Cycle 24: Smallest in 100 years

or

"What we think we know about the sun's polar fields"

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Abstract: We review measurements and estimates of the solar polar magnetic fields over the last half-century and compare the results with the strengths of the sunspot cycles during that time. A new method of estimating the polar fields is introduced. All measurements agree that the polar fields during the current solar minimum are significantly weaker than during the previous several minima. We predict the maximum sunspot number of the coming cycle 24 to be only 75 or ~40% lower than cycle 23.

The Flux-Transport Dynamo Model

Sunspot Areas: proxy for Toroidal Magnetic Flux

A small part of this (1/7) is assumed to be converted to Poloidal Magnetic Flux as the flux is being transported to the poles by Meridional Circulation

The polar fields are being "advected" down to the bottom of the Convection Zone and there join a "return flow" to the equator. While on its way back, the flux is being amplified by Dynamo "action" and some of it is converted back to Toroidal Flux
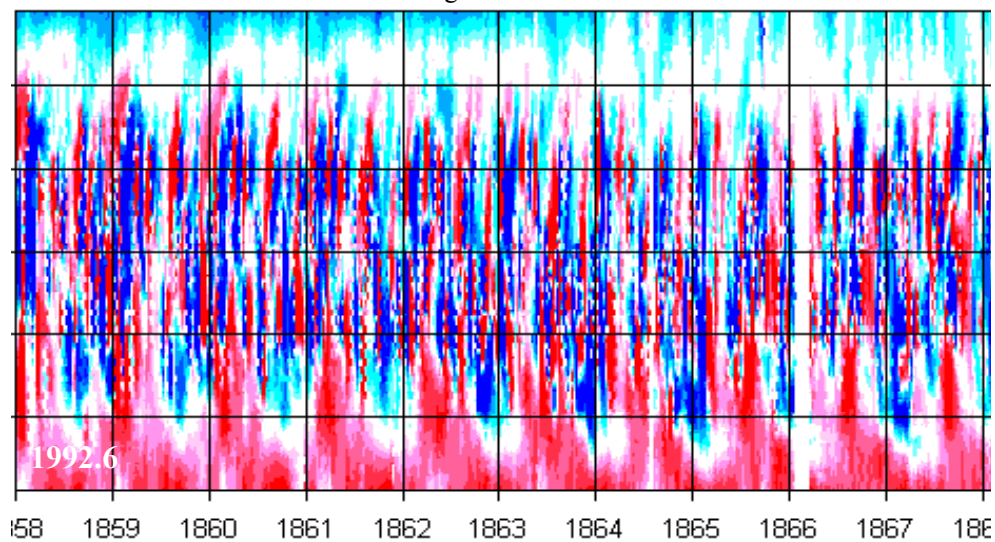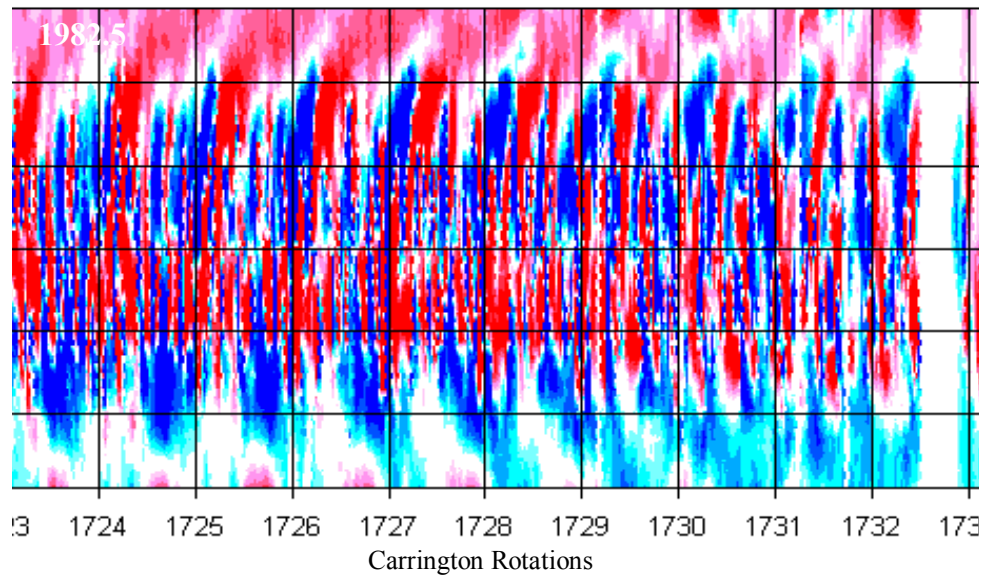
The newly appearing Toroidal Flux is buoyant and rises to the surface and collects there into sunspots, closing the cycle

The whole cycle is supposed to take a long time (17-40 years) meaning that several solar cycles' worth of polar fields are involved and stored up as the sun's "magnetic memory"

The Polar Fields may be Key to the Dynamo mechanism.

In this talk we shall summarize what we think we know about the sun's polar fields

Super-synoptic charts of magnetic field measured at WSO.

1982.5

| 1724 | 1725 | 1726 | 1727 | 1728 | 1729 | 1730 | 1731 | 1732 |

Carrington Rotations

| 1859 | 1860 | 1861 | 1862 | 1863 | 1864 | 1865 | 1866 | 1867 |

1992.6

Flux of *both* polarities are transported towards the poles. But only one polarity "makes it". The resulting polar cap magnetic flux is less than 1/1000 of the total flux erupting during the solar cycle, equivalent to only a handful of active regions.
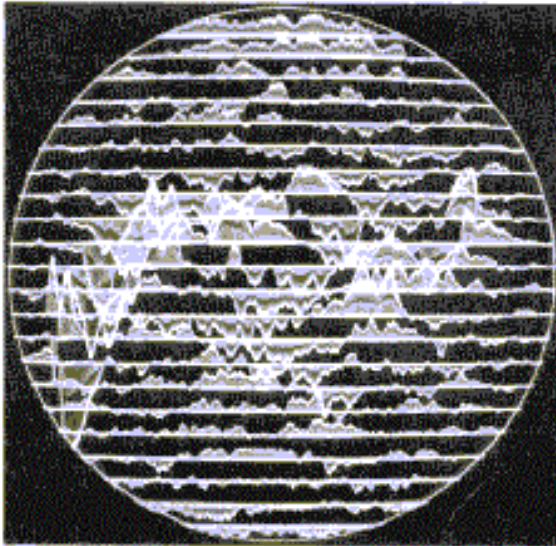
MWO magnetogram ca. 1953 by the Babcocks.

The scale is such that the distance between the lines corresponds to 2 Gauss (200 microTesla [uT]) at the limb.

Note the strong (~150 uT) fields in the polar caps.
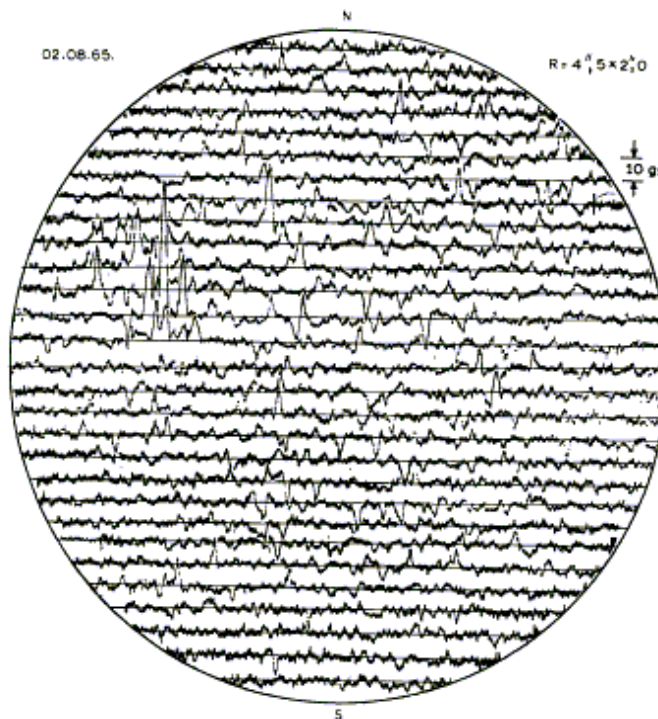
Crimean Astrophysical Observatory magnetogram 2 Aug. 1965. Distance between the lines corresponds to 10 Gauss (1000 microTesla [uT]). Note the weak (<100 uT) fields in the polar caps.
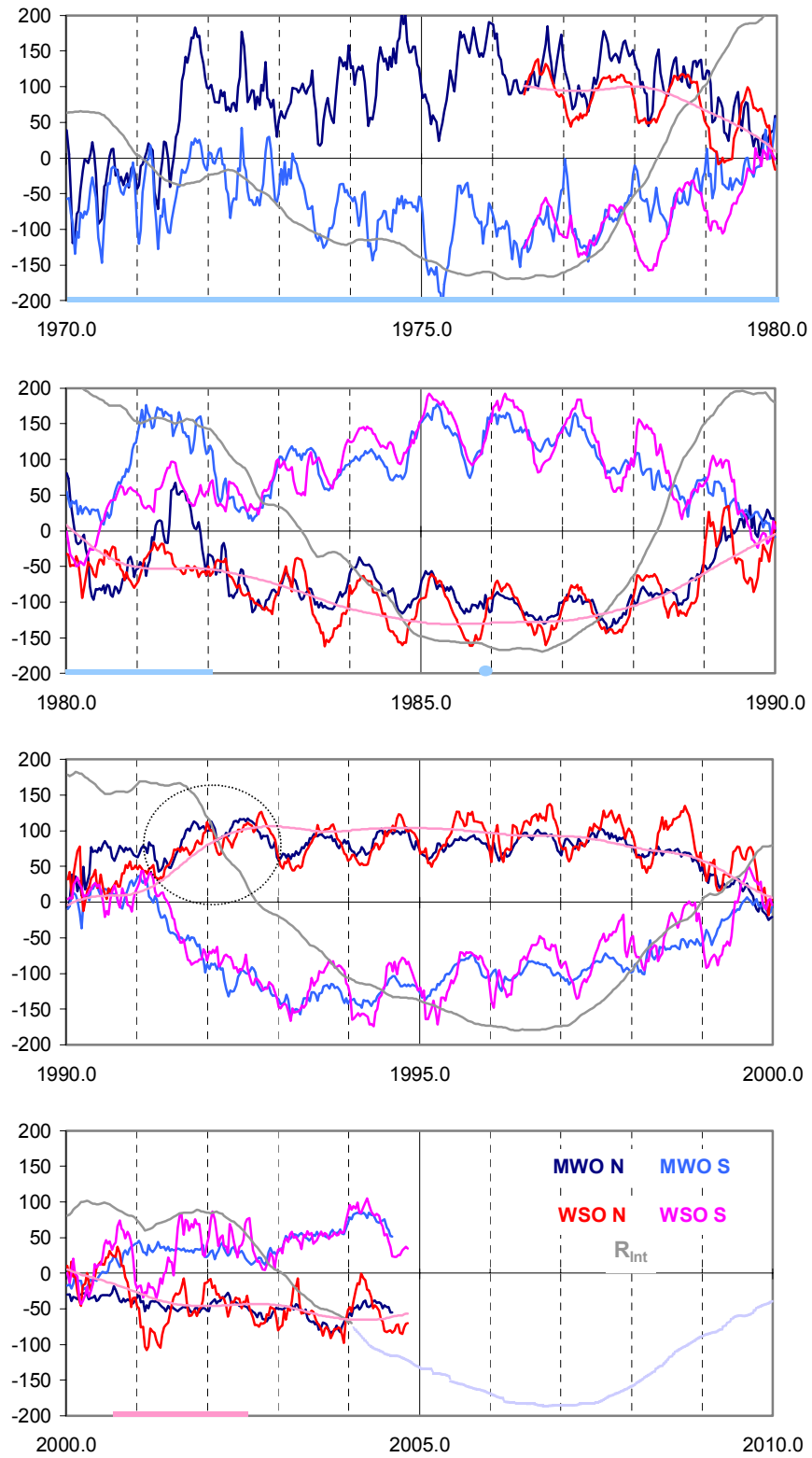
Polar fields observed at MWO and WSO 1970-2004.

About three years before the minimum the polar fields show a strong annual modulation (by a factor of two) lasting until the next reversal. This is due to the field being concentrated near the pole combined with the annual "tipping" of a pole to and fro by the 7 degree tilt of the sun's rotational axis. In March we see the South polar region best and in September we see the North polar region.

What about the polar fields observed at MWO before 1970?
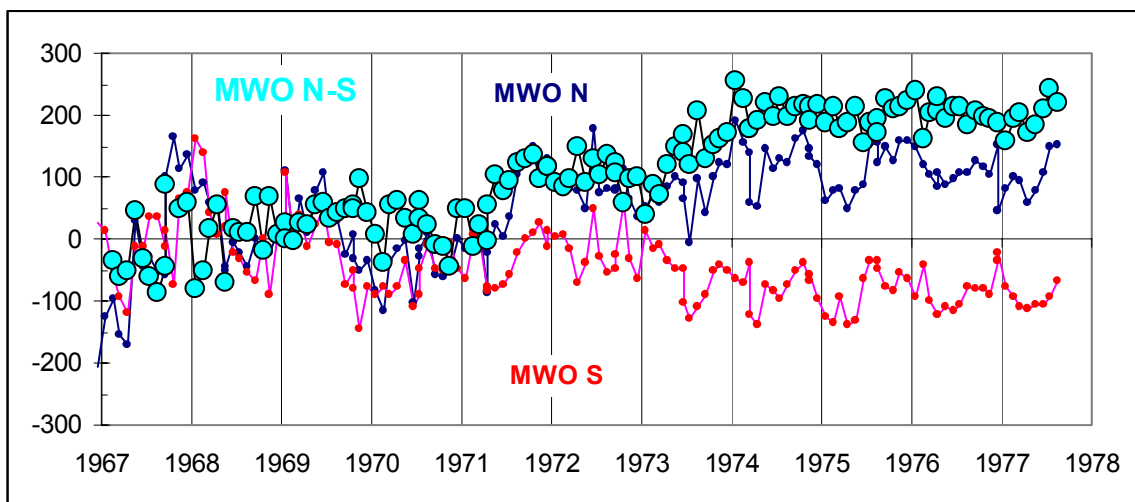
The MWO data before the polar field reversal in 1970 was very noisy with significant zero-level errors. The *difference* between the North polar fields and the South polar fields is less sensitive to zero-level errors. It seems that the polar fields 1967-1968 are weak, consistent with the fields being weak for the minimum before cycle 20.

What does the polar fields look like leading up to the coming solar minimum? The annual modulation has started in earnest as shown here by the WSO data (up to last week).
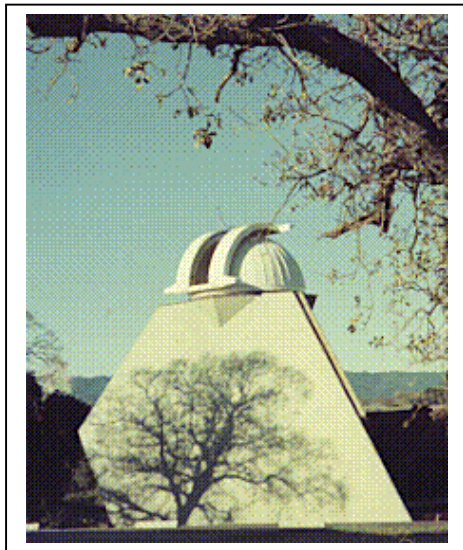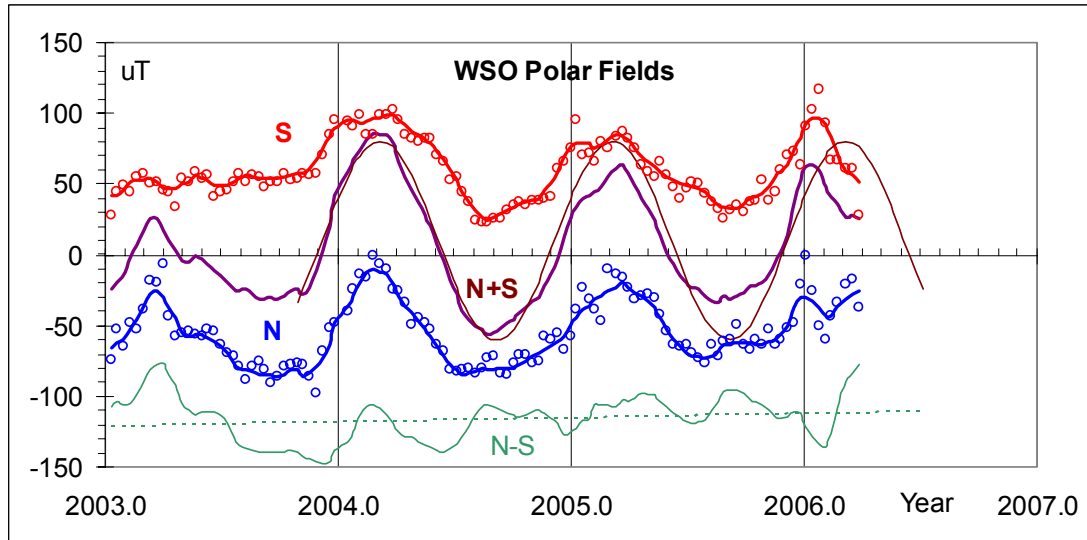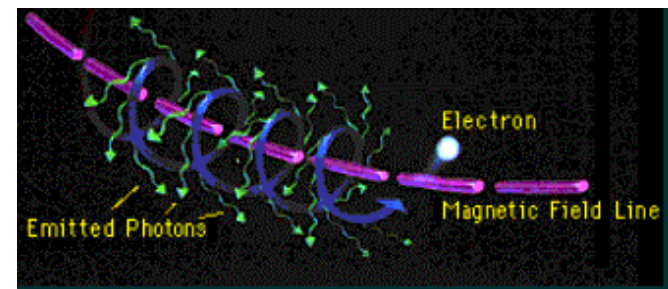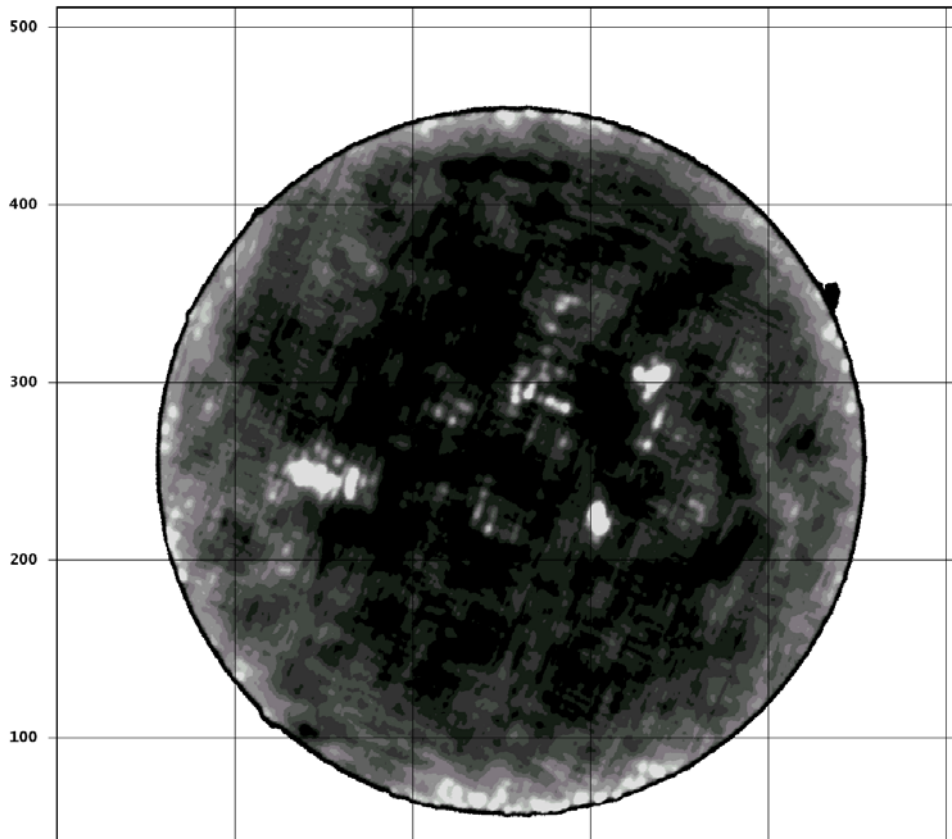

WSO Wilcox Solar Obs.
Good weather=good data
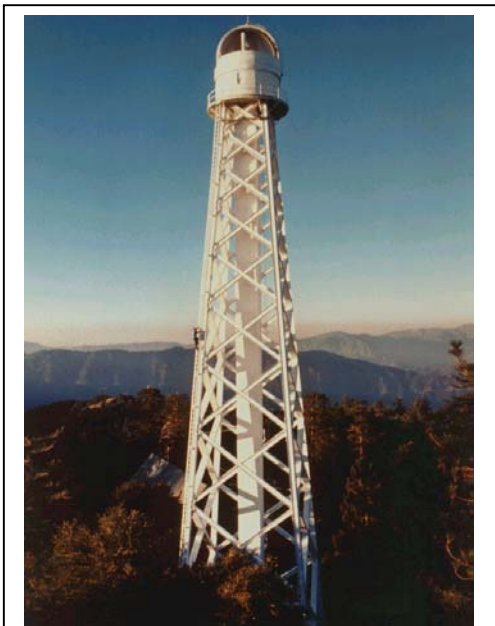
MWO Mt. Wilson Obs.

"And now for something completely different…"

Magnetic Fields from Radio Astronomy…
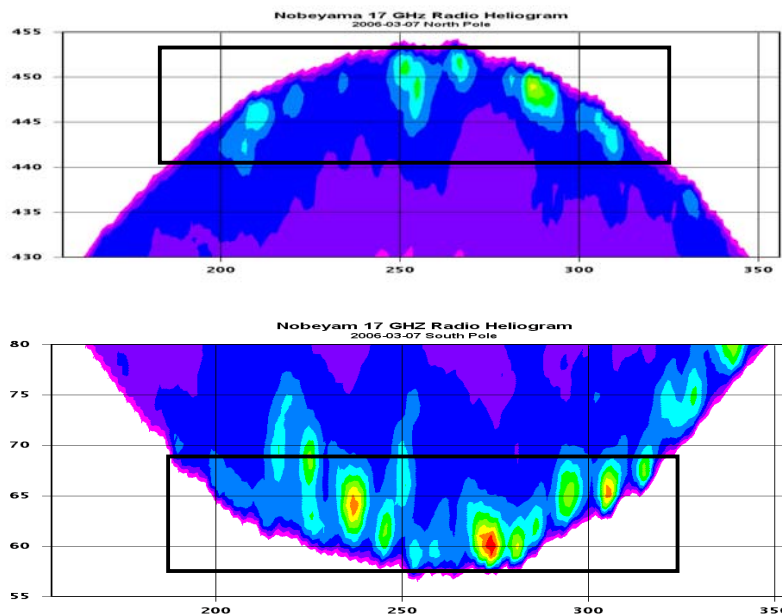

Nobeyama 17 GHz Radio Heliogram
2006-03-07

Nobeyama (Japan) Radio Heliograph operating at 17 GHz = 1.76 cm covering 1992 to the present.

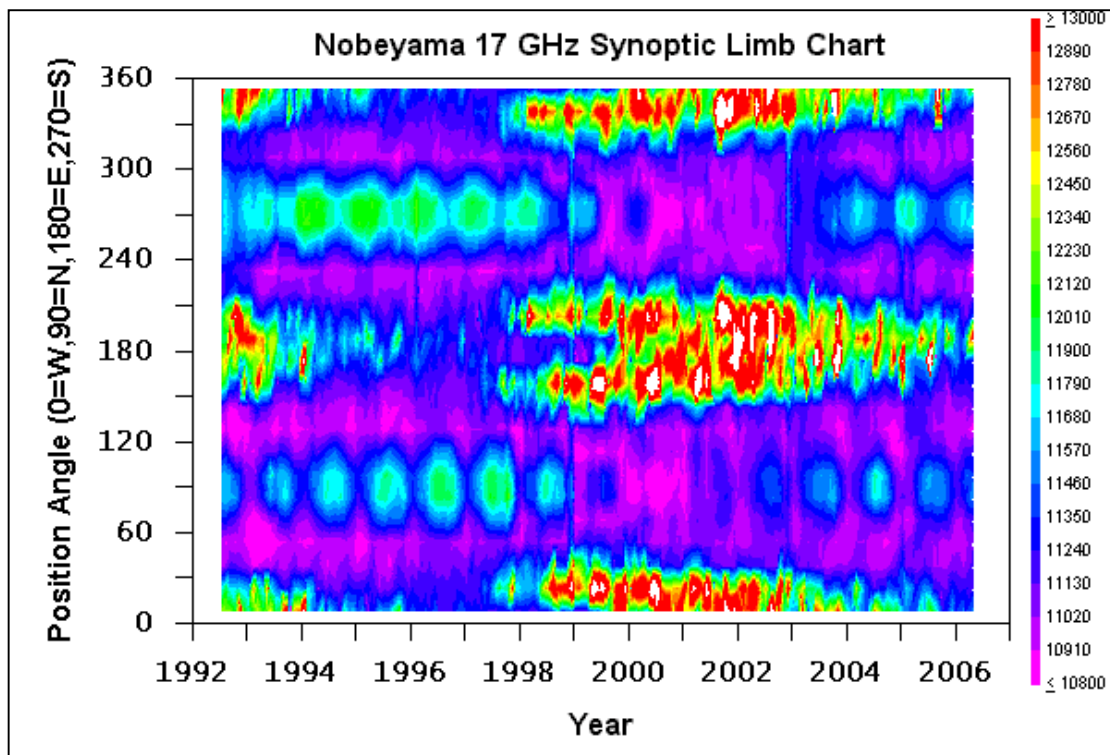The limb is **bright** with brighter patches where the magnetic field is strong.

Active regions on the disk are also visible.

Close up of Northern and Southern polar regions

Here is how the patches evolve over time. Note the annual modulation and also the usual active region areas.

The bright patches are locations of strong *magnetic* fields. Brightness integrated over WSO aperture correlates strongly (correlation coefficient R = 0.88) with strength of magnetic field measured over the aperture (averaged over a rotation). Note the clustering for data near the current and the previous solar minima.

Correlation WSO Polar Field - Nobeyama 17 GHz Temperature

$R^2 = 0.7709$

WSO

Tb
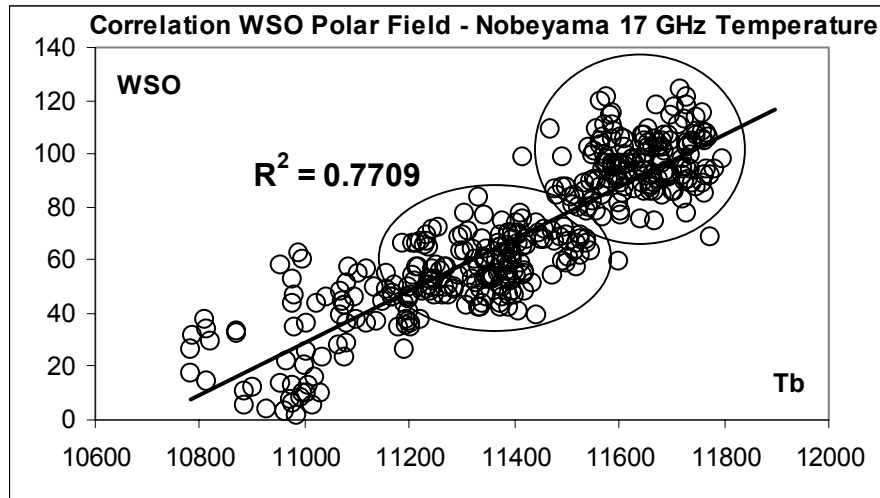
To eliminate the annual modulation we have averaged the North and the South. We can now convert the temperature (using the correlation) to a magnetic field and compare directly with measurements from WSO and MWO:

Magnitude of Solar Polar Fields

WSO microTesla

0.78 * MWO

Nobeyama 17GHz 0.115 (T - 10800)

Year
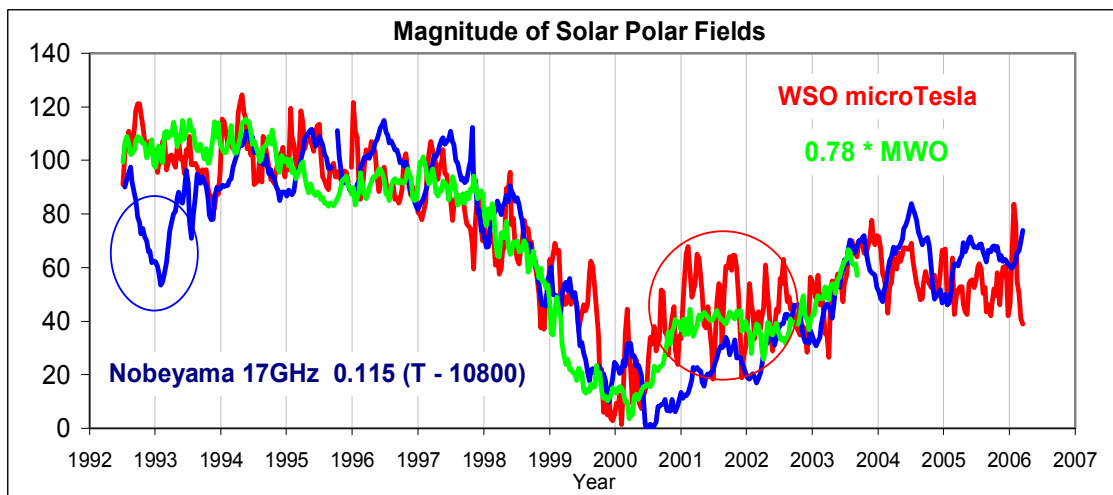
The radio data thus serves as an independent check on the (difficult) optical magnetograph data and confirms the weakening of the polar fields leading up to cycle 24.

The annual modulation rather than being a nuisance gives us an extra degree of freedom and carries additional information. We can compare with the modulation measured at WSO:

Nobeyama 17 GHz Brightness Temperature

WSO Solar Polar Magnetic Field Strength (3' aperture)
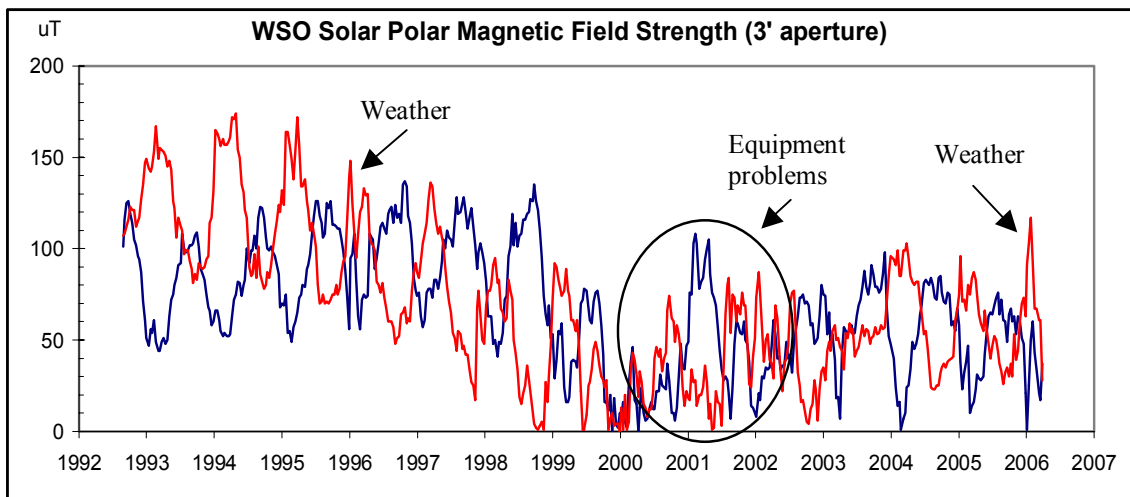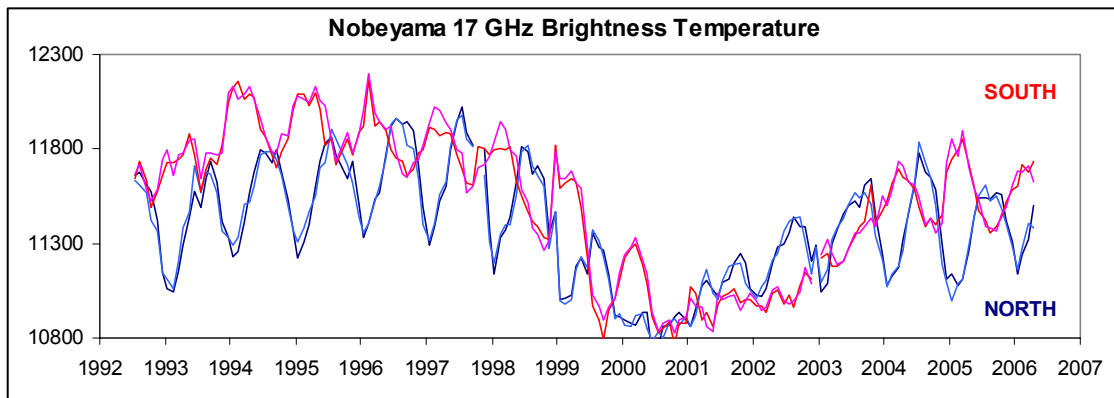
Here are the data since the annual modulation started again, i.e. since the polar fields became well defined and concentrated. First the Radio data:
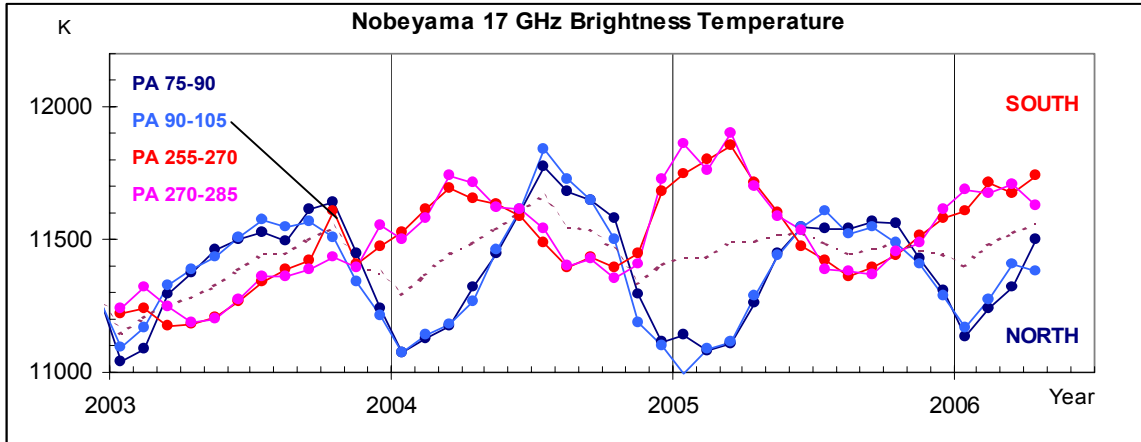

Then the data from three observatories (MWO 10-day, WSO 30-day, and SOLIS daily) adjusted to the WSO scale (WSO reports a 30-day average every 10 days), because of different spectral lines, aperture sizes, and reduction constants (the "fudge factor"):
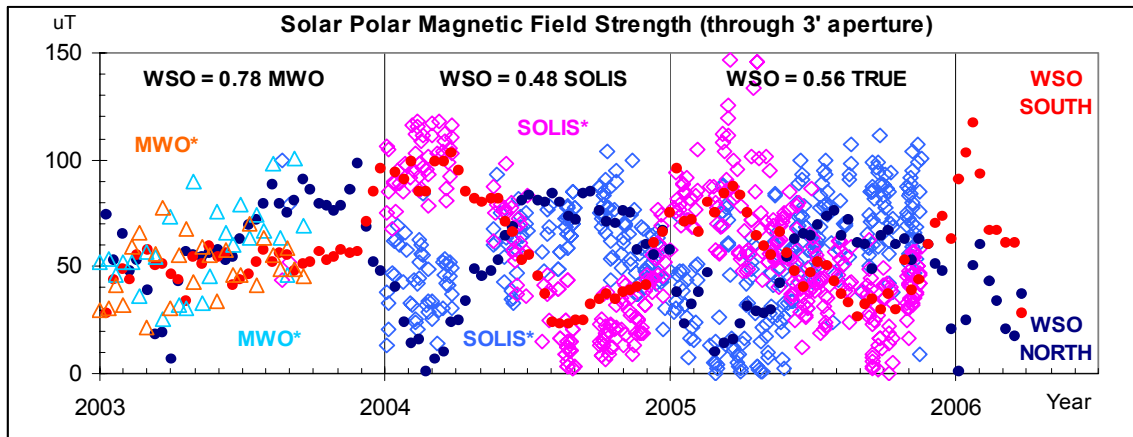
Note how the clean radio signal compares to the optical magnetographs (and the effect of bad weather at WSO in 2006).

Now that we have gained confidence in our measurements of the polar fields and of their long-term calibration, we may summarize their use as a precursor for the cycle strength:
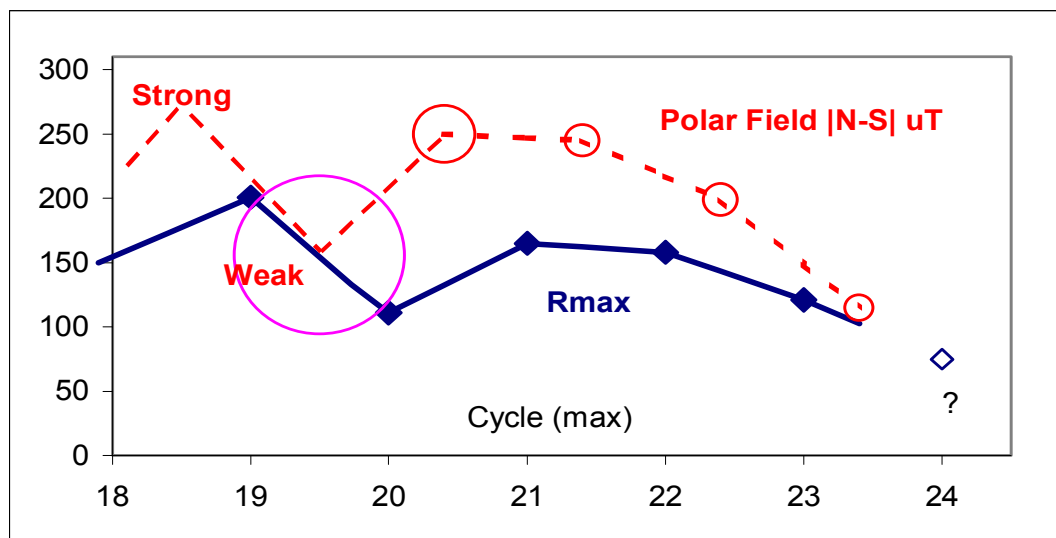
Estimated polar fields at the minima *preceding* solar maxima for cycles 19 through 24. The dark blue symbols show the maximum smoothed sunspot number (Rmax) for each cycle. Polar fields proceeding cycle 20 were very weak and mostly comparable to the noise level of the instruments.

As Charbonneau and Dikpati also observed [ApJ, 2000] "there is a well-defined correlation between the strength of a given cycle and the high-latitude surface magnetic field of a preceding cycle, in qualitative agreement with observational inferences". We have quantified that correlation and used it to predict the strength of cycle 24 based on the observed polar fields.

We describe the sun's magnetic dipole moment as the difference between the north and south polar fields and plot it as a function of time (weaker colors just show a mirror image):
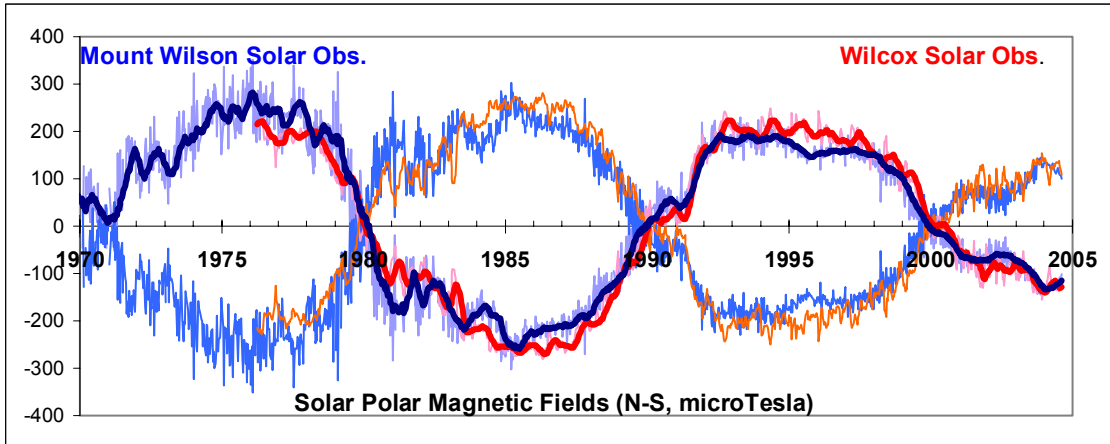
Here we plot the ratio between (the absolute value of) the dipole moment between reversals and the strength (Rmax) of the next cycle. With this normalization every cycle (from reversal to reversal) now looks approximately the same. We find that $Rmax_{24}$ = 75 achieves this nicely. Other values (e.g. the high value 165 in red and 50 in green) would make the current behavior of the polar field very unusual. We subscribe to the principle of uniformity:
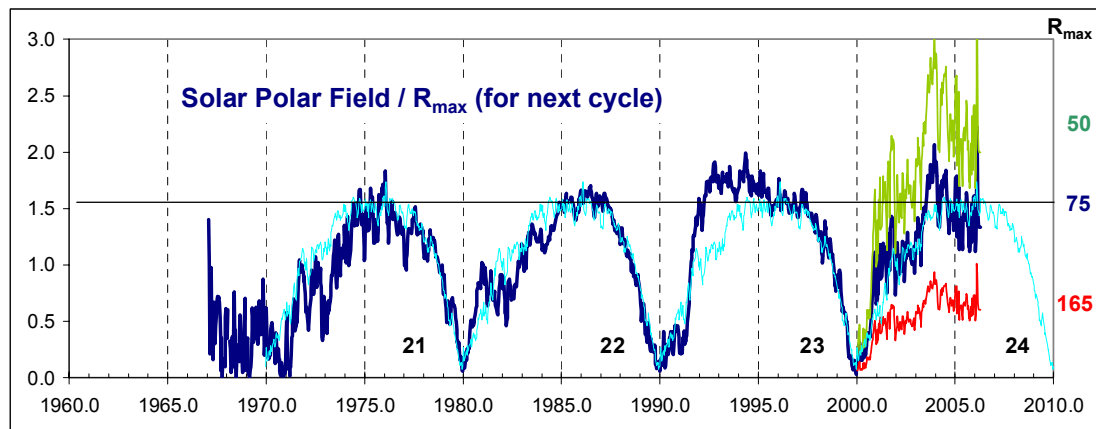
Light blue line is curve for average polar field/ Rmax ratio.

We can compare our prediction with the Dikpati *et al.* (DdTG, 2006) predictions (red areas and lines):
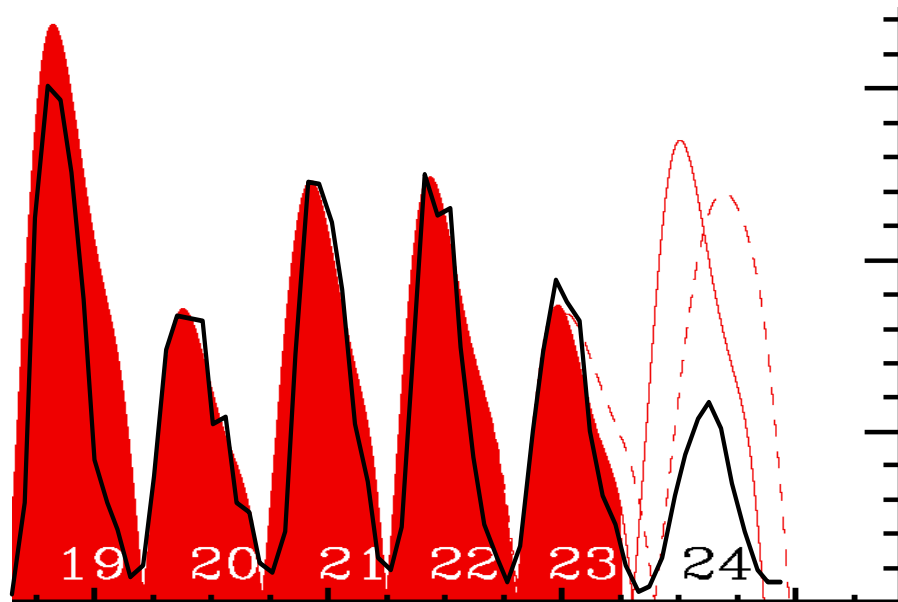
The full black line is observed (smoothed) sunspot number up through cycle 23 and the average of cycles 1, 7, 12, and 16 (all with Rmax~75) for cycle 24.

It would seem that the "50%" prediction having its minimum in 2006.0 has already fallen by the wayside as we are now past that and minimum is still at least a year away, consistent with the persistent claim by the group that the "minimum will be late". We conclude with the following stark comparison:

| Parameter	SC	DdTG "50%"	DdTG "30%"
T min	2007.5	2006.0	2008.0
R max	75	185	165
T max	2013.5	2010.0	2014.0

Polar Faculae

The "bright radio patches" are the elusive Polar Faculae (PF):

1) A PF consists of a collection of (maybe 10) discrete sub-microsecond, strong (0.16 Tesla) magnetic flux tubes all of the same polarity.
2) During polar field reversal PF are few and are of both polarities, otherwise all PF are of the same polarity within a given polar cap.
3) Life times are thought to be short (hours or days only) but this is very uncertain.

Neil Sheeley has attempted to count PF on old MWO white-light plates. He also noted that the PF count seemed to correlate with the polar field. Baffling are the short-lived (1-2 years) "surges" of flux (or PFs at least). It is hard to have a good calibration before ca. 1964.

Here is a plot of his result (suppl. with Russian/Belgian data after 1990). The PF counts have been given a sign equal to the sign of the polar fields and scaled to match the polar fields:


Polar Faculae Count (Sheeley, MWO) and Polar Magnetic Field (WSO)
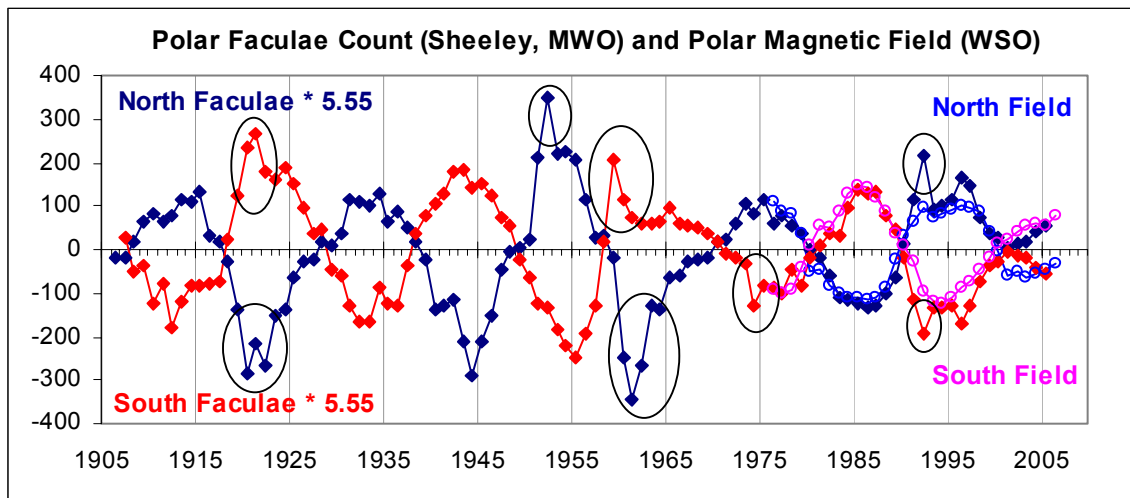
Sunspot Areas

Sunspot areas are often used as a "better" proxy for solar activity. Better because they are more "physical" than the arbitrary Wolf numbers ($R = 10\,g + f$). However, sunspot areas are not well determined; various observers disagree by up to a factor of two. Even if you correlate the observers' data against each other and "scale" them to a common scale (using overlapping values), they still disagree somewhat:
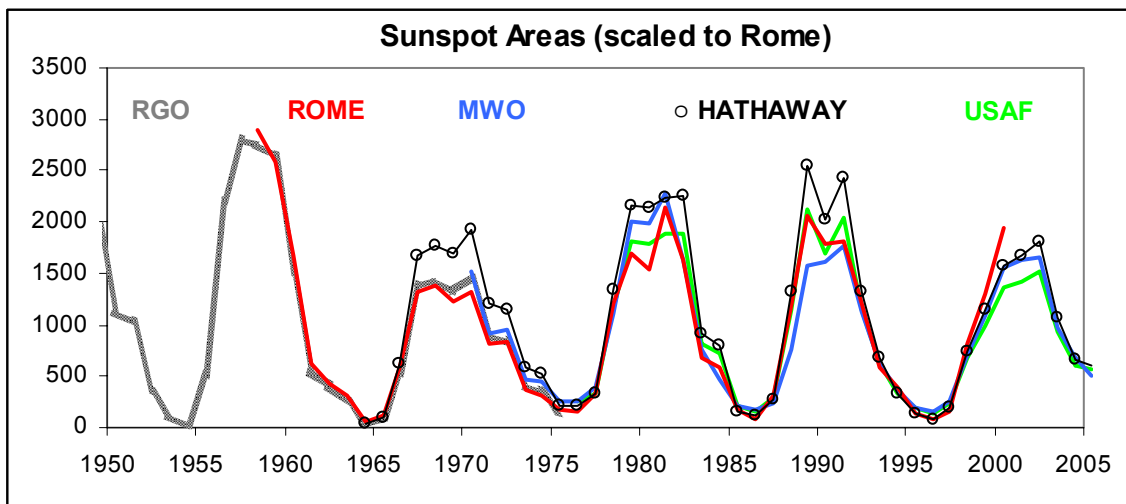
Run the Flux-Transport Dynamo using sunspots instead.
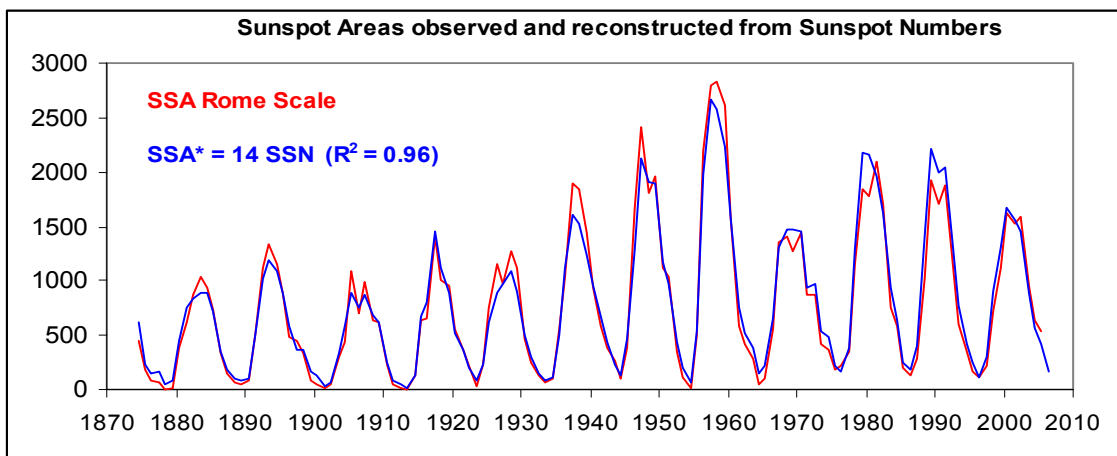
Since the sunspot areas are somewhat uncertain, the model should not be sensitive to small changes in the input. Use the sunspot numbers (or their equivalent sunspot areas) for cycle 1 through 4 to load the "conveyor belt" and see what happens to the "lost" sunspot cycle (between 4 and 5) that has been suggested from time to time (first by Faye in the 19th century). These things should be trivial to try out and might cast light on this interesting problem.

The dynamo model is "completely self-contained and exited with no external sources of flux". "The peak amplitude of the dynamo fields will be the same for all cycles" unless some external "magnetic forcing" (i.e. a proxy of the observed flux) is introduced. So, the prediction of cycle 20 based on cycles 17-19 would give an amplitude that "is the same for all cycles", unless the observed amplitude of cycle 20 is used to "force" the result. It would be interesting to see what the predicted amplitudes of cycle 16 through 22 would be *before* forcing each cycle.

"It cannot be said that much progress has been made towards the disclosure of the cause, or causes, of the sun-spot 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.