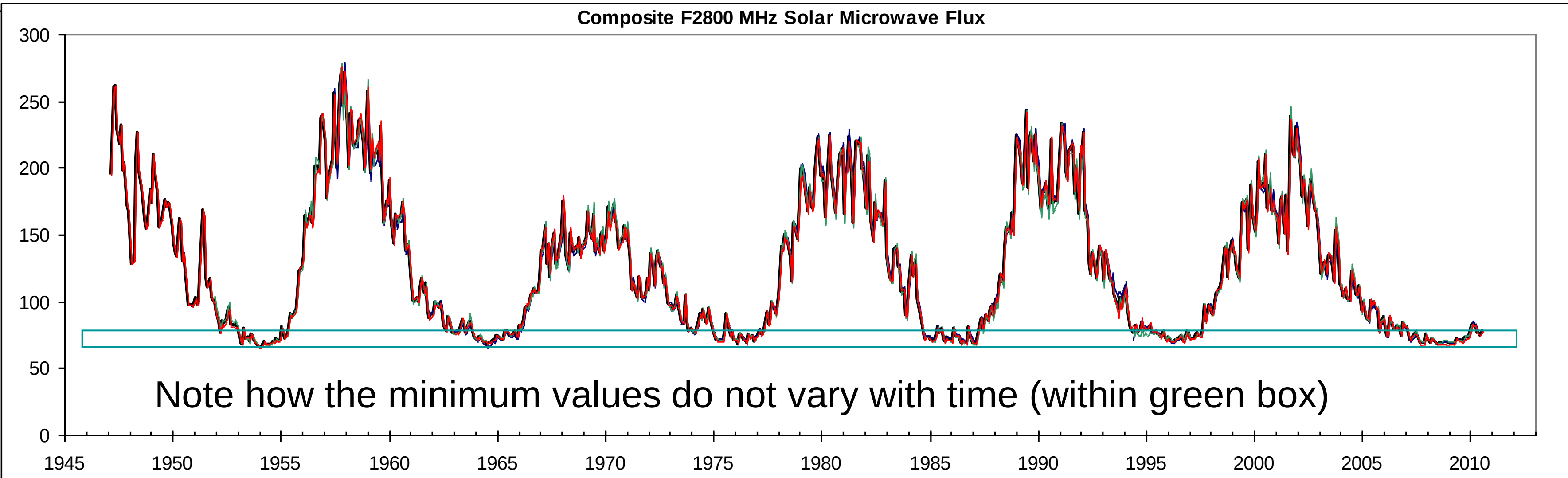


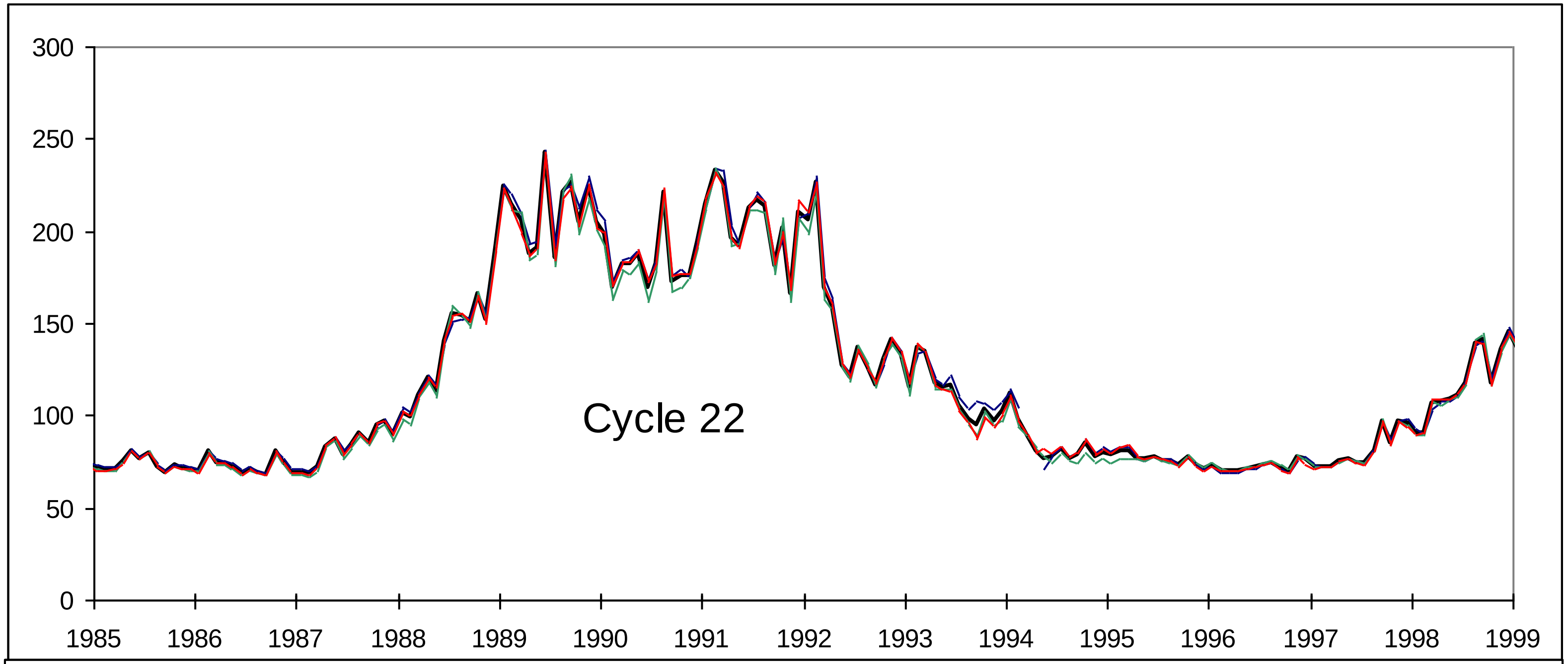
Within the scatter, the ratios appear to be lower than 1 before 1991 and higher thereafter. We interpret that as a 2% downward jump in Pentiction compared to Ottawa. We therefore reduce the Ottawa 2800 MHz flux by 2%.

After the correction, we rescale 2000 and 3750 MHz again to 2800 MHz, and construct a composite








300
250
200
150
100
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0
1985
1986
1987
1988
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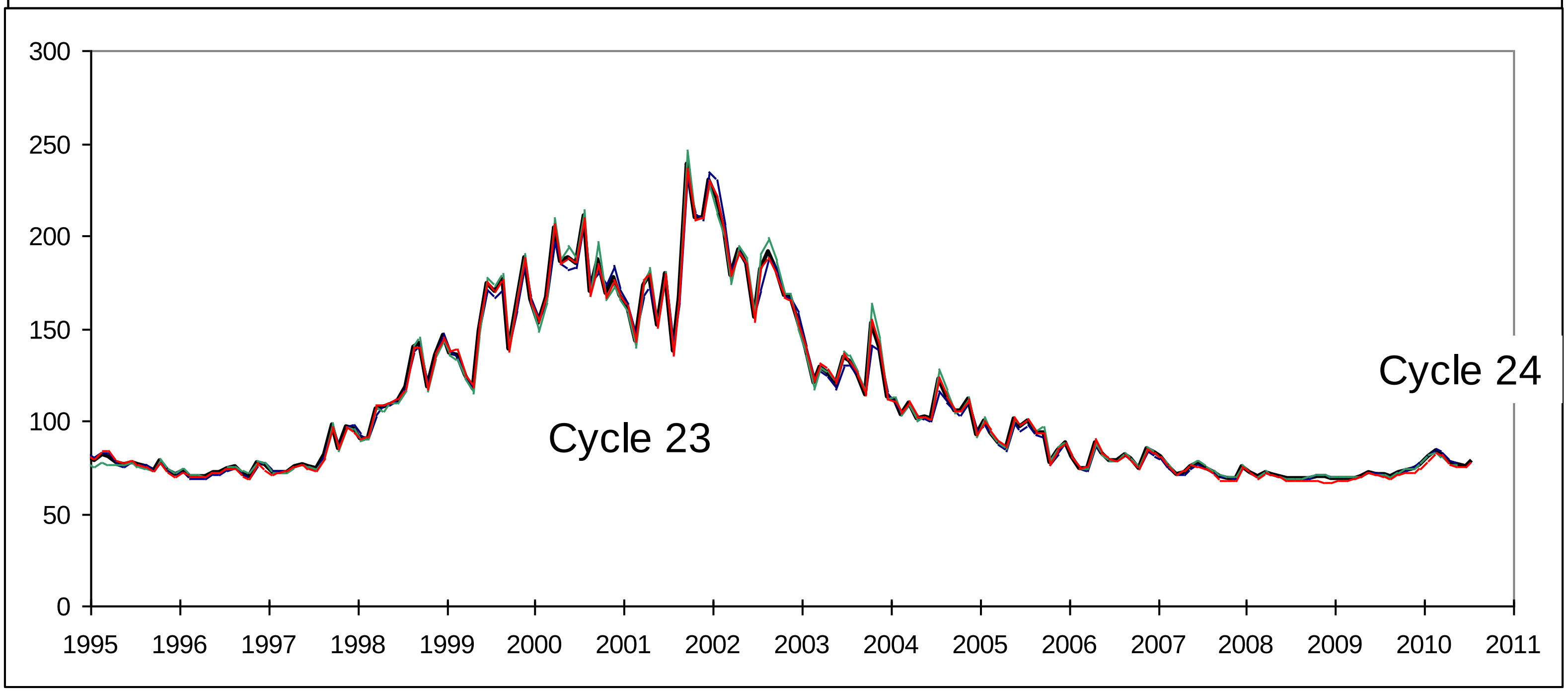
1992
1993
1994
1995
1996
1997
1998
1999
Cycle 22


300
250
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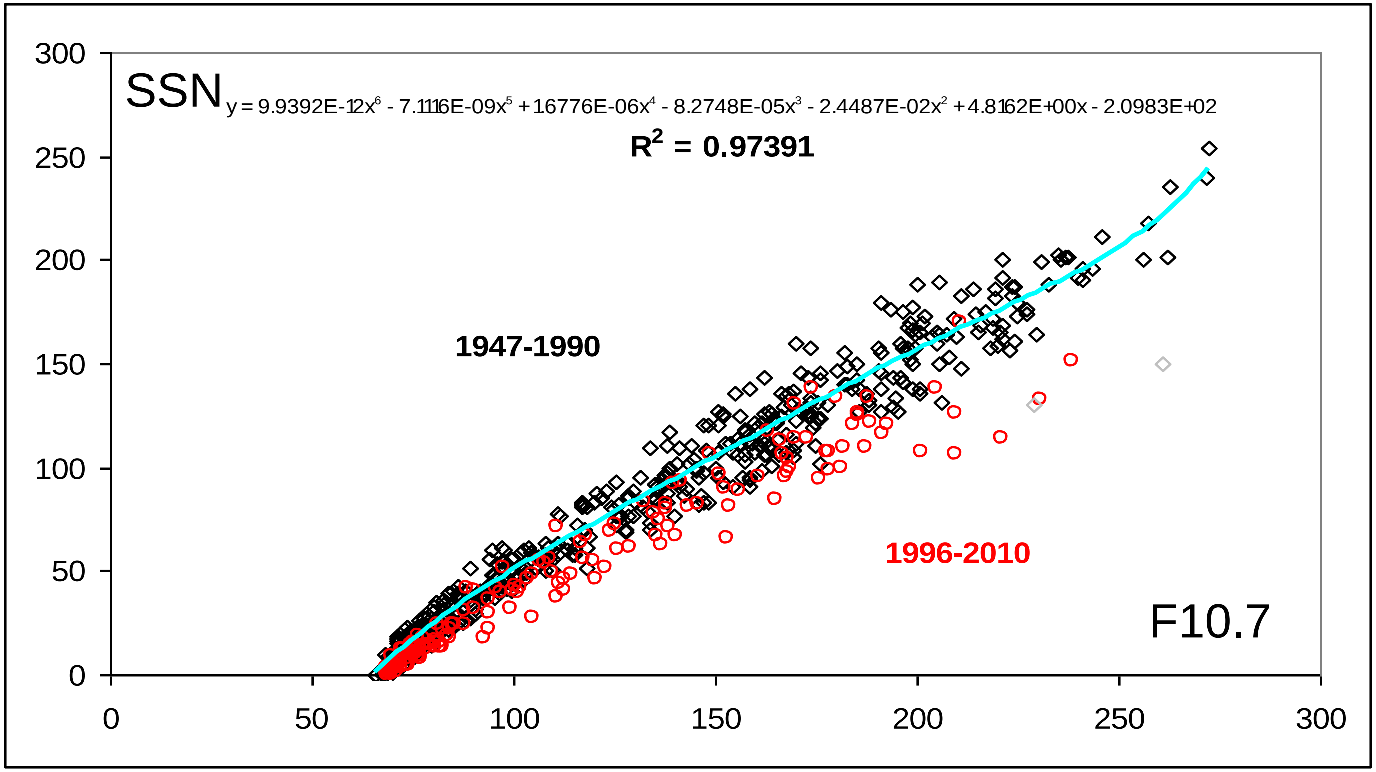
100
50
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Cycle 23
Cycle 24

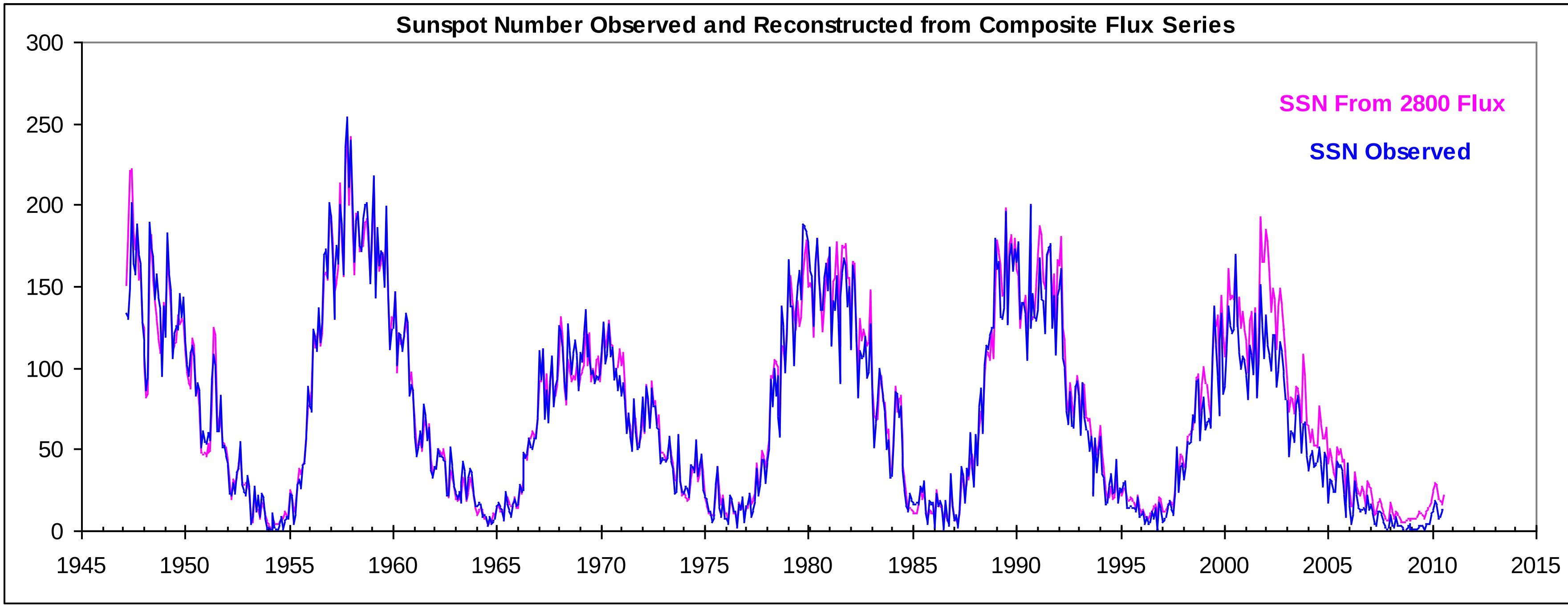
There is a well-known, strong [slightly non-linear] relationship between the solar flux and the sunspot number (black diamonds). This relationship seems to have changed in solar cycle 23 (red circles).



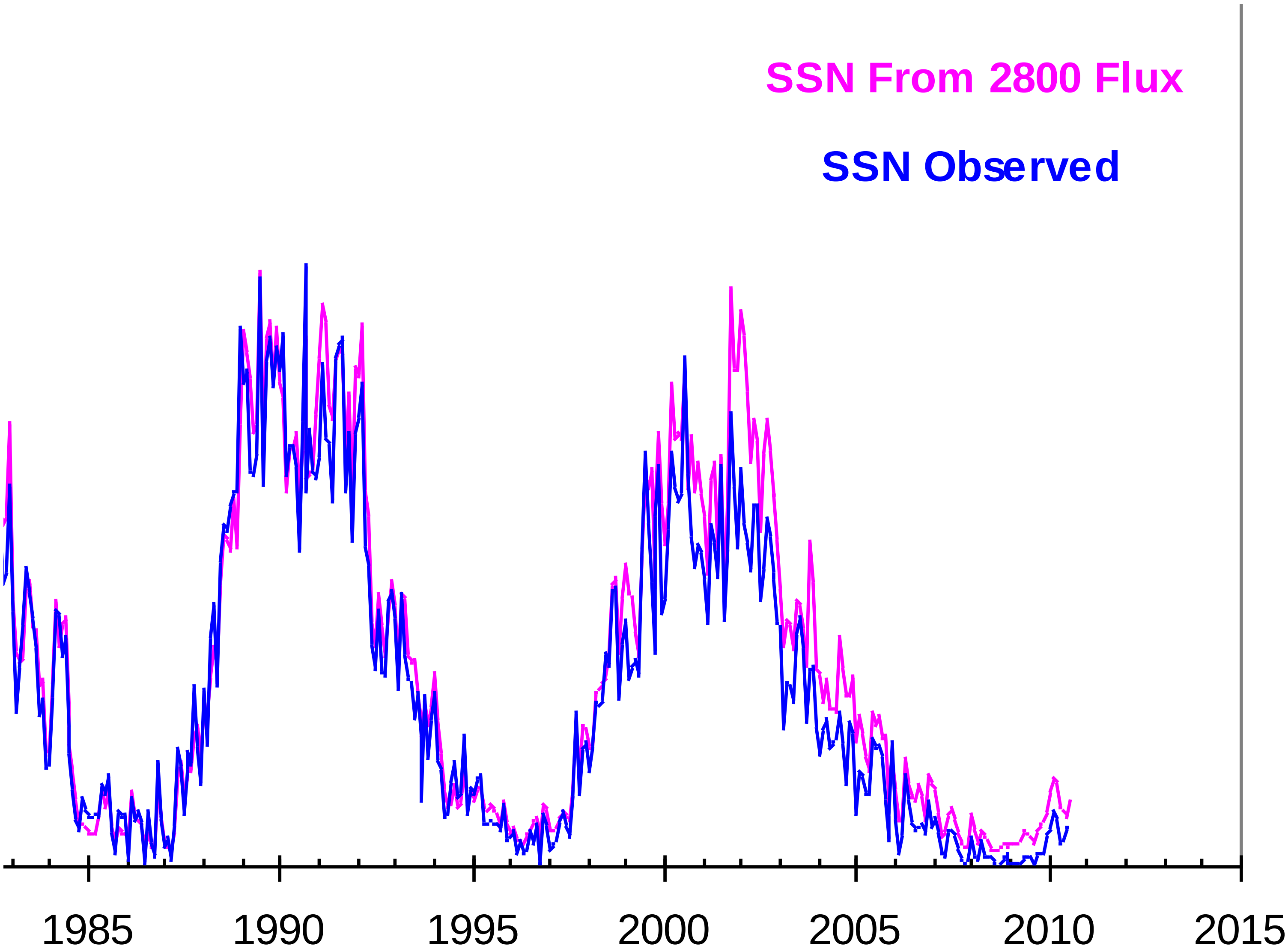
Same conclusion reached by others, *e.g.* Tapping (2010)

Because of the agreement between the Japanese and Canadian measurements we must conclude that the change is in the Sun

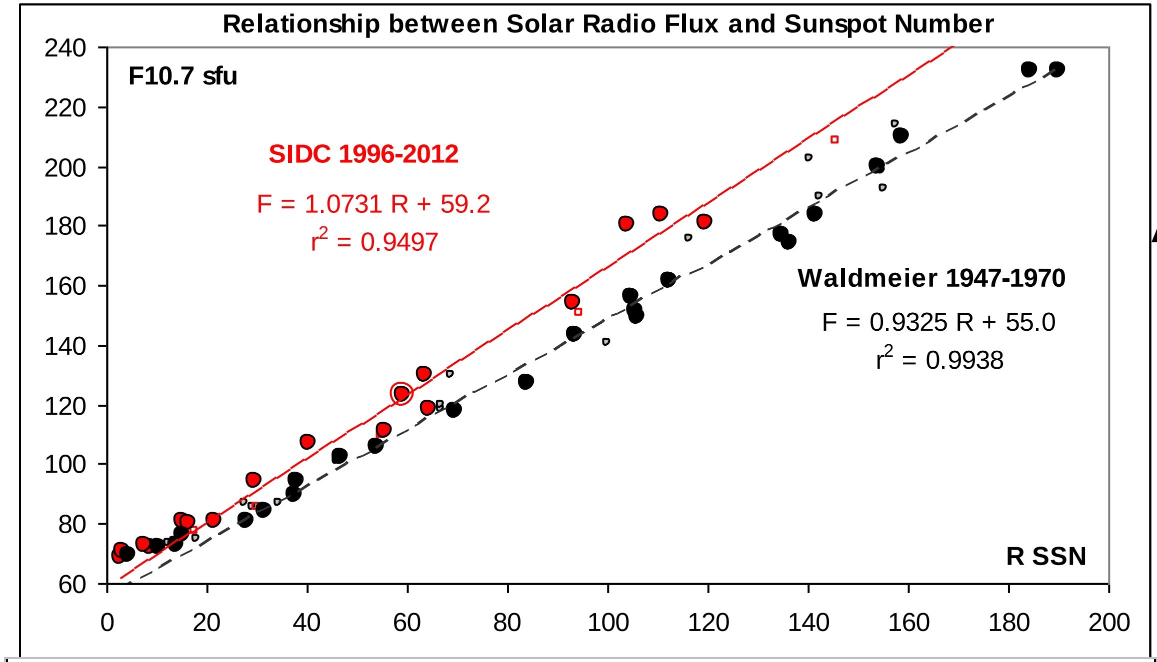
Plotting the reconstructed Sunspot Number (pink) from the composite 2800 MHz flux using the 1947-1990 relation shows the increasing discrepancy with the SIDC 'official' sunspot number (blue) the past ~15 years:

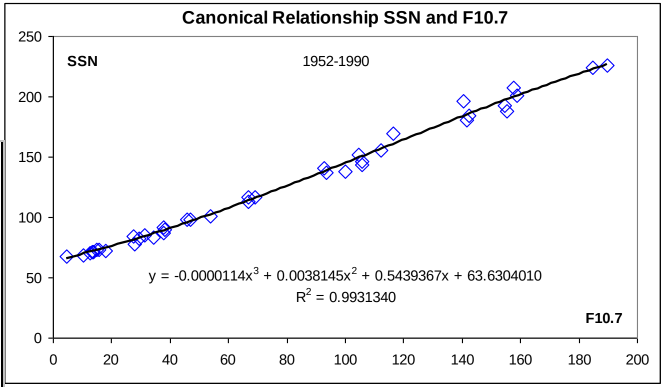


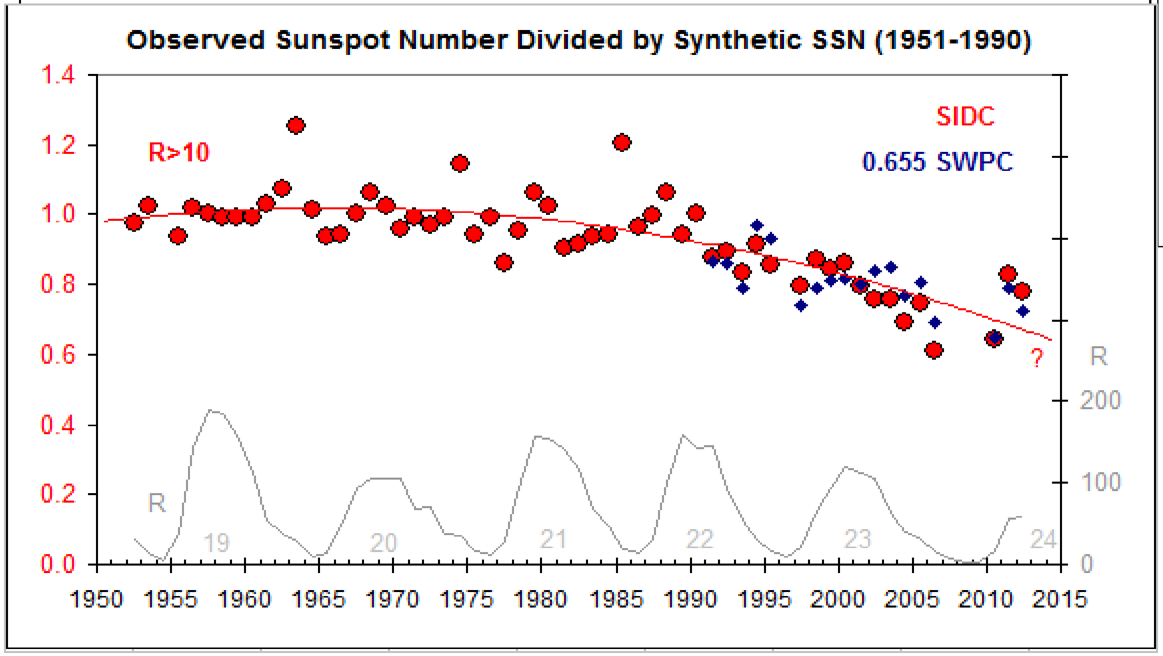
As the Japanese and Canadian microwave data support each other so well, we must ask: how sure are we of the calibration and stability of the sunspot number?


SSN From 2800 Flux
SSN Observed
1985
1990
1995
2000
2005
2010
2015

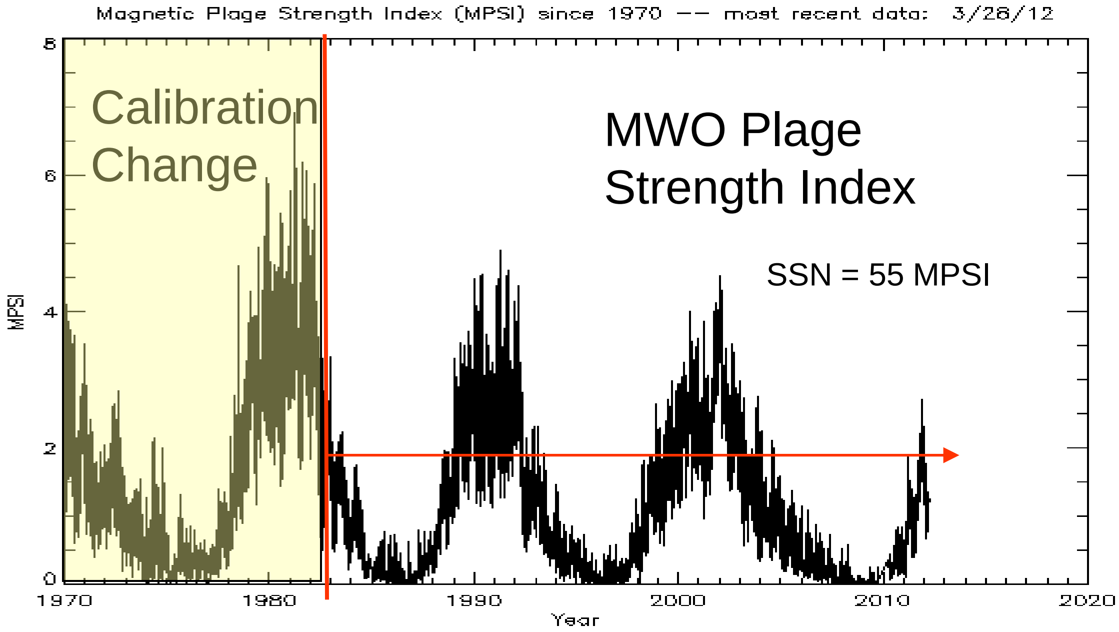
Is the SSN Always a Good Measure of Solar Activity?





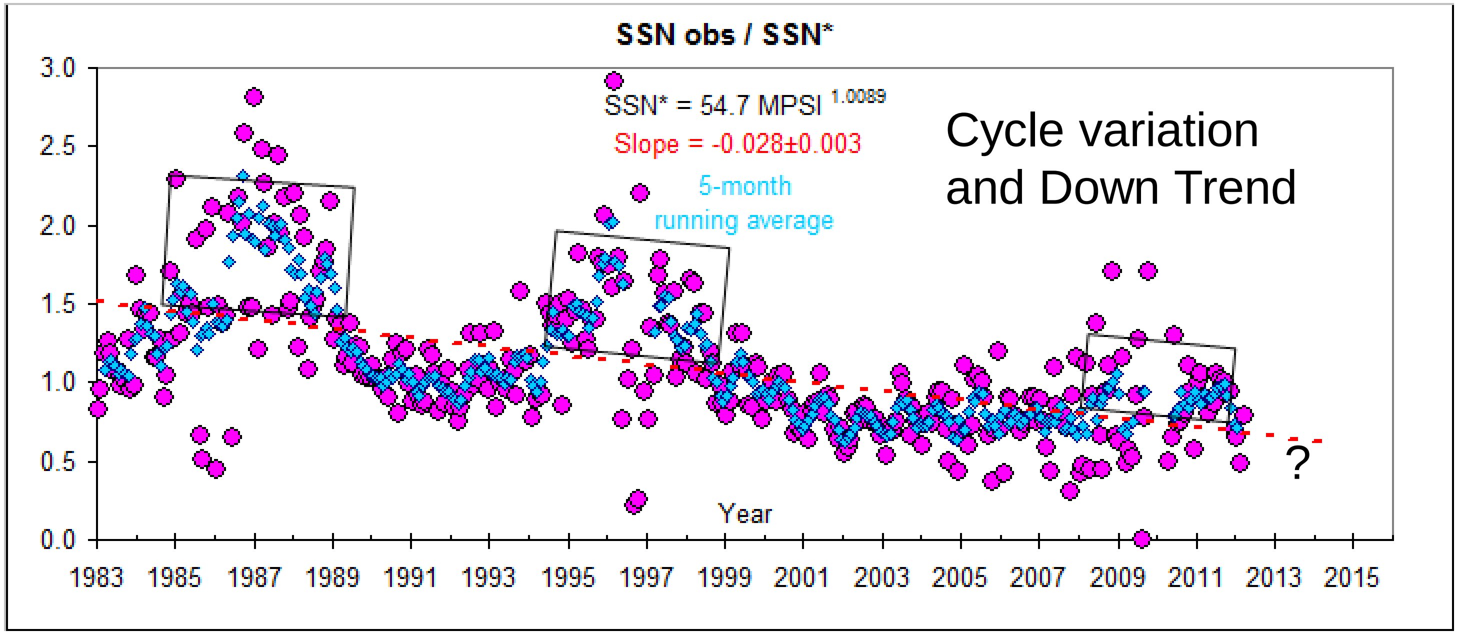


Since ~1990 we record progressively fewer sunspots than expected from observations of F10.7 microwave flux



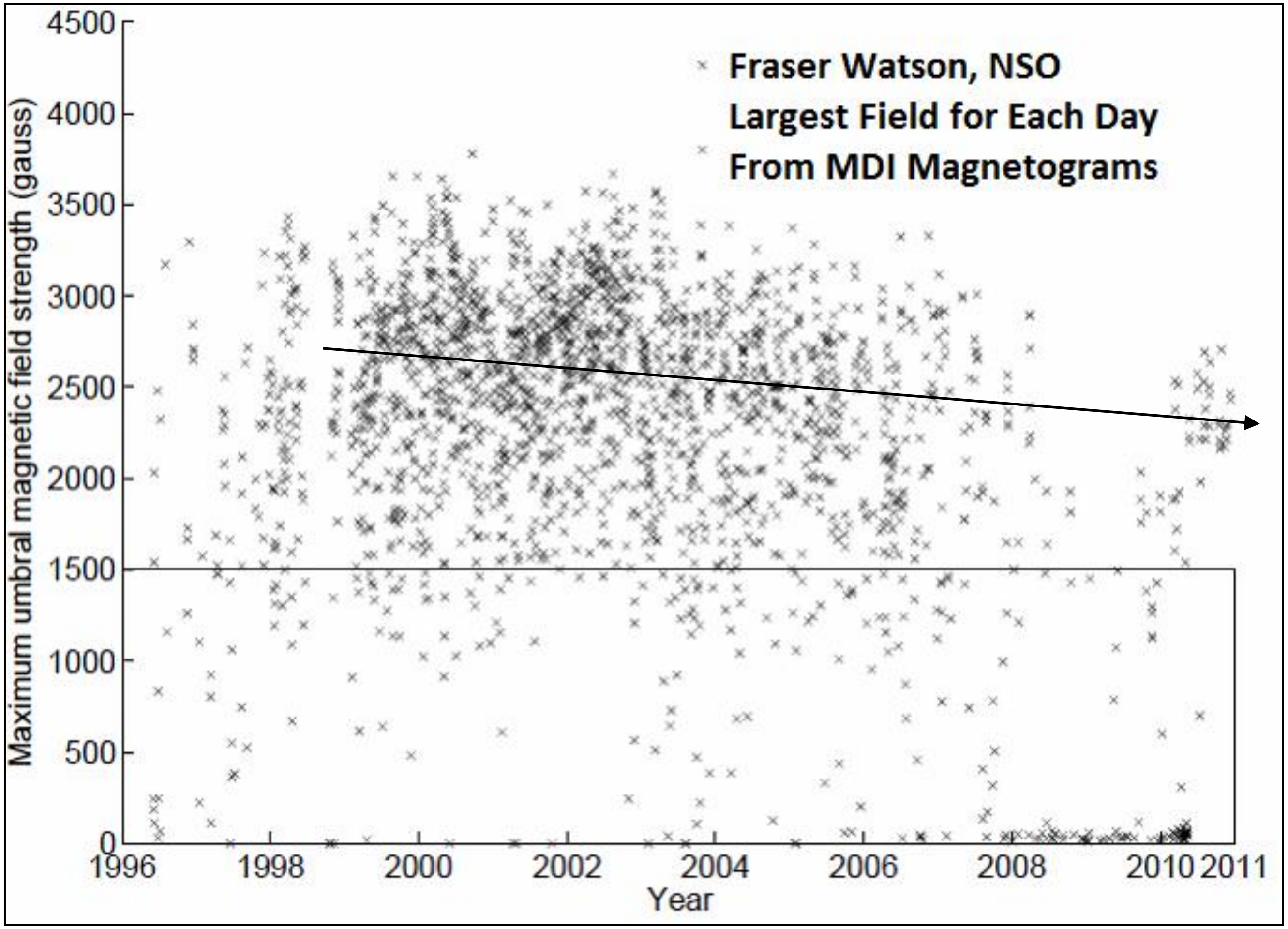
We see fewer sunspots for given MPSI

MPSI is the sum the absolute values of the magnetic field strengths for all pixels where that value is between 10 and 100 gauss. The sum is then divided by the total of number of pixels in the magnetogram.



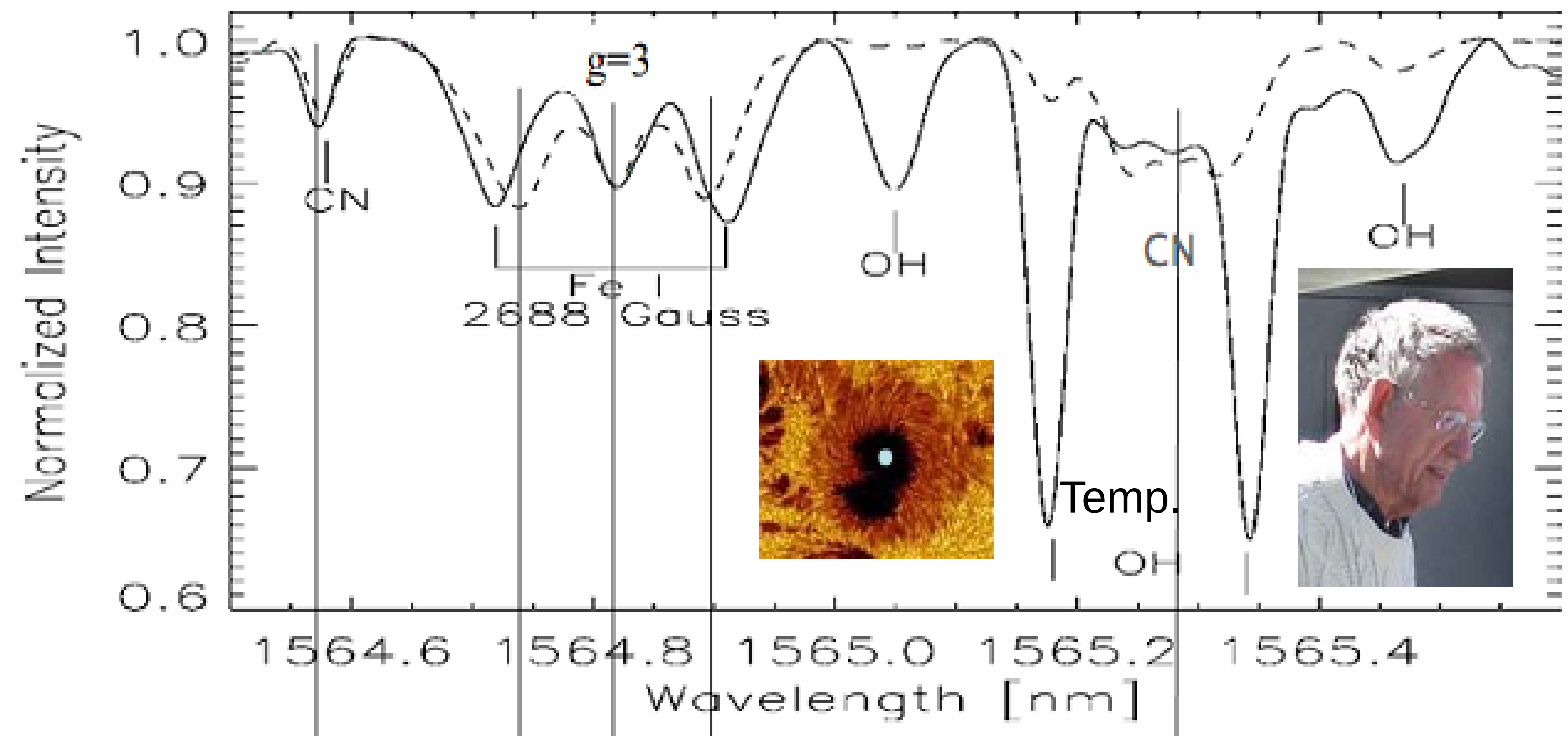
Same result if Ca II or Mg II index is used

Confirmation Using MDI Magnetograms



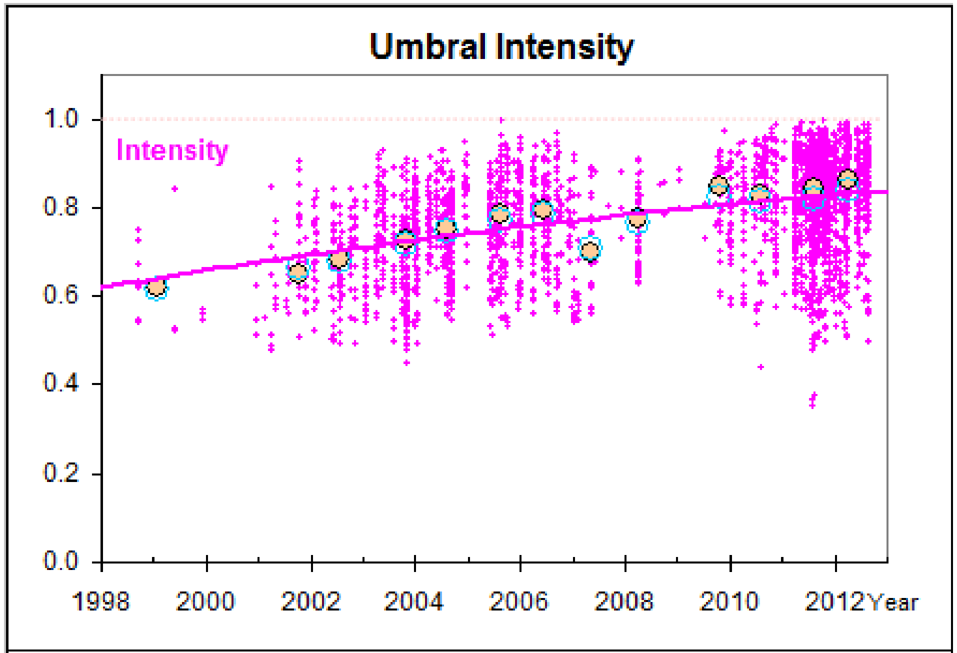
The STARA Algorithm does not perform well for very small spots [box, under ~1500 G]

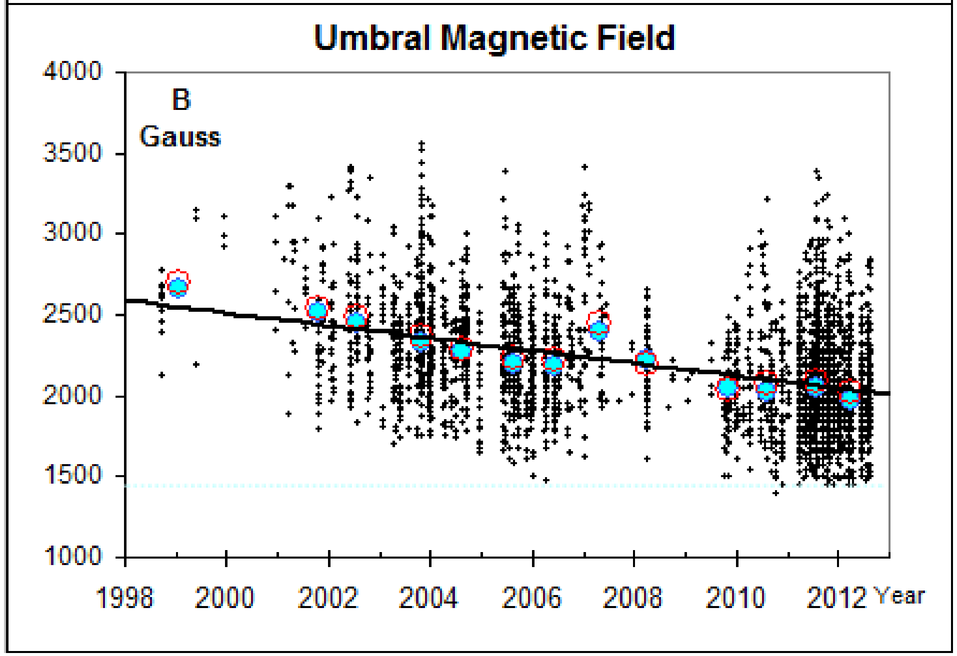
The Livingston & Penn Data

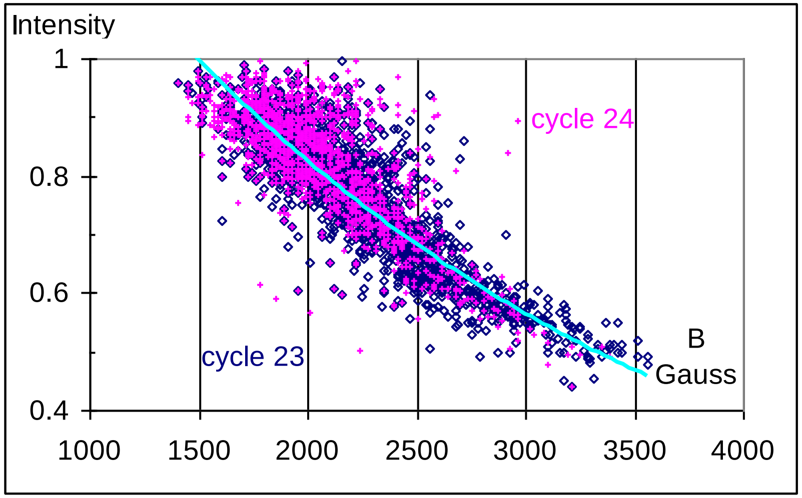


From 1998 to 2012 Livingston and Penn have measured field strength and brightness at the darkest position in umbrae of 3148 spots using the large Zeeman splitting of the infrared Fe 1564.8 nm line..

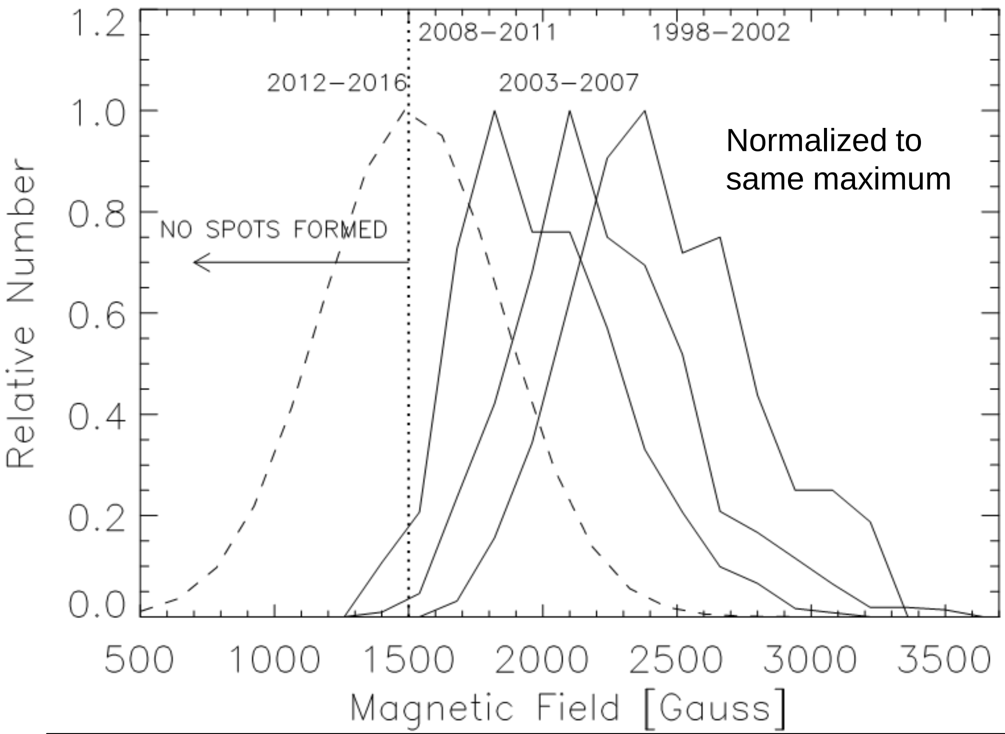
Spot Umbral Intensity [Temperature] and Magnetic Field Changing

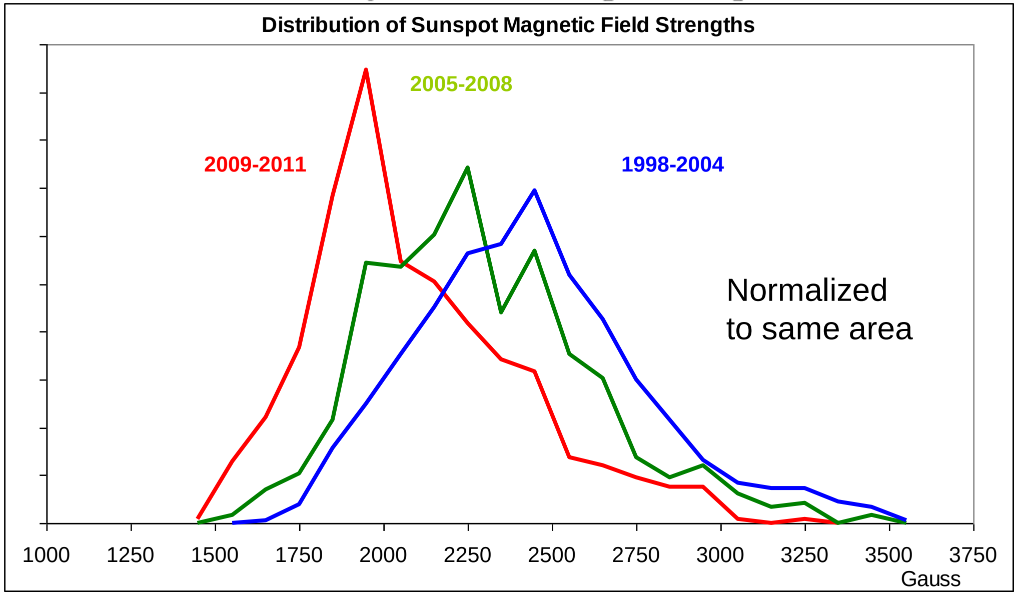






Evolution of Distribution of Magnetic Field Strengths





Sunspots form by assembly of smaller patches of magnetic flux. As more and more magnetic patches fall below 1500 G because of the shift of the distribution, fewer and fewer visible spots will form, as observed

Conclusion

Recent work has argued that either a full blown grand minimum or much weaker cycles are likely in upcoming decades. If the Sun indeed is near a transition from a state of relatively vigorous to relatively low activity, a comprehensive observational record of Cycle 24 (both resolved and disk-integrated) is paramount. In any event, current observations (e.g, of the polar fields, solar wind and cosmic ray fluxes) suggest that Cycle 24 will be unlike any of the four prior cycles of the space era.

The Nobeyama observations form a homogenous and extensive archive and must be continued in order to cover this transition into potentially uncharted territory

Abstract

The size of a solar cycle seems to be controlled by the strength of the polar fields at the preceding minimum, which therefore provides a good precursor for the prediction of the next cycle. Measurements of the magnetic fields at the poles are difficult because of severe projection effects. It appears that the magnetic field elements with strong vertical fields have a signature in the radioheliographic maps in 17 GHz produced at Nobeyama. These observations thus provide an alternative method of determining the polar fields, without the projection problems of the direct measurements of the magnetic field. Now that minimum is past, we focus on the upcoming polar field reversals which we already know will be highly asymmetric, with the reversal of the South Pole seemingly much delayed with respect to the North Pole. Such asymmetry is important for the question in dynamo theory of to what degree the two hemispheres are coupled (or as it appears - de-coupled). We'll discuss the asymmetry in this and several previous solar cycles relating it to hemispheric asymmetry in sunspot production and decay.