Prediction of Solar Cycles

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On occasion of Phil Scherrer's 70th birthday

Chaminade, Santa Cruz, CA

The Origin of the Polar Field Precursor Method

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USING DYNAMO THEORY TO PREDICT
THE SUNSPOT NUMBER DURING SOLAR CYCLE 21

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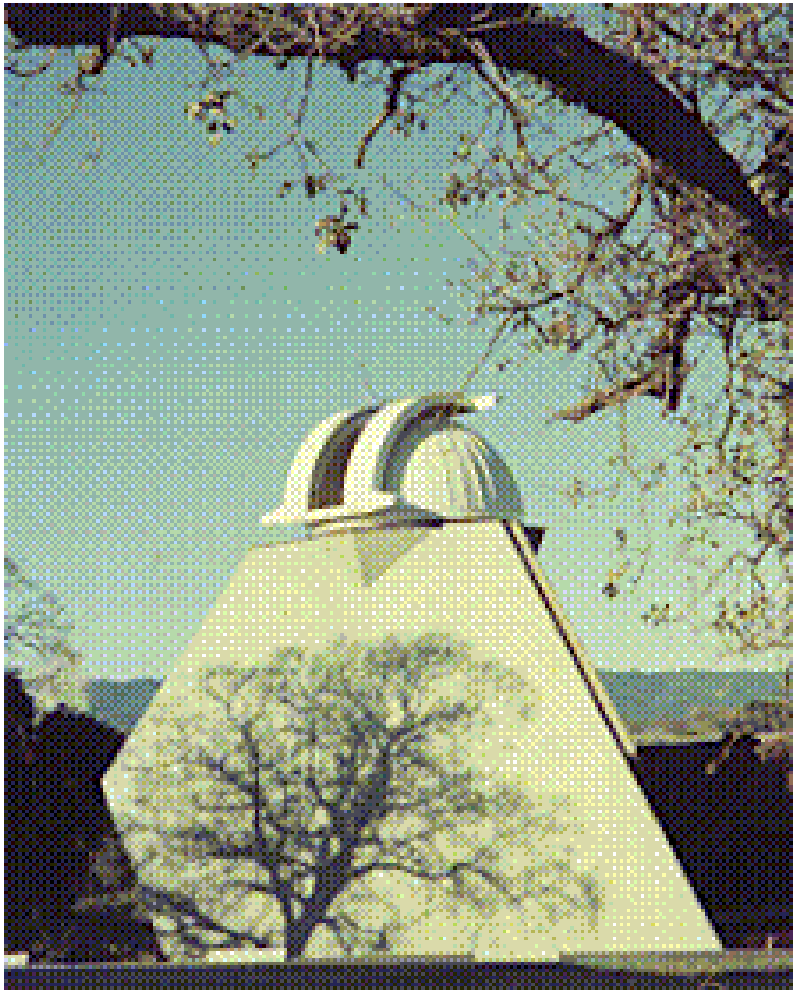
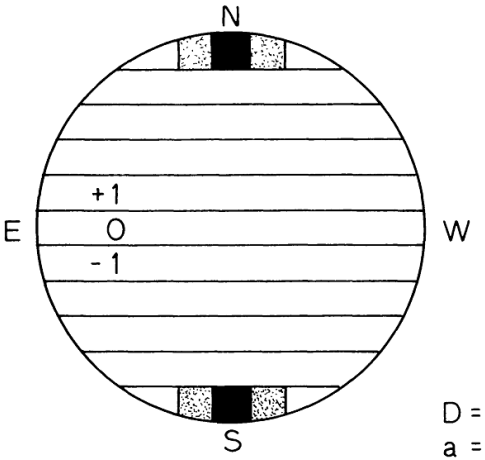
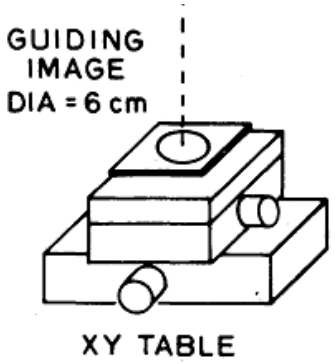
Abstract. On physical grounds it is suggested that the sun's polar field strength near a solar minimum is closely related to the following cycle's solar activity. Four methods of estimating the sun's polar magnetic field strength near solar minimum are employed to provide an estimate of cycle 21's yearly mean sunspot number at solar maximum of 140 ± 20. We think of this estimate as a first order attempt to predict the cycle's activity using one parameter of physical importance based upon dynamo theory.

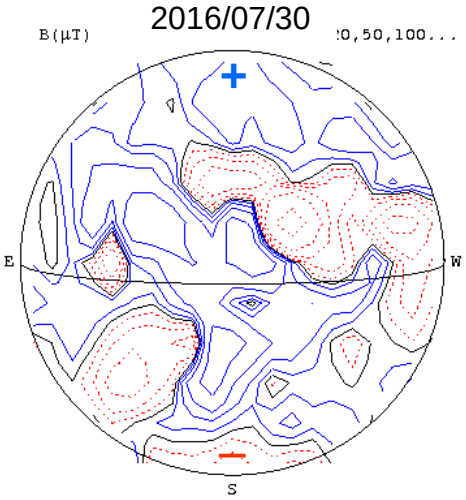
The Authors 31 years later

Wilcox Solar Observatory (WSO) Polar Field Measurements





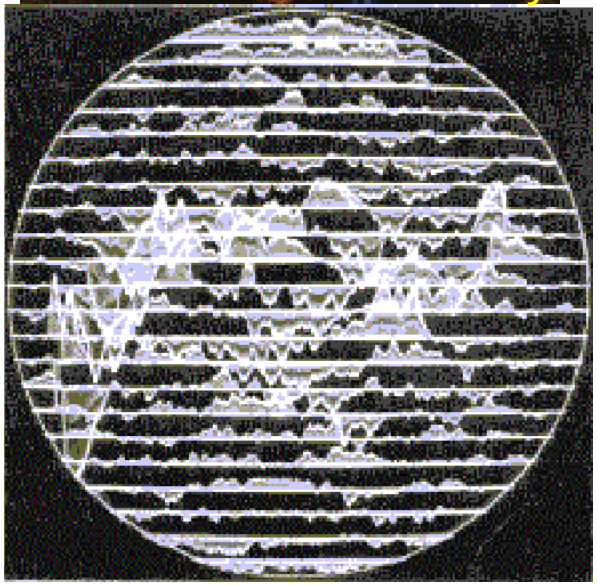




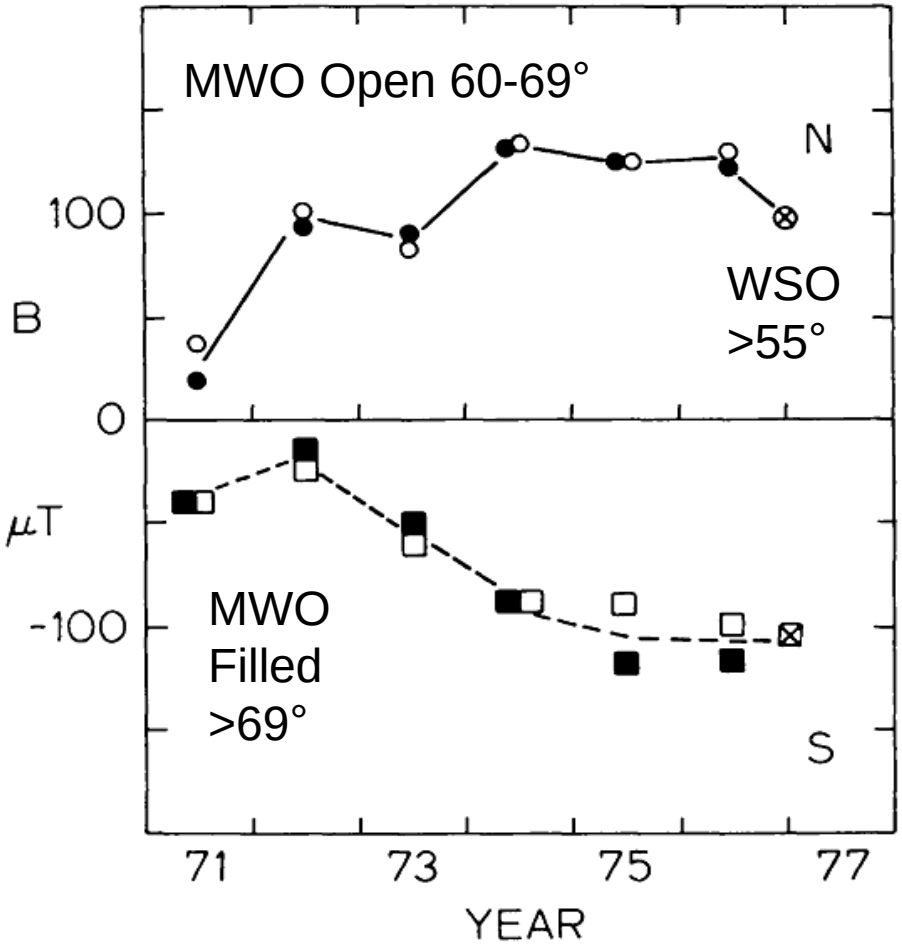
Wilcox Funding
Scherrer Design
Svalgaard Software
Duvall Scanning

Howard Advice

MWO Polar Fields

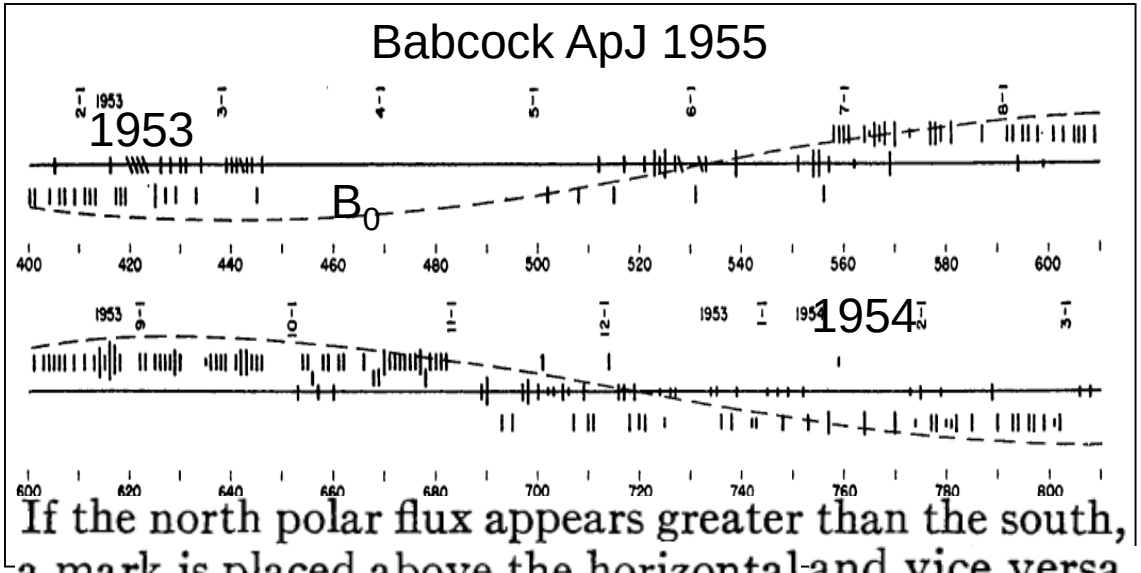


MWO Magnetogram 1953

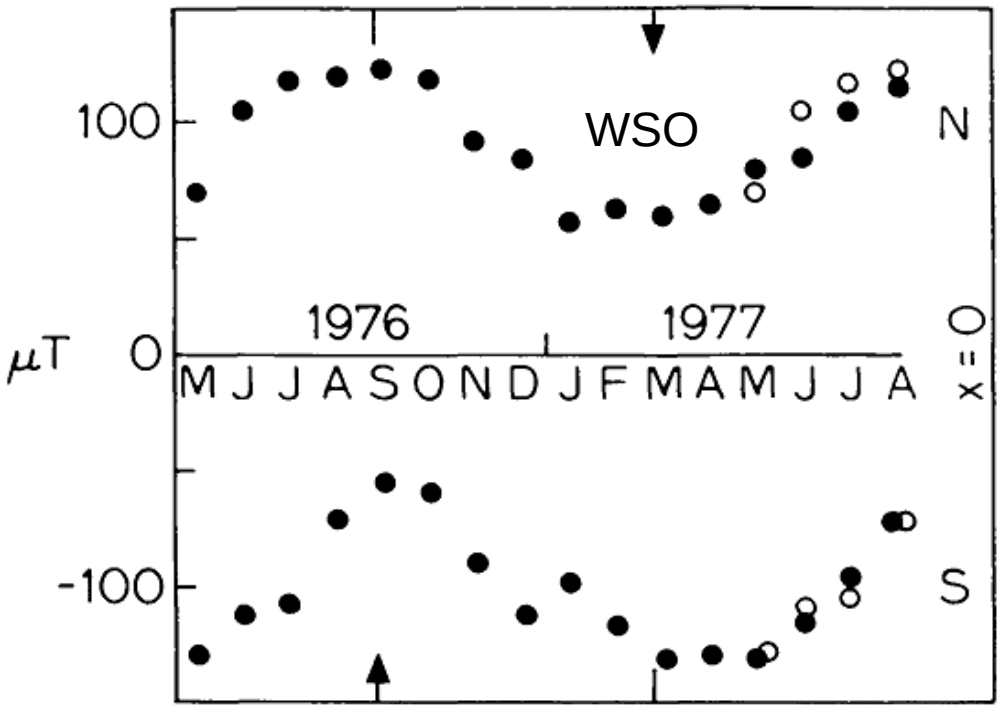


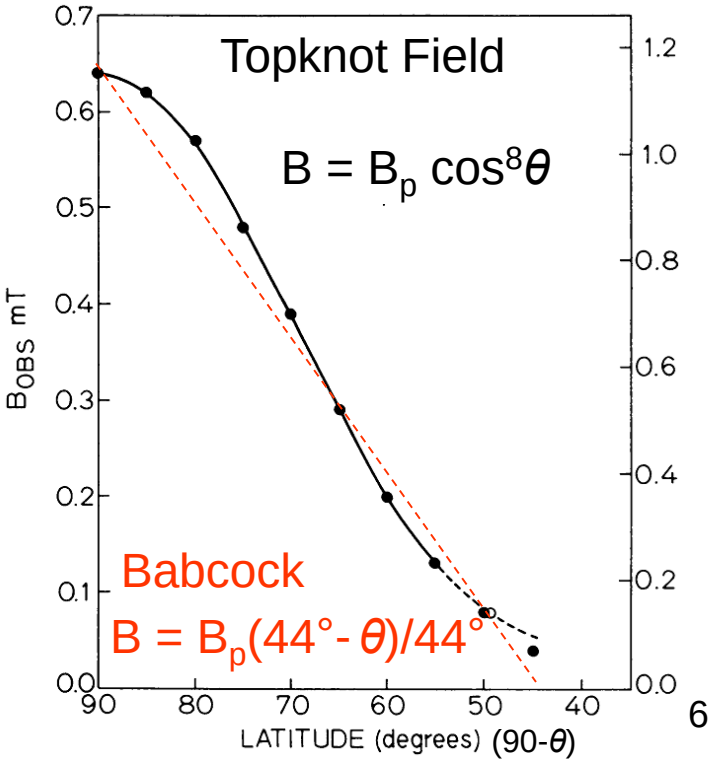
Initial WSO polar fields agreed with MWO

Discovery of the Topknot Polar Fields

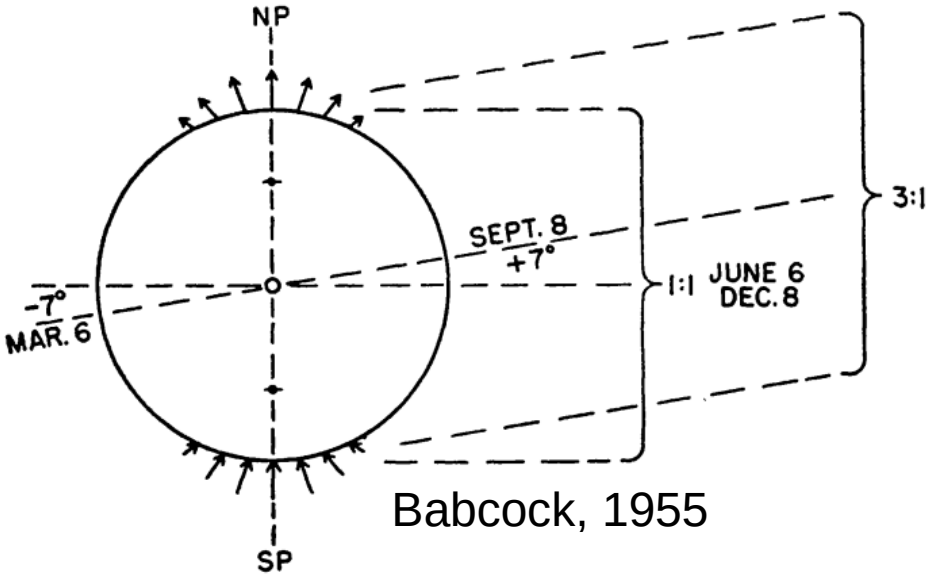


Annual Modulation of Line-of-Sight Magnetic 'Field'

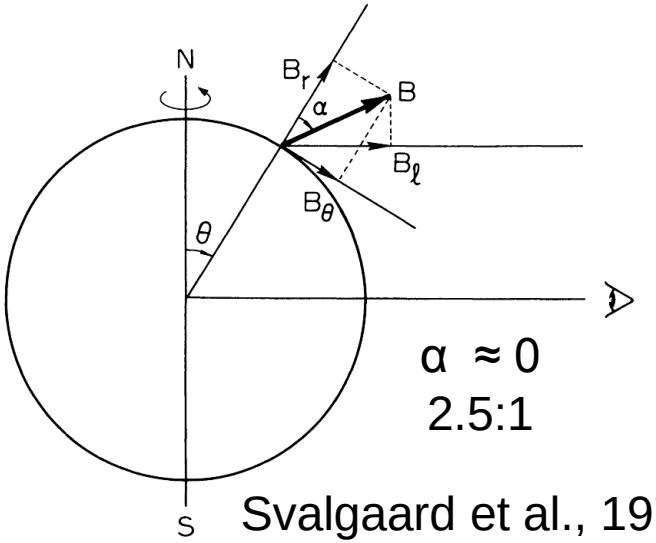




Explanation of the Yearly Variation



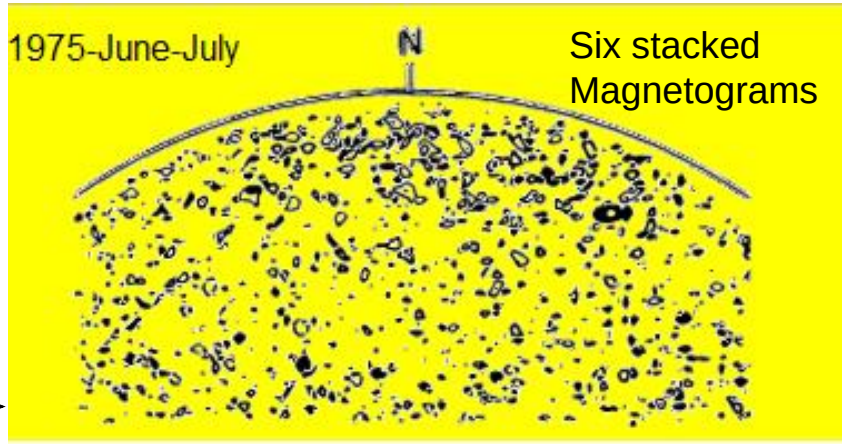
Babcock, 1955



Svalgaard et al., 1978

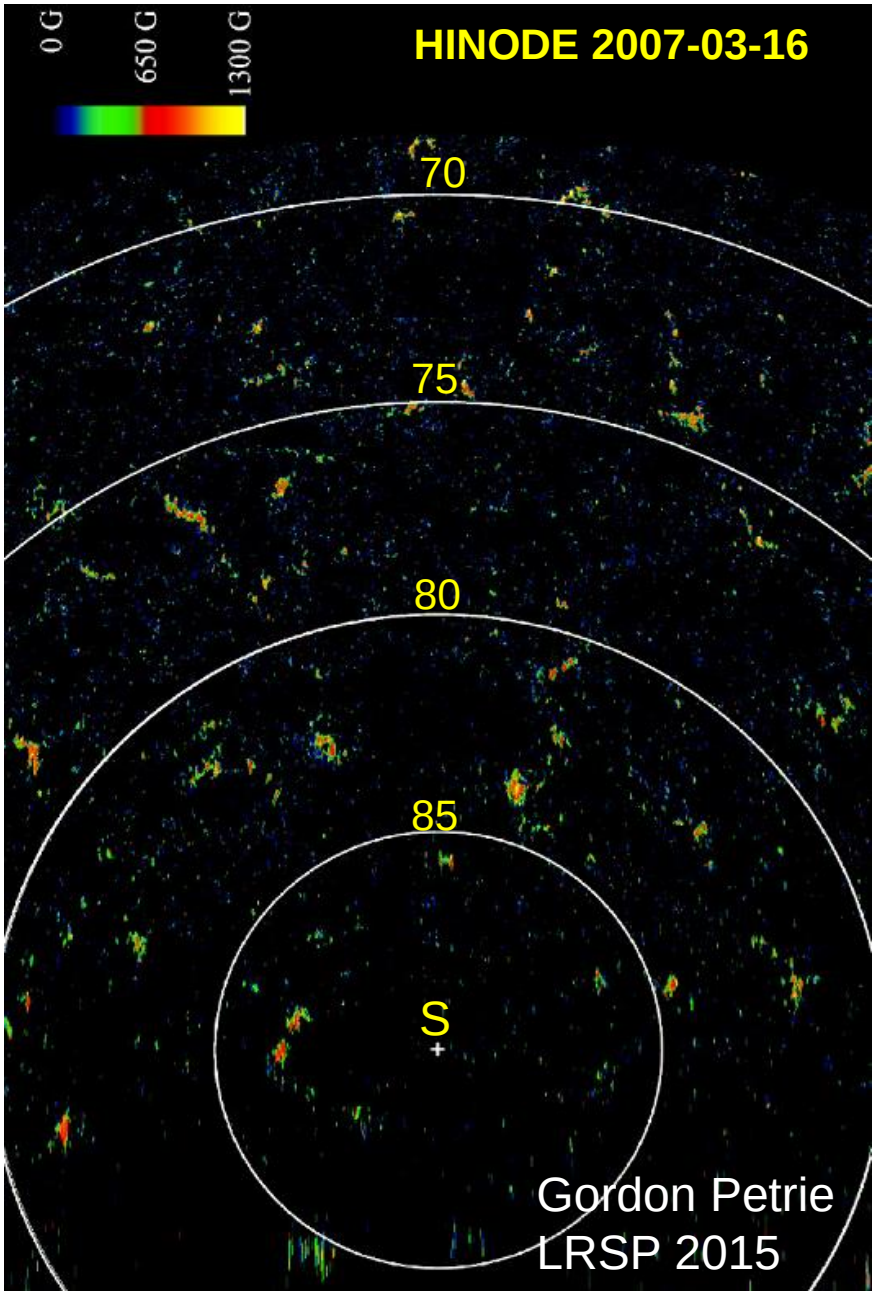
If the magnetic field over the poles were uniform and radial, there would be no effect on the line-of-sight component of tilting the solar axis. We also found α≈0, i.e. radial field.

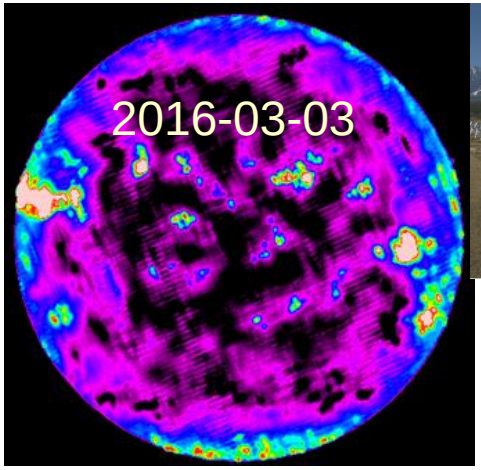
The concentration of flux near the poles has been observed for a long time; a meridional flow seems to be needed for this



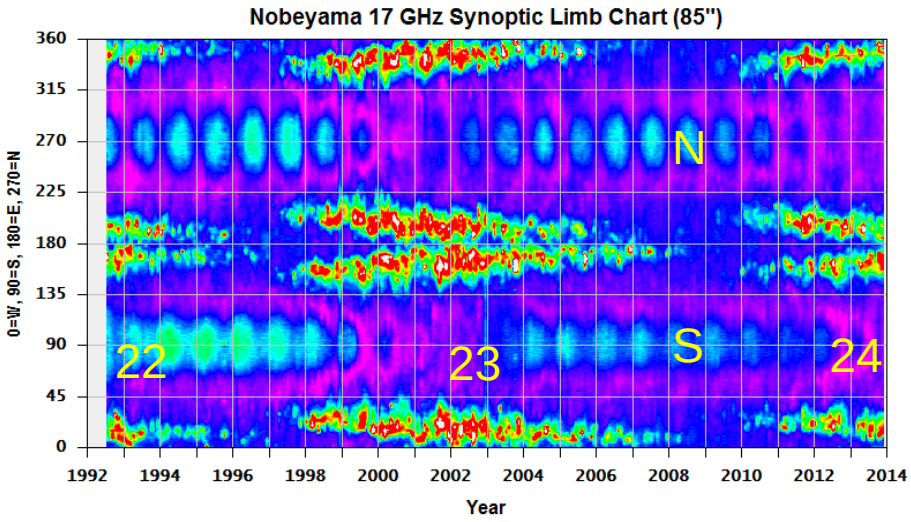
MWO: Howard, R., Solar Physics, 59, 243 (1978)

Fine Structure of kG Polar Fields

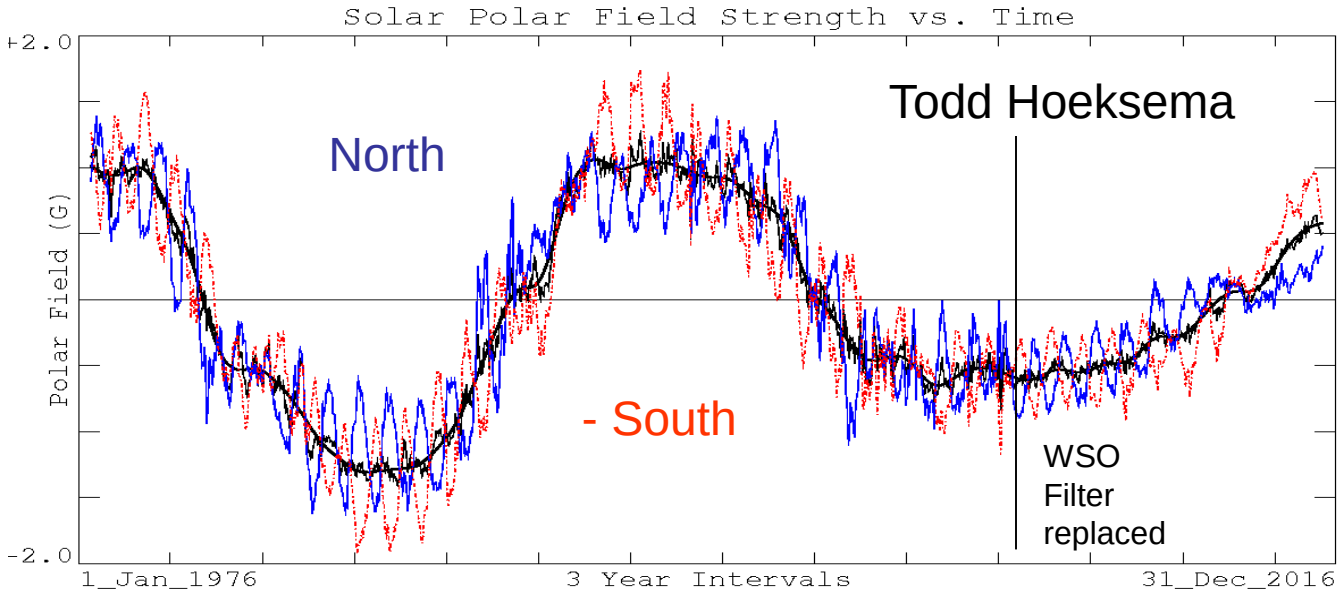




Nobeyama (Japan) 17 GHz Microwave Chromospheric Emission



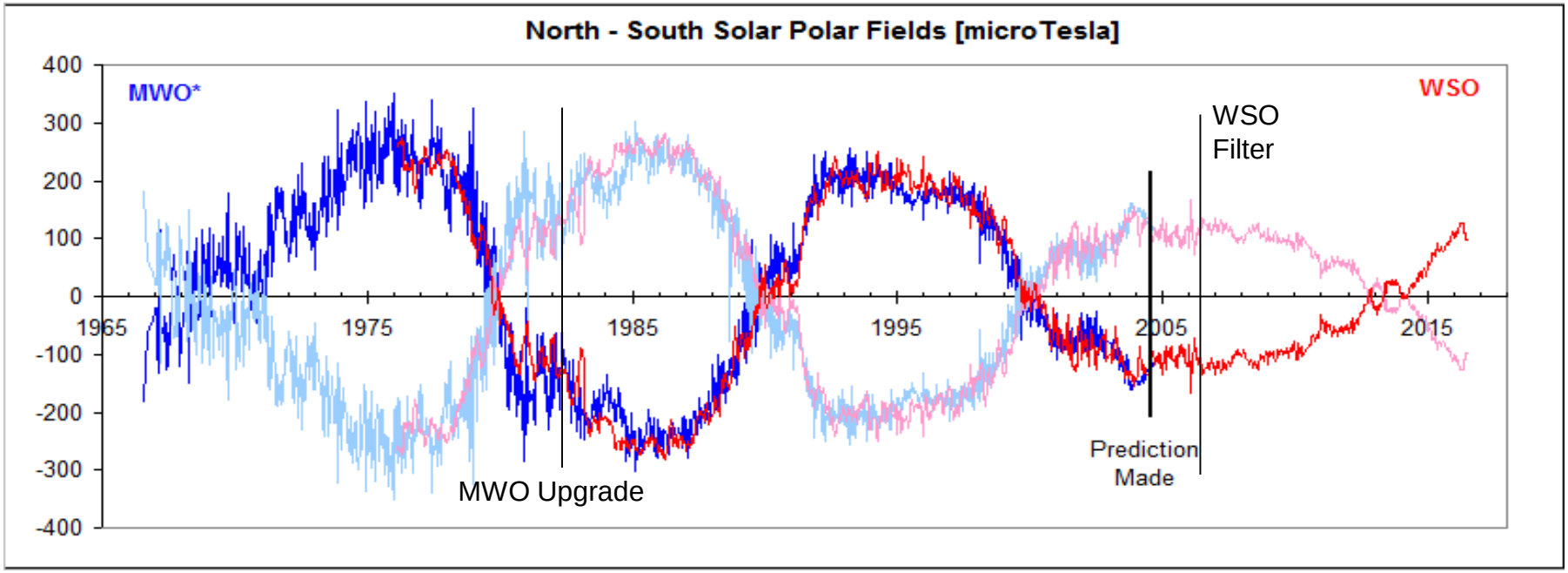
The 17 GHz emission ~ Magnetic Flux



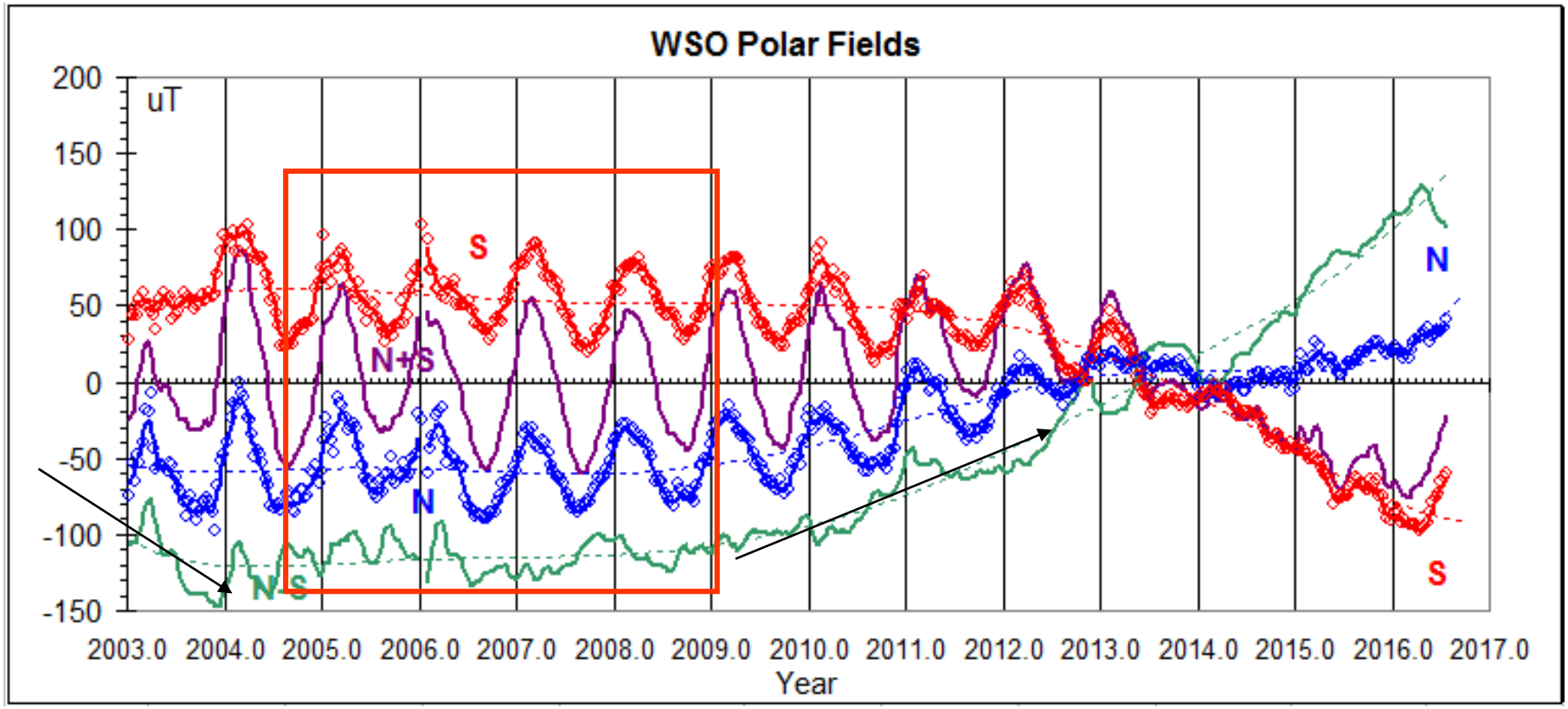
Longer-term Record of Polar fields

Solar 'Dipole Moment'
$= B_{North} - B_{South}$

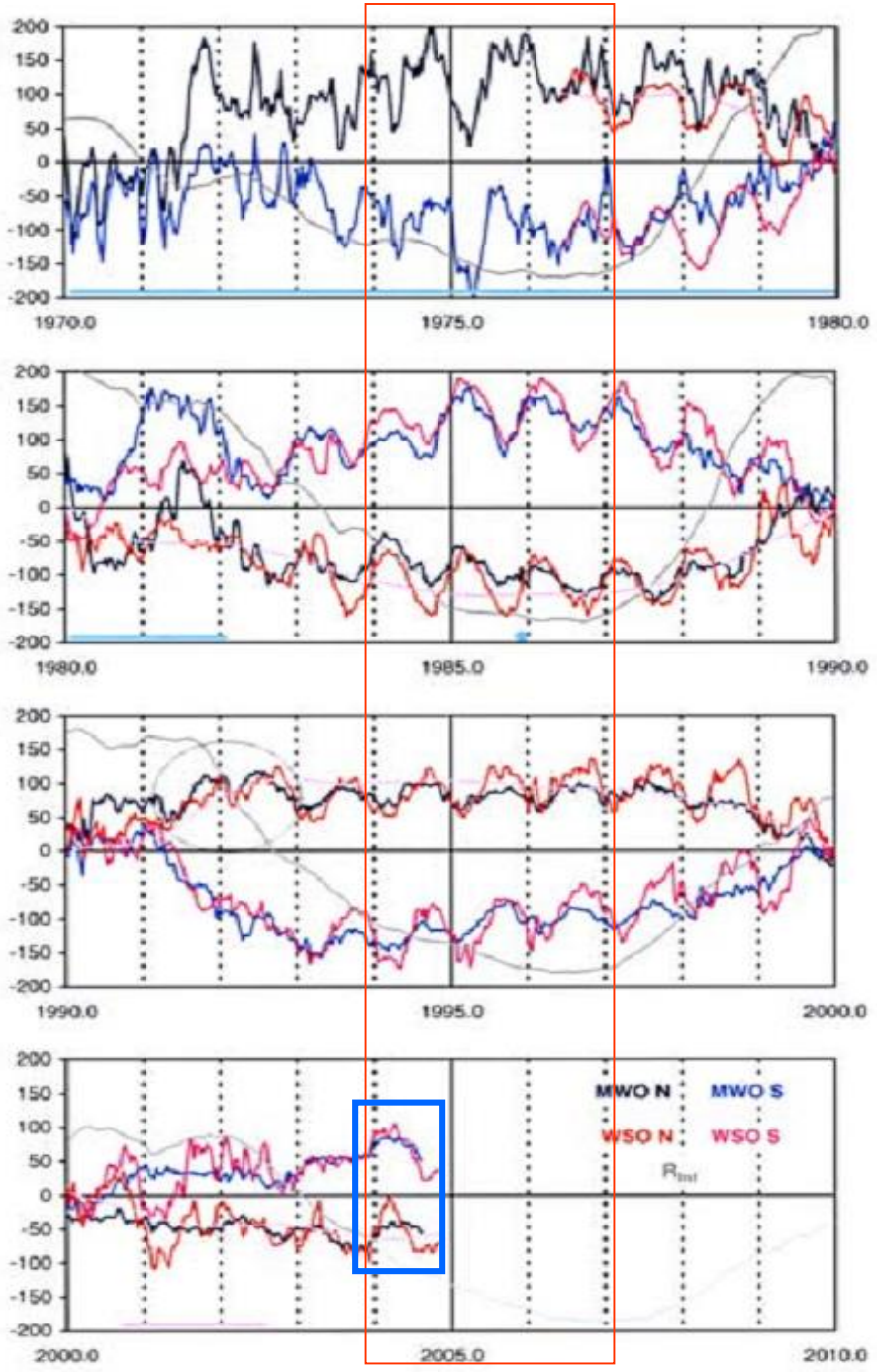
Removes Zero-level errors (for MWO) and annual modulation



Stability of Solar Polar Fields

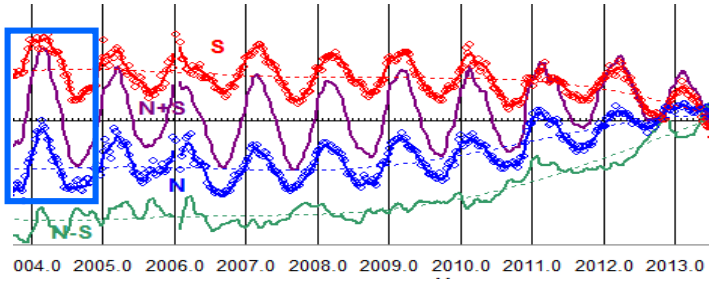


We had noticed that for 3-4 years before the minimum, the polar fields became rather stable: there was little new flux from the dwindling old cycle added and the reversing effect of flux from the new cycle spots had not yet begun in earnest.

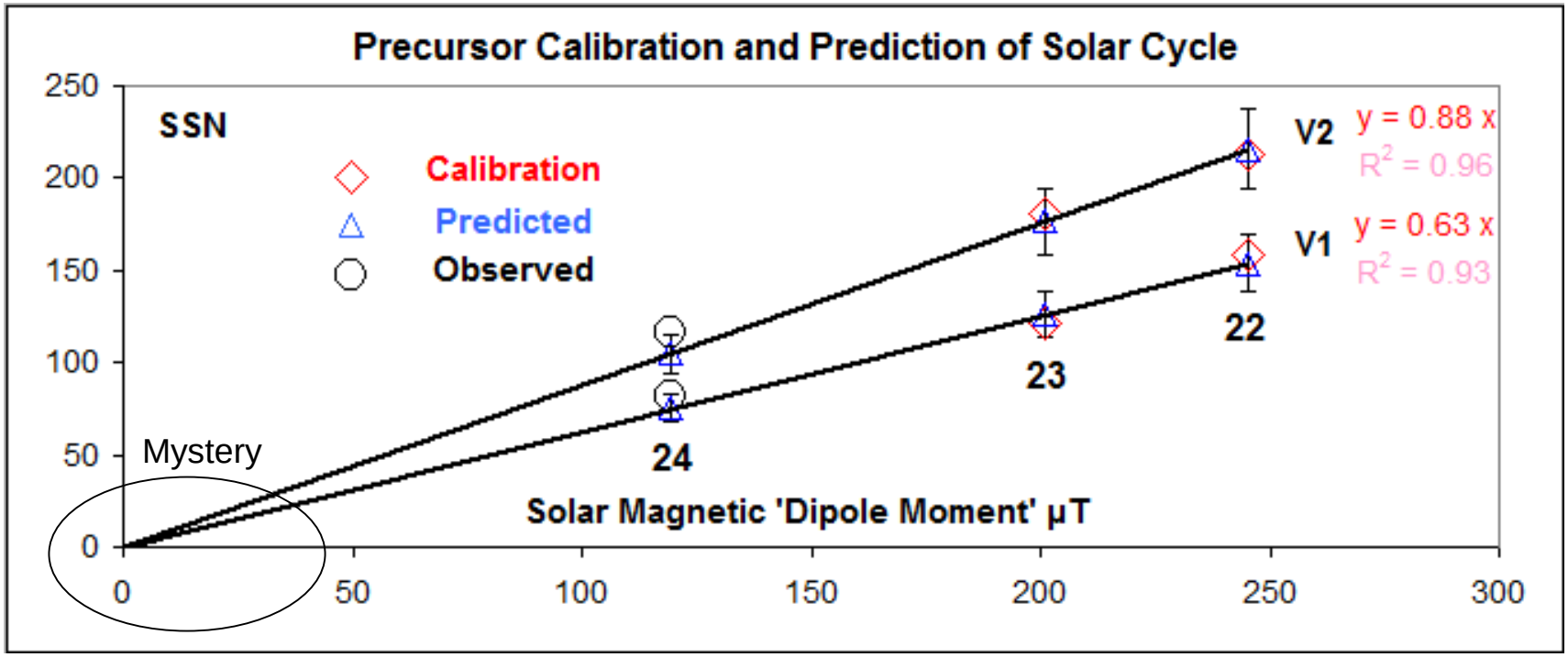


Using the Measurements of the Solar Polar Fields we [Svalgaard, Cliver, Kamide, GRL 2005] made a Prediction of the coming SC24 (thanks to WSO)

The idea was to note that once a stable yearly variation was reached, the polar fields would not change much until the minimum and might be used as a precursor for the size of the next cycle.



Calibration of the Precursor

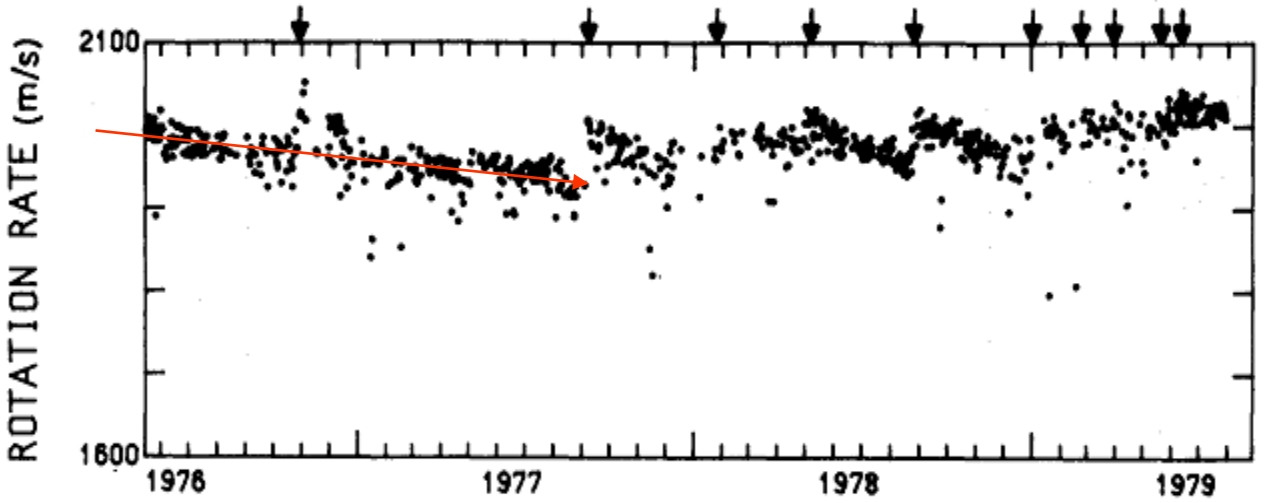


We assume that the polar field precursor method works and that we only need to calibrate the relationship. We use Cycles 22 and 23 for this and find that the prediction of Cycle 24 is correct within the ‘error bar’ [which is hard to estimate].

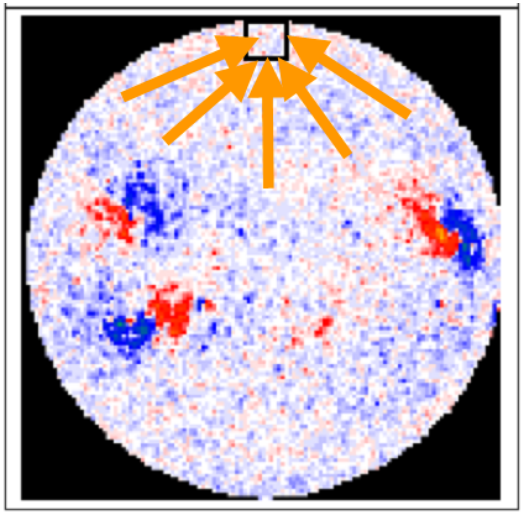
Why did we not use Cycle 21? One reason was that our WSO data only began in 1976. Another more serious problem [discovered later] was that of scattered light …

The Effect of Scattered Light

SCHERRER, WILCOX, AND SVALGAARD ApJ 1980

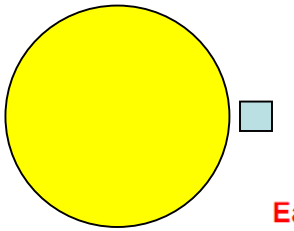


At WSO we also measure the rotation rate of the Sun. We found that the Sun rotated slower and slower as time went on, until we cleaned the mirrors and optics [arrows]. Dirty optics means scattered light. **In 1976-1977 that was particularly bad.**



Scattered light is the reason for the lower WSO fields, as light from mixed polarity areas are scattered into the polar aperture, diluting the measured polar field.

Making the mirrors dirty on purpose shows the effect very clearly:



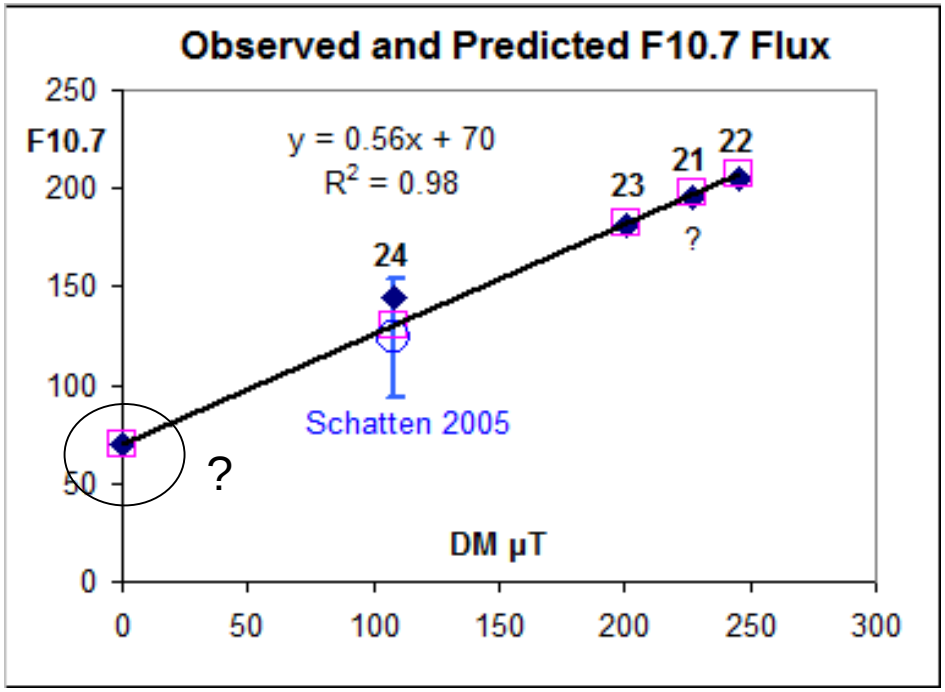
scattered %	Reduction
1.0	1.0000
3.0	0.8178
6.7	0.7402
11.1	0.5869
13.0	0.5424

Each % of scattered light decreases B by ~3.5%

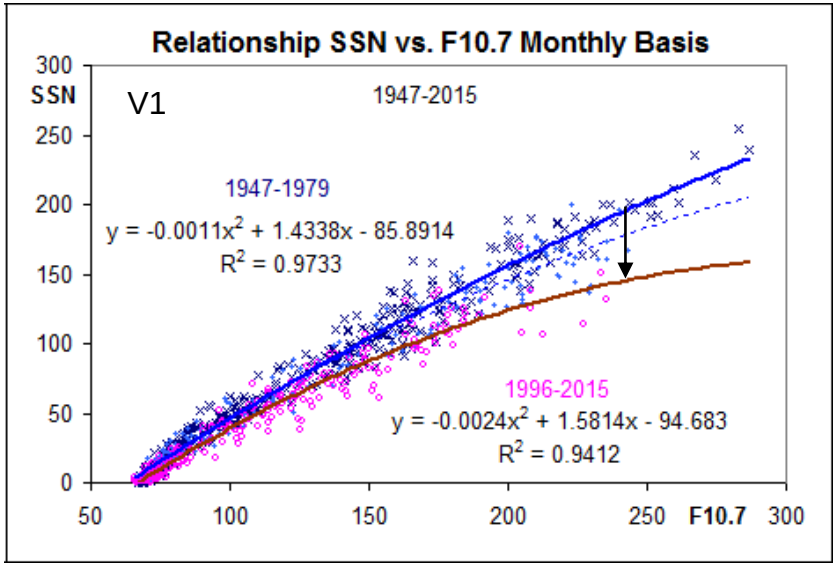
In 1976-1977 scattered light was about 5%

I didn't think of that for the field until 2007.

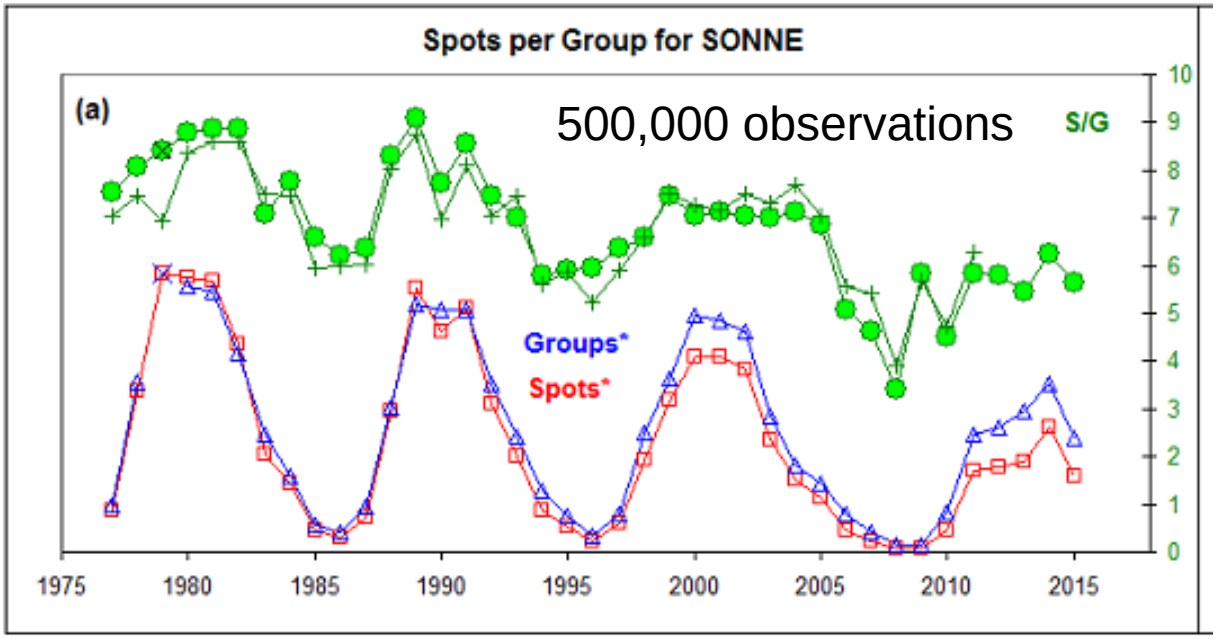
The F10.7 cm Microwave Flux is another Proxy for Solar Activity



Here, I have corrected cycle 21 for the scattered light effect. Blue diamonds are observed values. Pink squares are predicted values. Note Ken Schatten's 2005 excellent prediction using a variant of the polar field precursor technique.

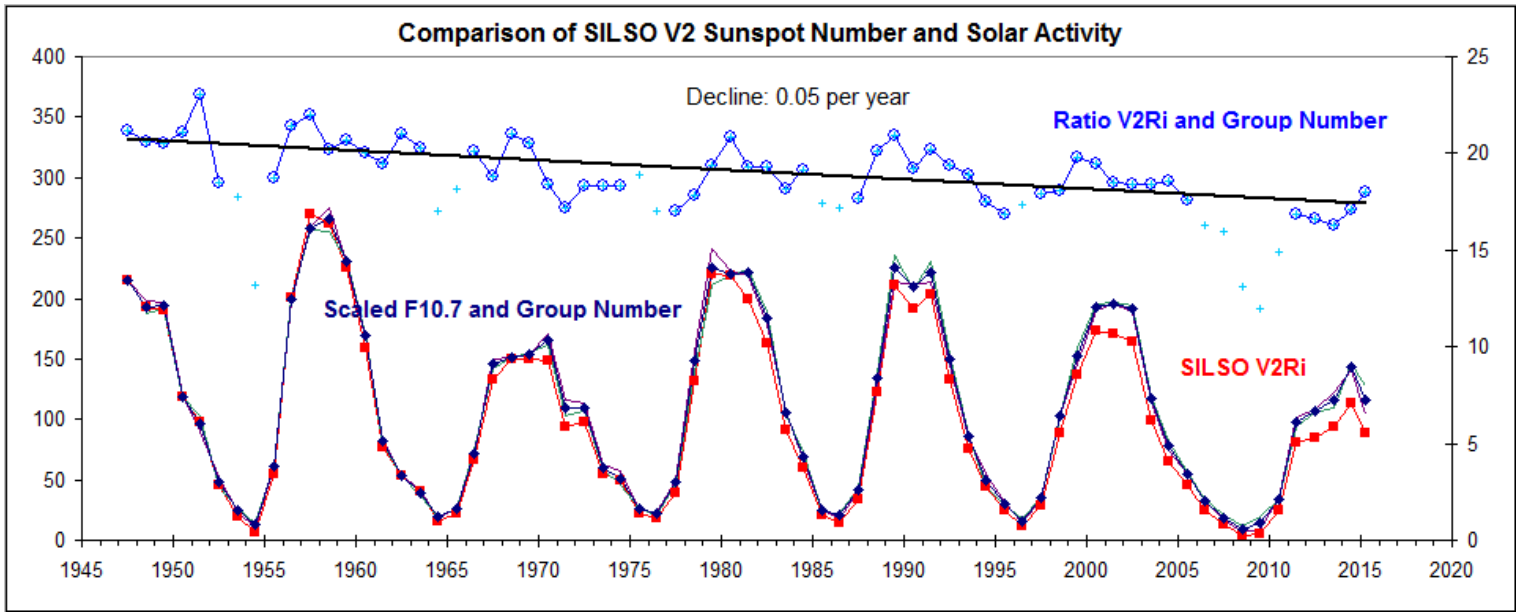


It used to be that the relationship between F10.7 and the SSN was stable and tight (blue). This seems no longer to be the case. The SSN is now too low for a given F10.7 flux for cycles 23 and 24. So what should we predict? What is 'real' solar activity?



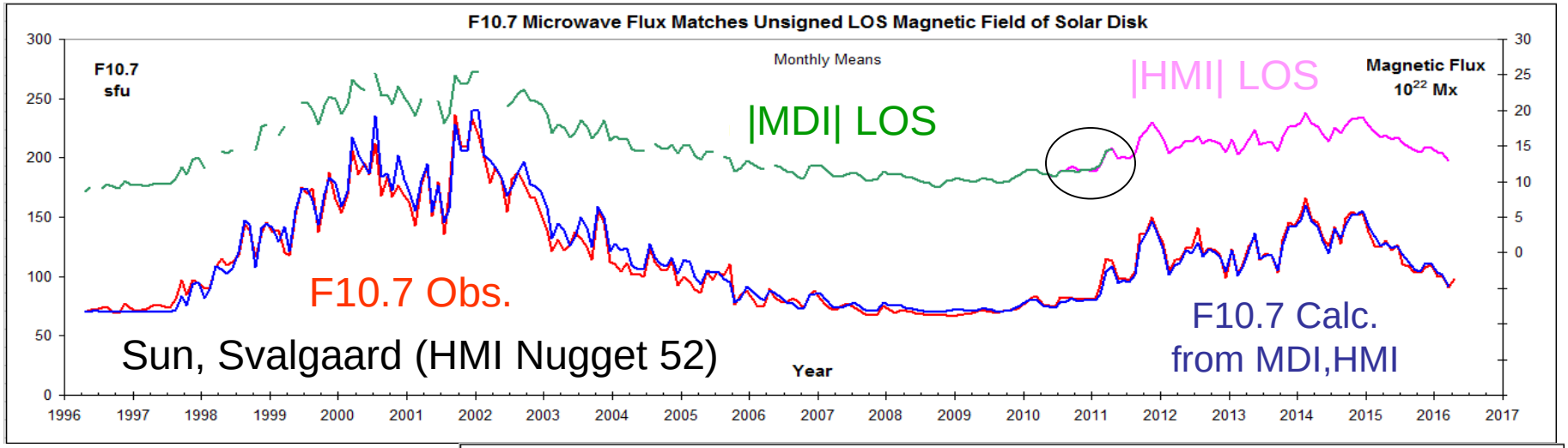
The Number of Spots per Group is Decreasing

So using a constant (i.e. 10) weight for groups in Wolf's definition of the Relative Sunspot Number SSN = k (10 G + S) is now problematic. A good reason to prefer F10.7 as a measure of solar activity.

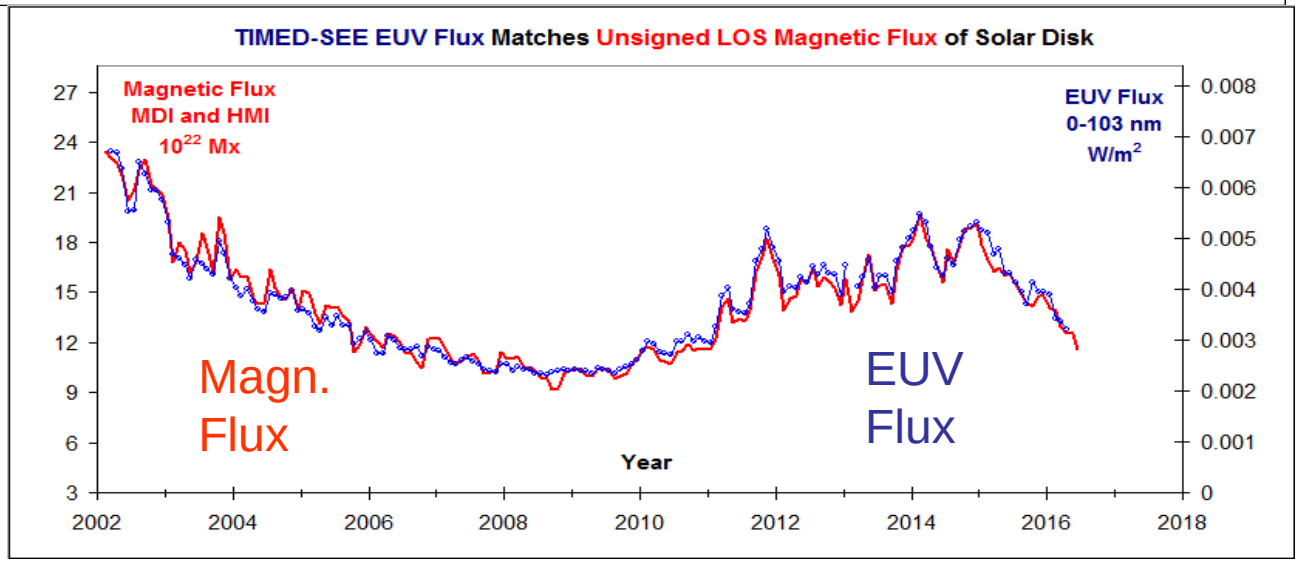


We should not stop counting sunspots. In future we should keep track of the Groups, G, and Spots, S, separately.

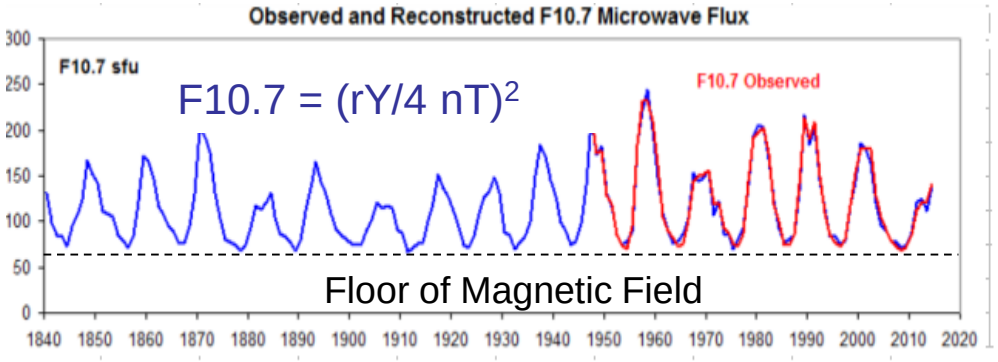
“Phil (and Team) to the Rescue”



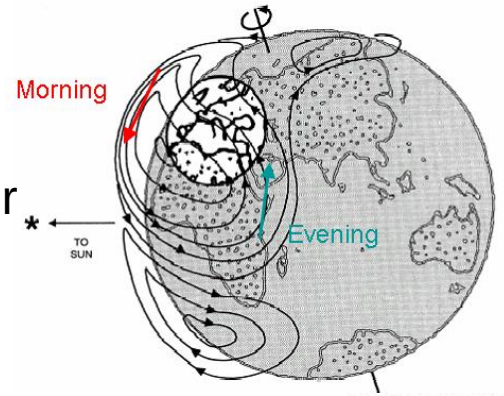
The [unsigned] disk average of the LOS magnetic flux measured by MDI and HMI tracks F10.7 flux very closely, and also the EUV Flux responsible for creating the E-Layer in the ionosphere.

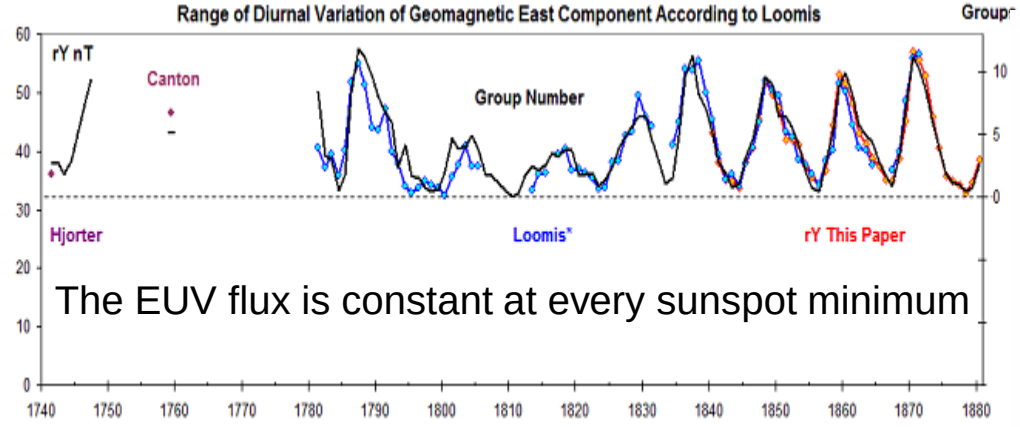


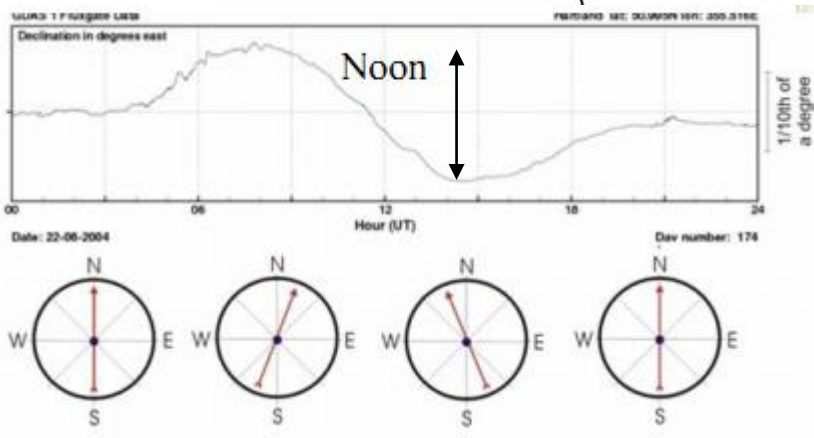
We can with Confidence Reconstruct F10.7 (and EUV) back to the 1740s



Dynamo current in the E-layer at 105 km altitude

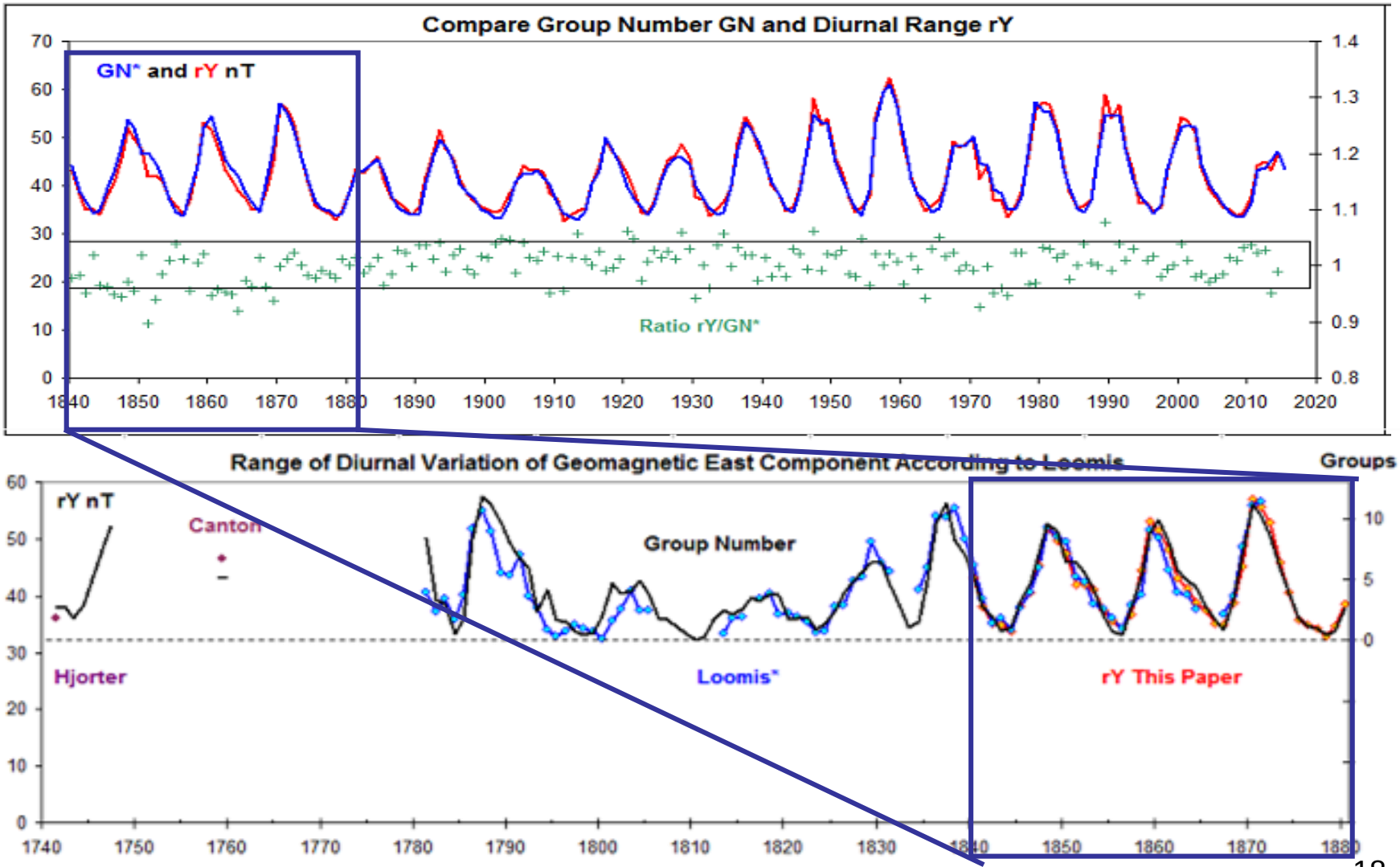






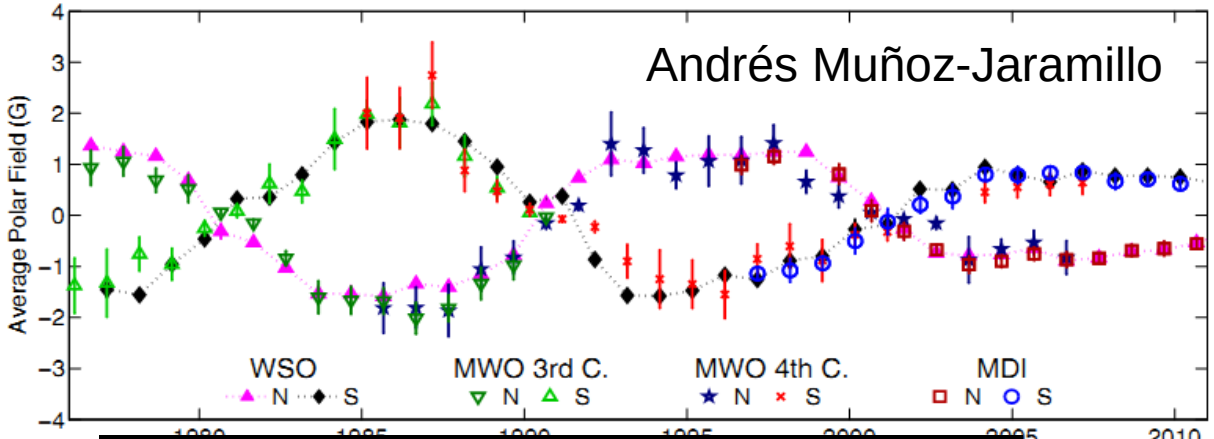
The F10.7 flux is what we should predict because we find that the Sunspot Number may be undergoing a qualitative secular change as we seem to be losing the small spots (either not present or less visible)

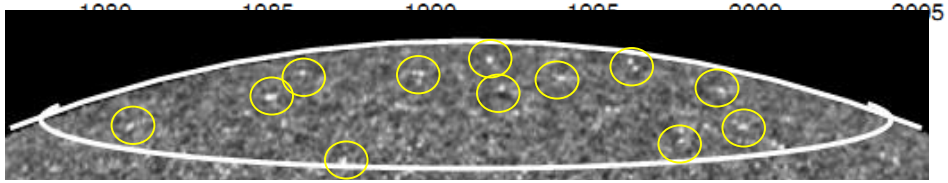
The Sunspot Group Number

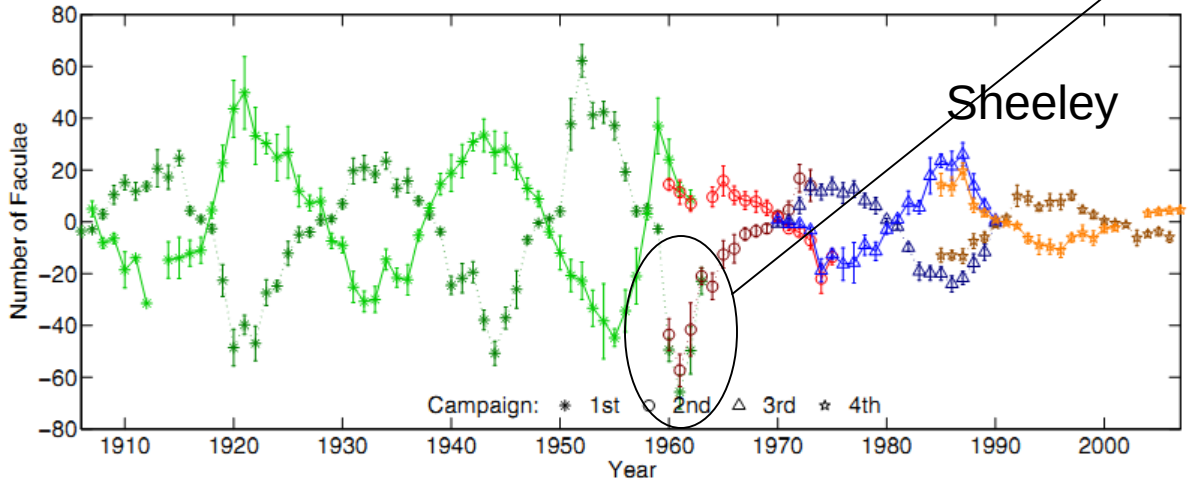


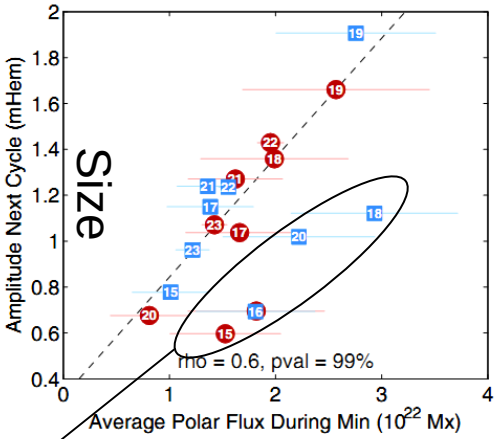
The Group Number is not affected by the loss of the small spots

Polar Faculae as Proxy for Polar Magnetic 'Field' [Flux] and predictor







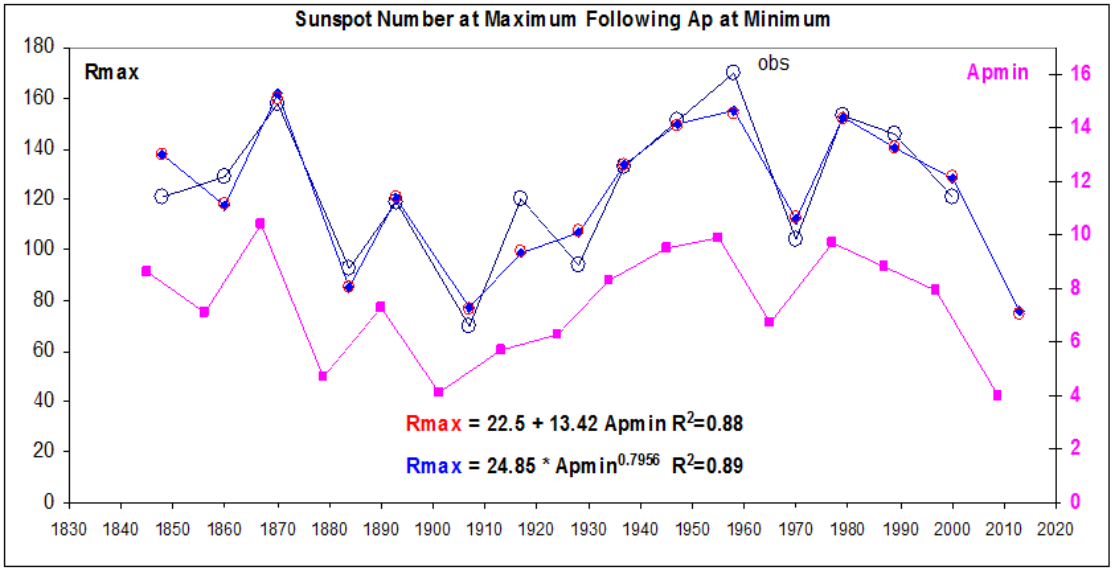


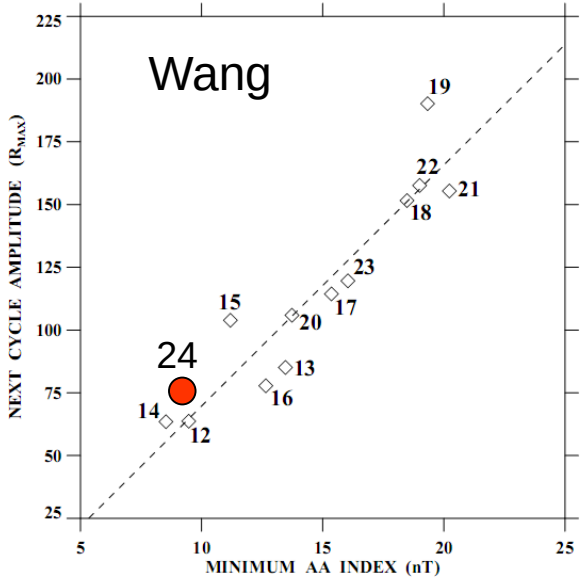
Polar Flux

The inferred polar flux at minimum is a fair proxy for the size of the next solar cycle.

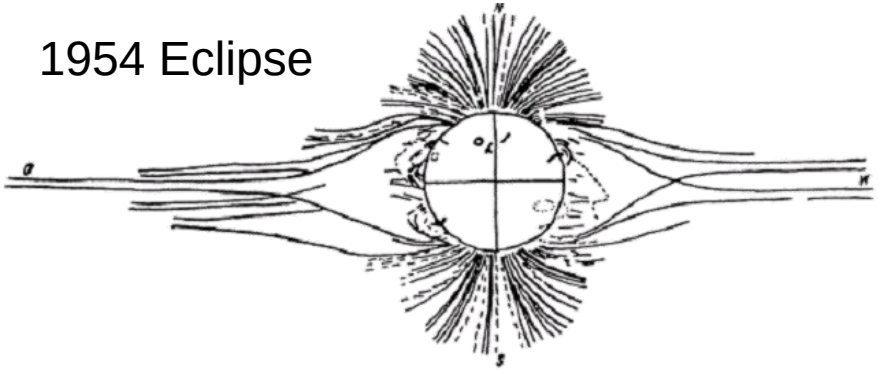
Some outliers are due to 'spikes' (surges) in the faculae count.

Geomagnetic Activity Seems to be a Decent Precursor



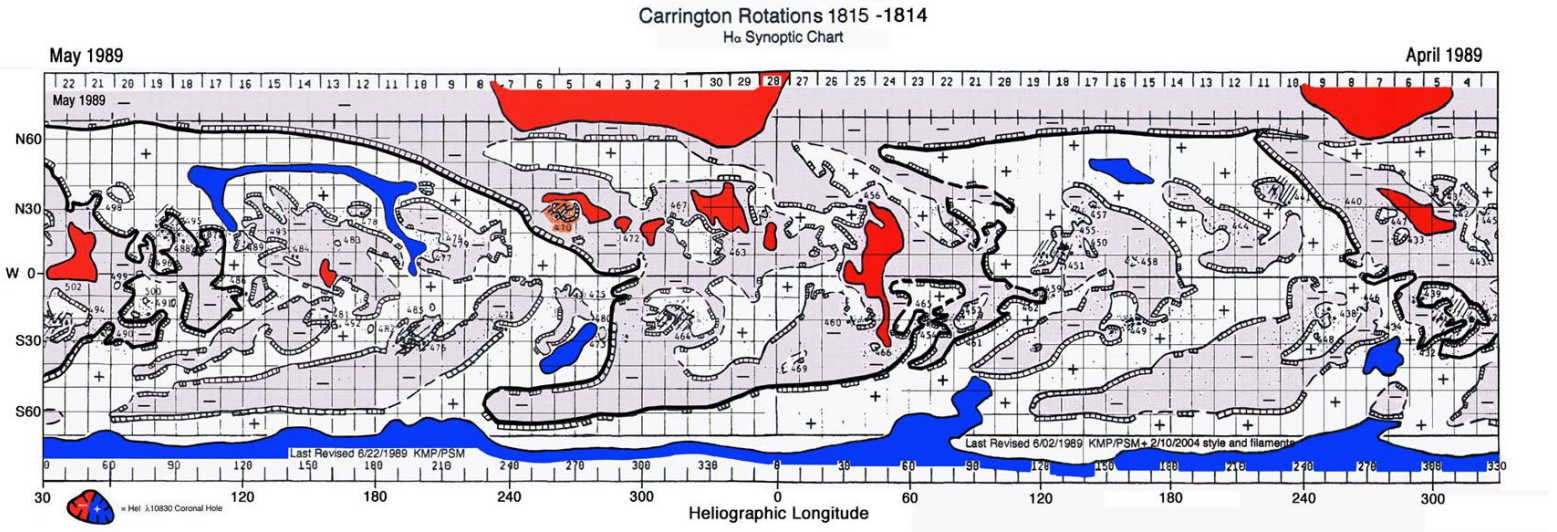


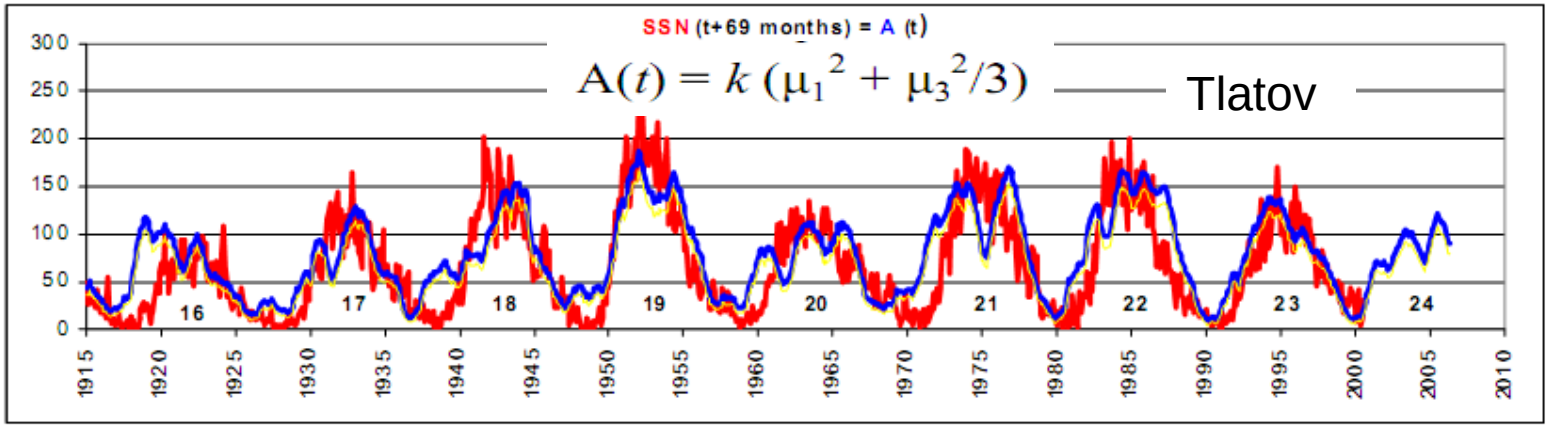
1954 Eclipse



The idea is that the polar fields at sunspot minimum makes up most of the magnetic flux in the heliosphere and that geomagnetic activity depends on that flux.

‘Large-Scale’ Fields are also a Precursor

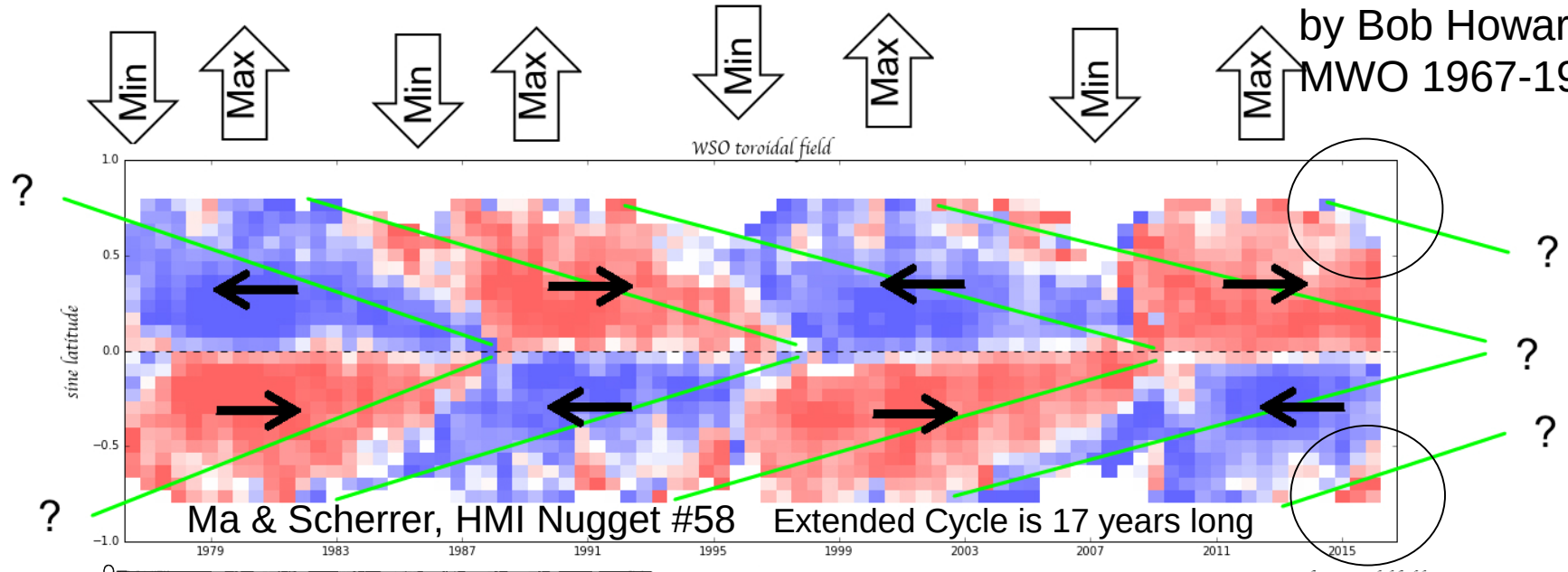




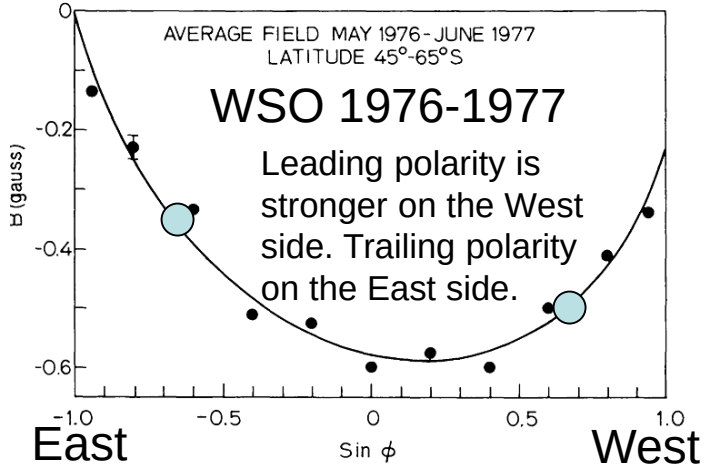
Assign fields of +1 and -1 to areas between neutral lines and calculate the global dipole μ1 and octupole μ3 components. They predict the cycle 69 months ahead

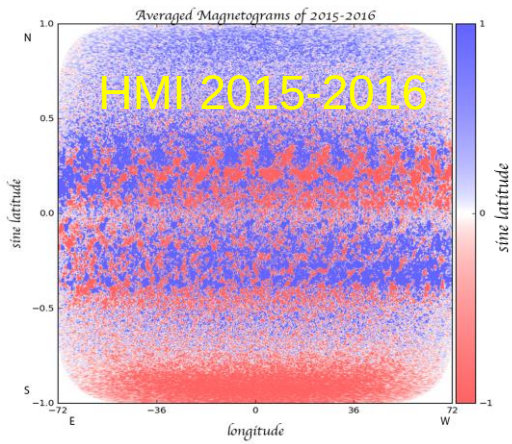
Toroidal Field Shows SC25 has Begun

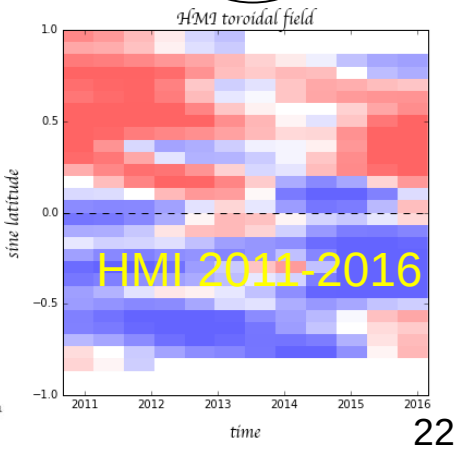
Effect discovered by Bob Howard MWO 1967-1973



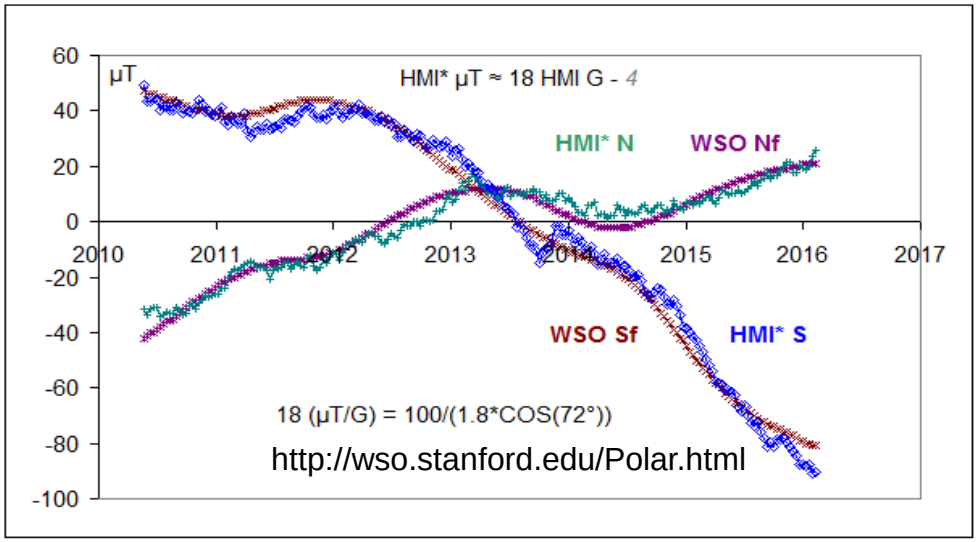
Ma & Scherrer, HMI Nugget #58 Extended Cycle is 17 years long

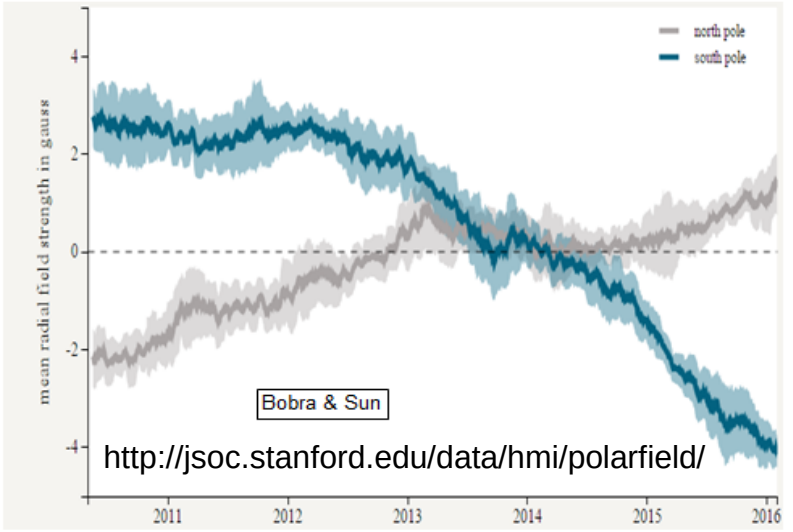






Comparing HMI and WSO Polar Field Data





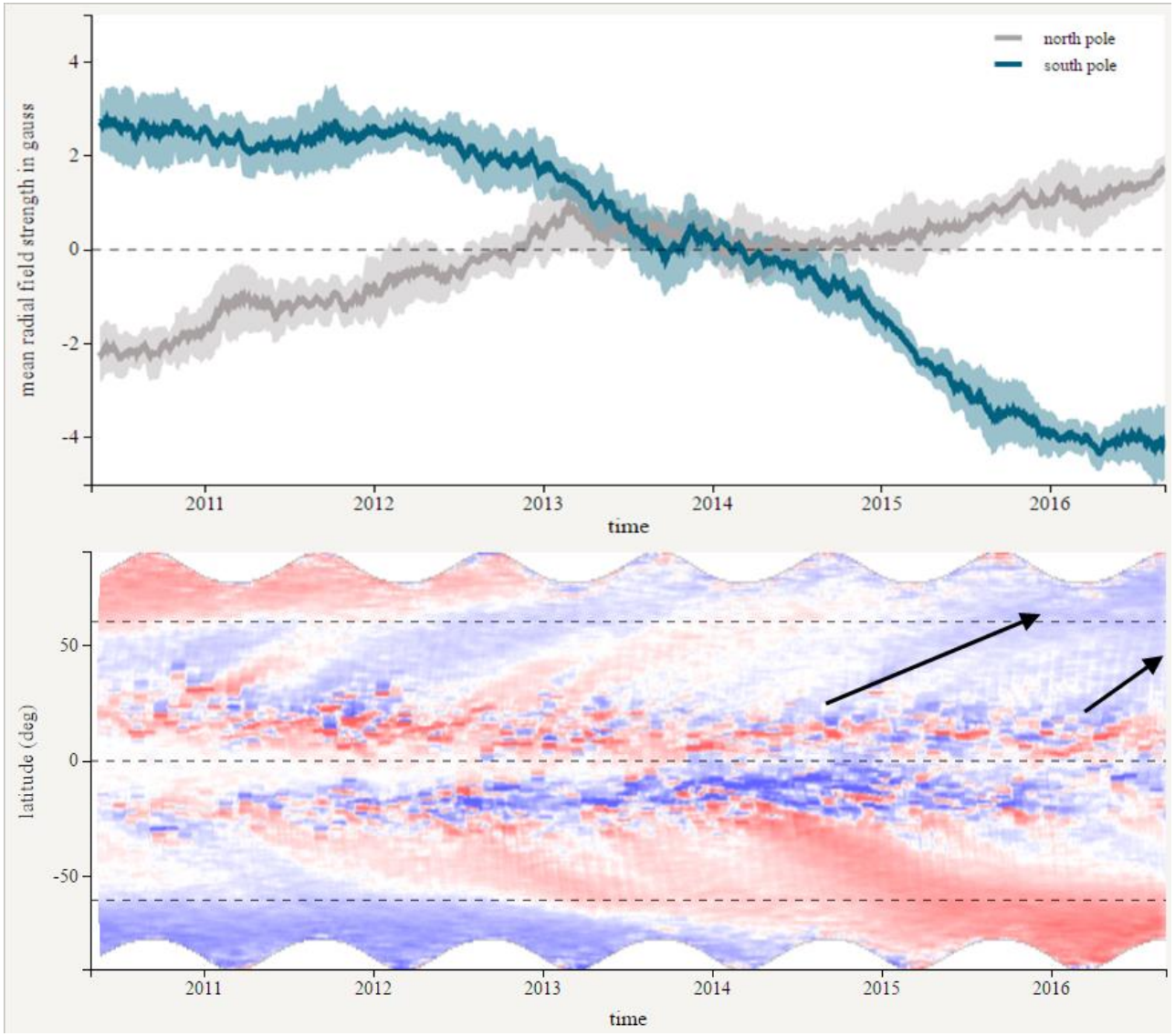
WSO: The pole-most aperture measures the line-of-sight field between about 55° and the poles. Each 10 days the usable daily polar field measurements in a centered 30-day window are averaged. A 20nHz low pass filter eliminates yearly geometric projection effects.

HMI: The raw (12-hour) data have been averaged into the same windows as WSO's and reduced to the WSO scale taking saturation (the 1.8) and projection (the COS(72°)) into account.

HMI: Line-of-sight magnetic observations (*Bl* above 60° lat.) at 720s cadence are converted to radial field (*Br*), under the assumption that the actual field vector is radial. Twice-per-day values are calculated as the mean weighted by de-projected image pixel areas for each latitudinal bin within ±45-deg longitude. A 27.2-day running average is then performed.

Good agreement !

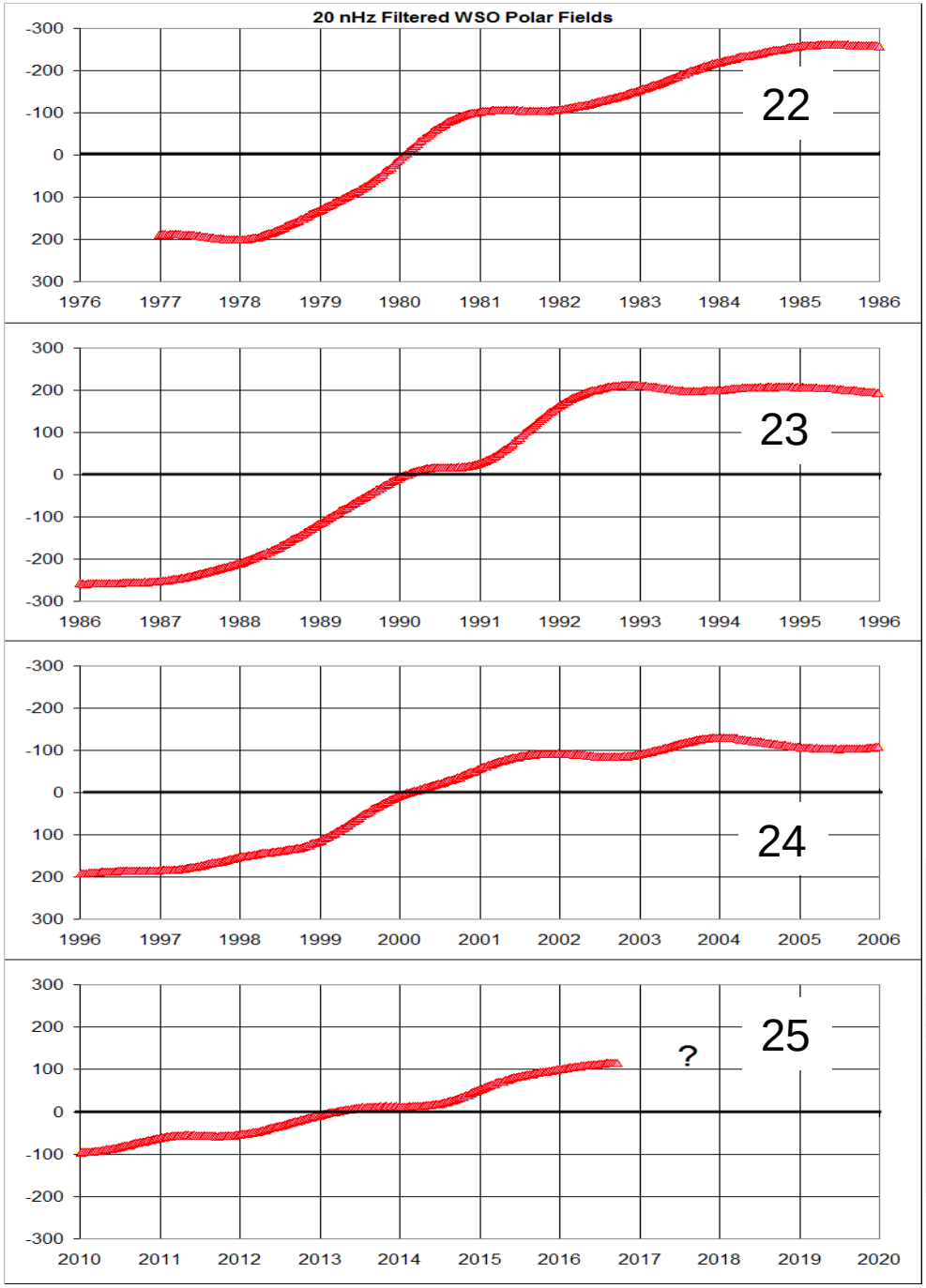
Update of HMI Polar Fields



The south polar fields have now stabilized while the north polar fields are still increasing, with more flux [arrows] in the pipeline on its way to the pole.

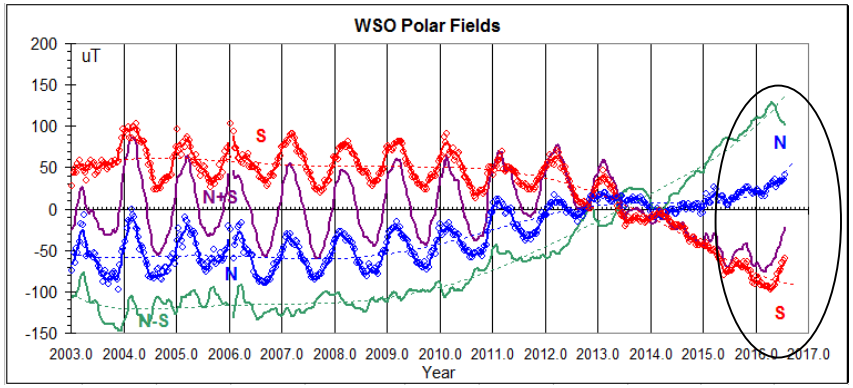
If this holds up, cycle 25 might be stronger than SC24.

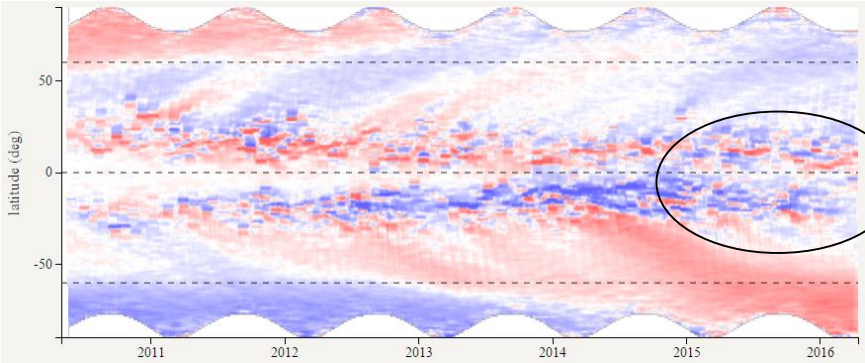
Added 2016-09-10



How Does That Compare with Earlier Cycles?

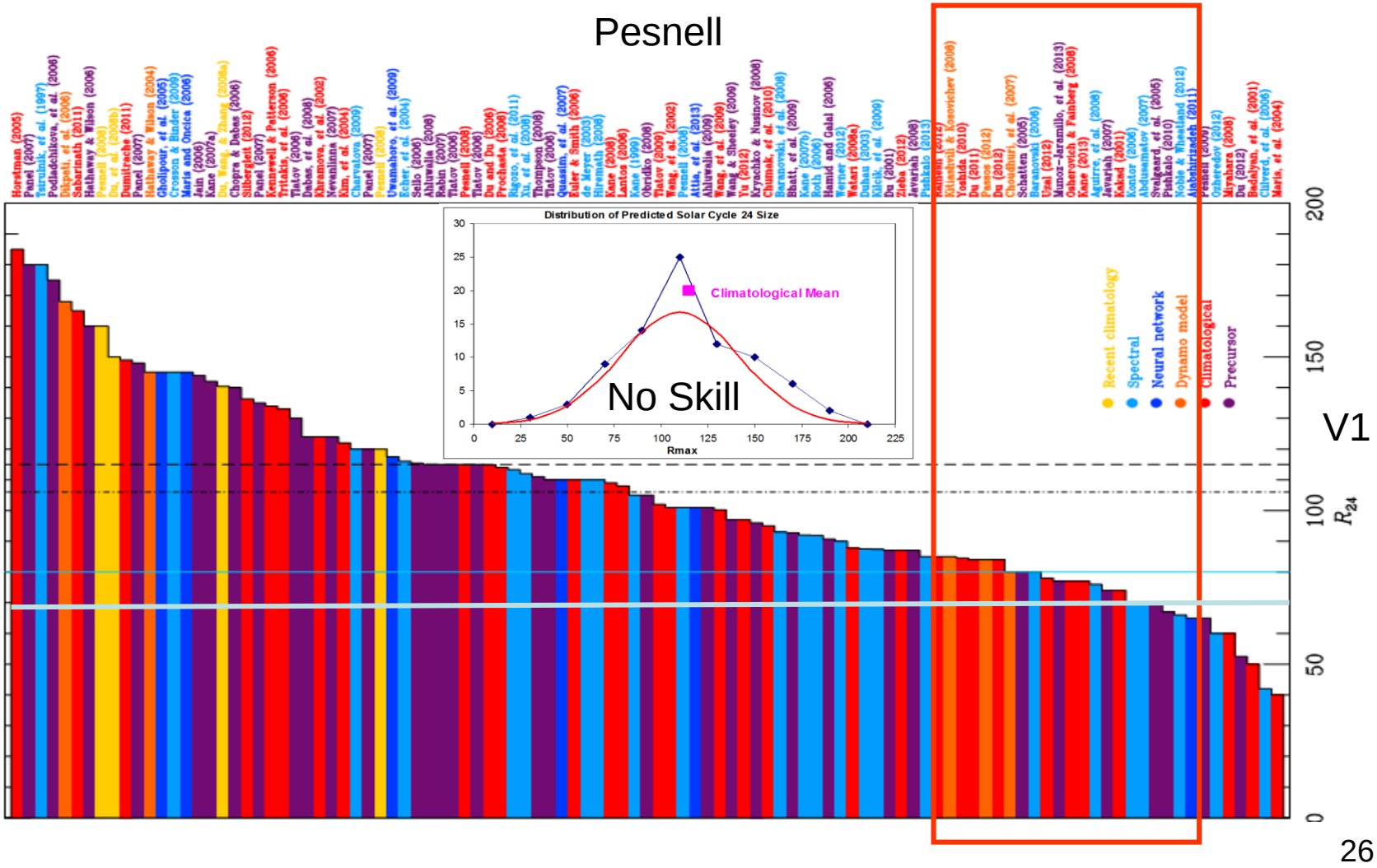
Preliminarily it looks like a repeat of Cycle 24, or at least not any smaller.





Sun & Bobra 2016

How did we do for Cycle 24?



"It cannot be said that much progress has been made towards the disclosure of the cause, or causes, of the sunspot cycle. Most thinkers on this difficult subject provide a quasi-explanation of the periodicity through certain assumed vicissitudes affecting internal processes. In all these theories, however, the course of transition is arbitrarily arranged to suit a period, which imposes itself as a fact peremptorily claiming admittance, while obstinately defying explanation"

Agnes M. Clerke, A Popular History of Astronomy During the Nineteenth Century, page 163, 4th edition, A. & C. Black, London, 1902.

Have we made Progress? Perhaps Some, but maybe not Much. Cycle 25 might give us needed confidence, except we, full of hope, say that for every new cycle…

A society that travels to other planets needs forecasts of the solar activity visible from any point in the solar system several years in advance. Given the wide range of the predictions for the amplitude of Solar Cycle 24 and the many methods that were used to produce them, we look forward to this cycle [25?] answering important questions about how to predict solar activity at the Earth and throughout the solar system (Pesnell, 2016)

The End