Solar Maximum…We Hardly Knew Ye

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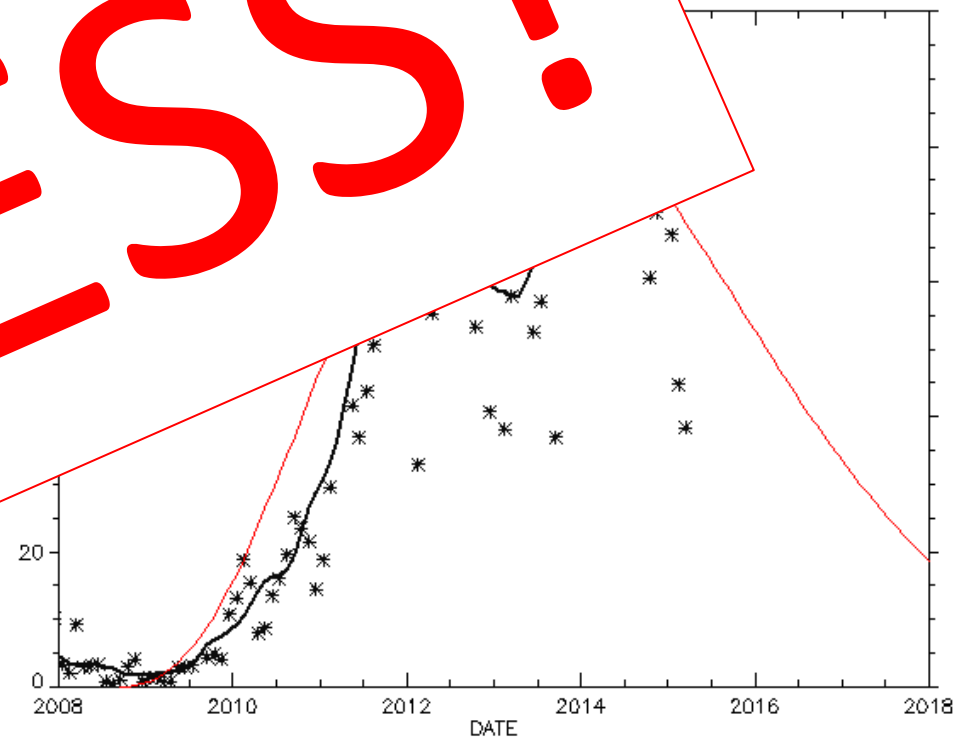
NOAA/SWPC

Image courtesy of Yohkoh SXT

Start with the 2009 Predi[illegible]n

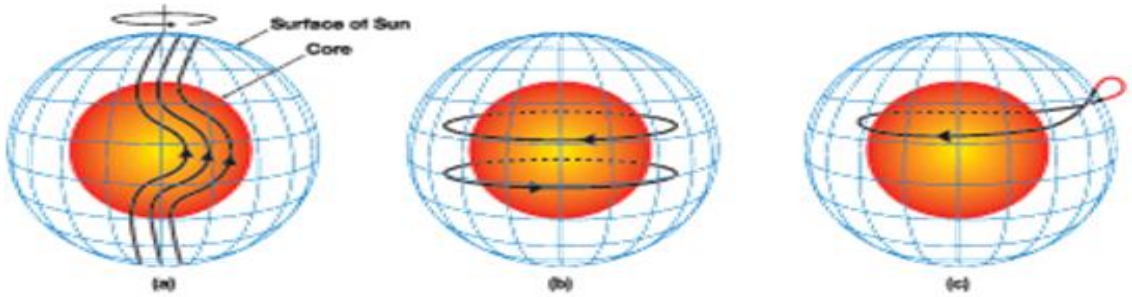
- Forecast was for peak of 90 in May, 2013
- Actual was a peak of [illegible] 2014
  - Within t[illegible]
  - [illegible]
- Su[illegible] cur[illegible] ybe ever[illegible] fitting' the si[illegible]spot number

SUCCESS!



Geomagnetic Precursors

- **Utilize information from the declining phase of a cycle or from solar minimum to predict the intensity of the subsequent maximum**
  - Based in dynamo theory, whereby poloidal field of cycle N is converted into toroidal field of cycle N+1
- **Historically, these techniques have provided the best skill at predicting the solar cycle.**



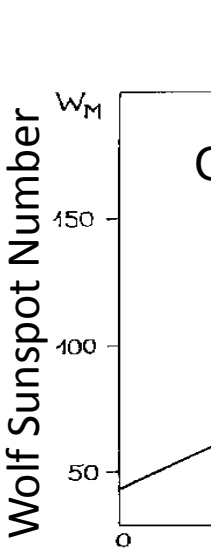
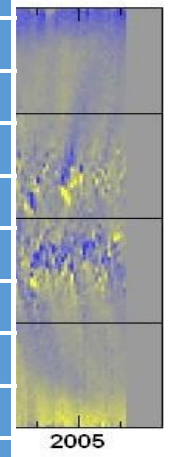


Figure 1. A relation between the indexes of recurrent magnetic disturbances and Wolf's number W_M in the maximum of the next 11-year cycle.

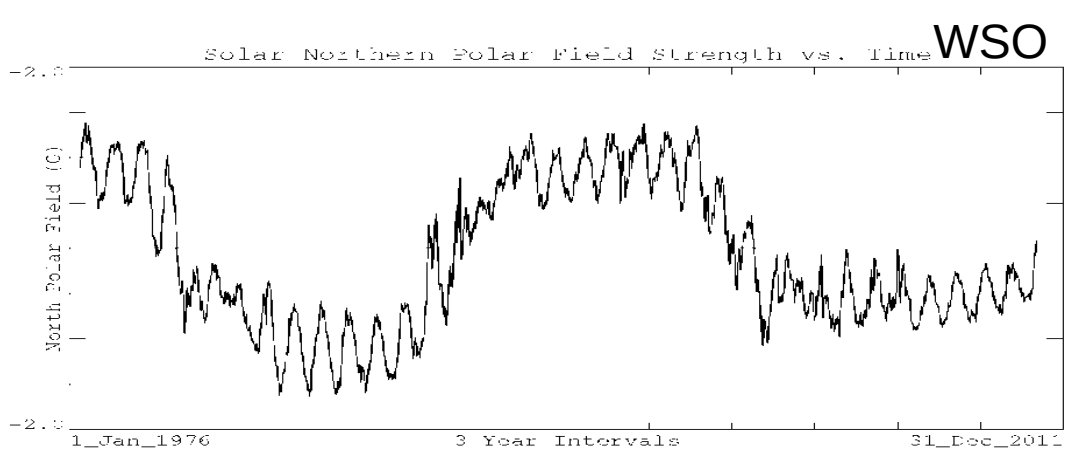
Prediction Method	Cycle 19	Cycle 20	Cycle 21	Cycle 22	Cycle 23	RMS
Mean Cycle	-94.8	-9.1	-53.5	-48.6	-10.1	53.7
Secular Trend	-91.6	8.7	-36.2	-25.3	17.8	46.3
Gleissberg Cycle	-80.4	18.5	-51.6	-51.1	-9.6	49.4
Even-Odd	-59.3		-22.3		61.1	50.8
Amplitude-Period	-74.1	0.3	-61.2	-25.3	9.7	44.7
Maximum-Minimum	-83.9	21.6	-22.9	-15.0	1.8	40.6
Ohl's Method	-55.4	19.1	21.8	4.4	22.2	29.7
Feynmann's Method	-42.8	9.6	26.9	3.6	41.1	29.5
Thompson's Method	-17.8	8.7	-26.5	-13.6	40.1	24.1

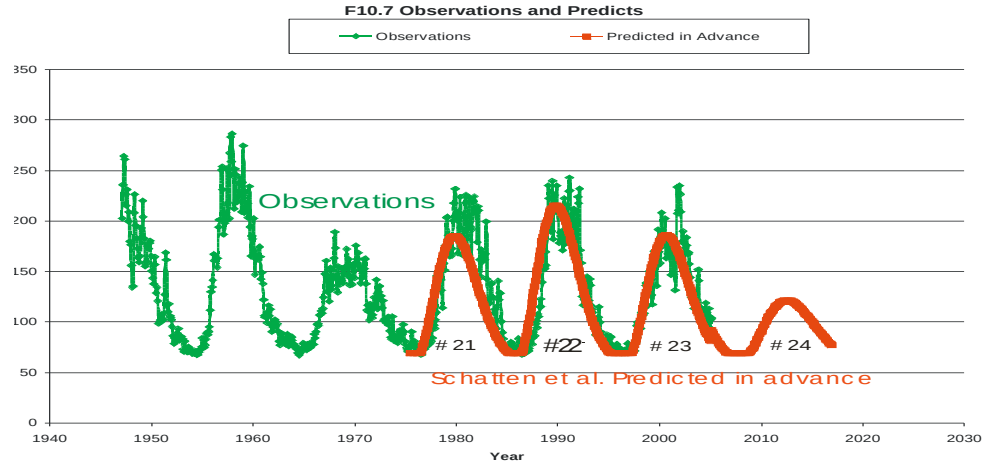


Courtesy D. Hathaway

Polar Field Precursor Methods

- A model calling for a small cycle – short recycle time
  - Skip the ‘proxy’ (geomagnetic disturbances)



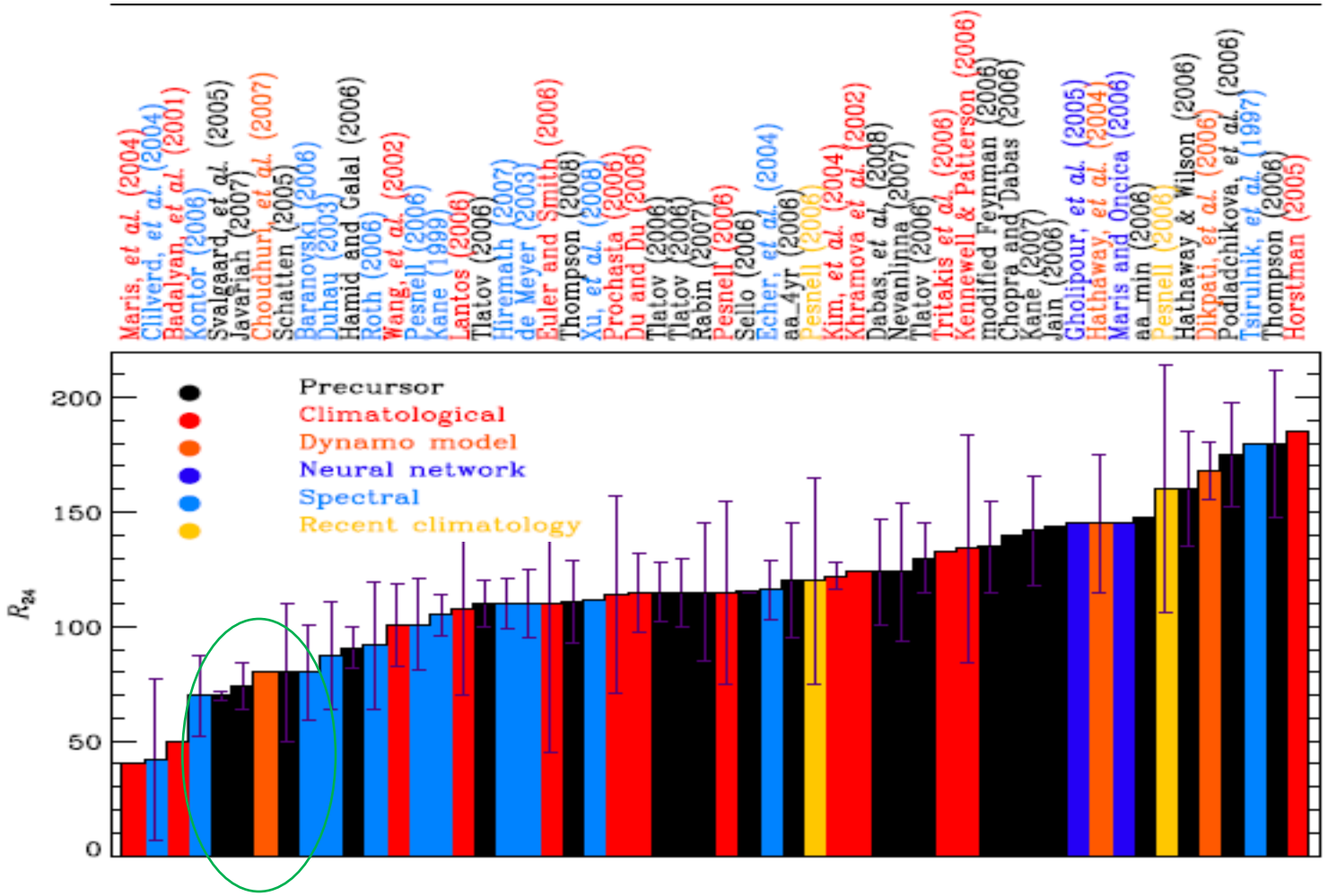


$$\mathrm{SODA} = 60 + 146\left[\left(\frac{B_{pol}}{1.28}\right)^2 + \left(\frac{\mathrm{F10.7} - 60}{146}\right)^2\right]^{1/2}$$

Schatten and Pesnell (1993)

Here's what we started with

- Spectral (S) techniques include Fourier, Wavelet, and auto-regressive analyses
- Precursor (P) techniques look for leading indicators of solar activity



D. Pesnell 2008

Do we have a winner?

The cycle peaked at 81.9 in April, 2014

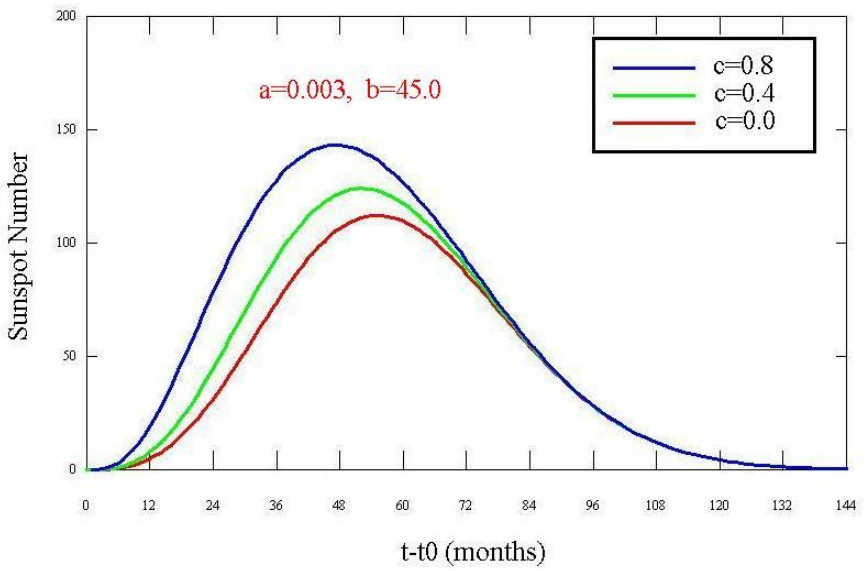
81.9

SSN	Timing	Author	Technique
91.9	1/2011	Roth (2006)	**Spectral**
87.5	-	Duhau (2003)	**Spectral**
80	2012	Baranovski (2006)	**Spectral**
80	2012	Schatten (2005)	**Precursor (polar fields)**
80	-	Choudhuri et al (2007)	**Flux Transport Dynamo**
74	-	Javariah (2007)	**Precursor (sunspot area)**
70	-	Svalgaard et al (2005)	**Precursor (polar fields)**
70	12/2012	Kontor (2006)	**Spectral**

A Functional Form for the Cycle

Fitting the cycle with amplitude *a*, starting time t_0, width *b*, and asymmetry *c*.

$$f(t;a,t_0,b,c)=\frac{a(t-t_0)^3}{\exp\left[(t-t_0)^2/b^2\right]-c}$$



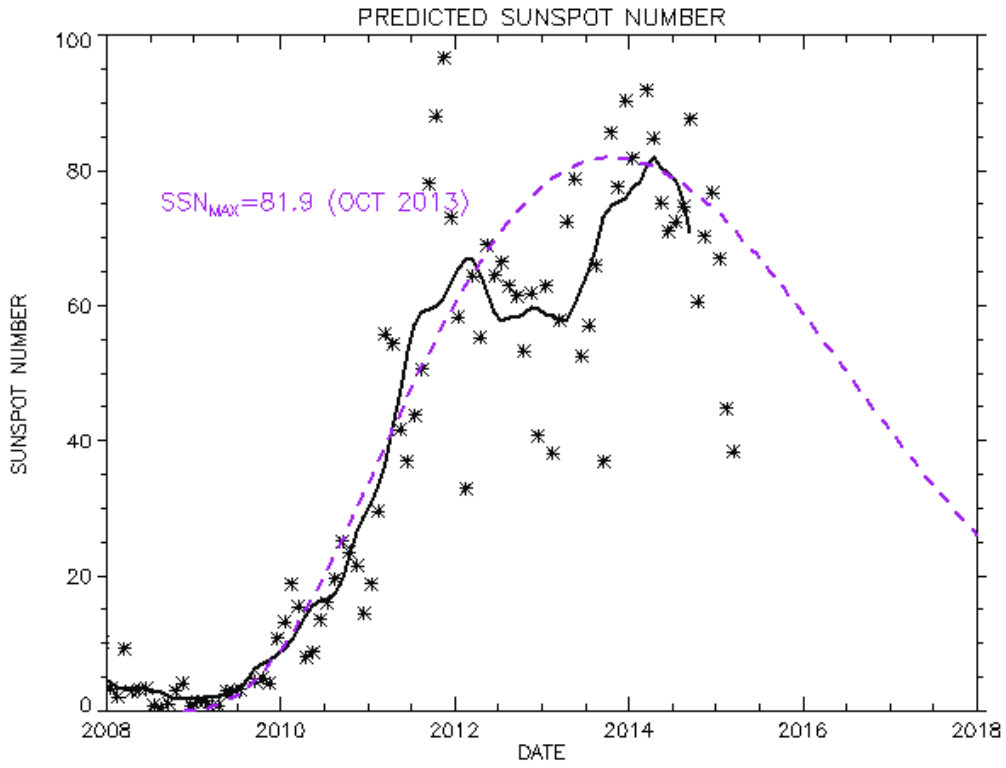
Hathaway *et al*. 1994

Asymmetry is constant (c=0.71) and width varies with amplitude.

Therefore, we need only specify a start time (solar minimum) and a peak amplitude (maximum SSN).

Apply the Hathaway shape using actuals

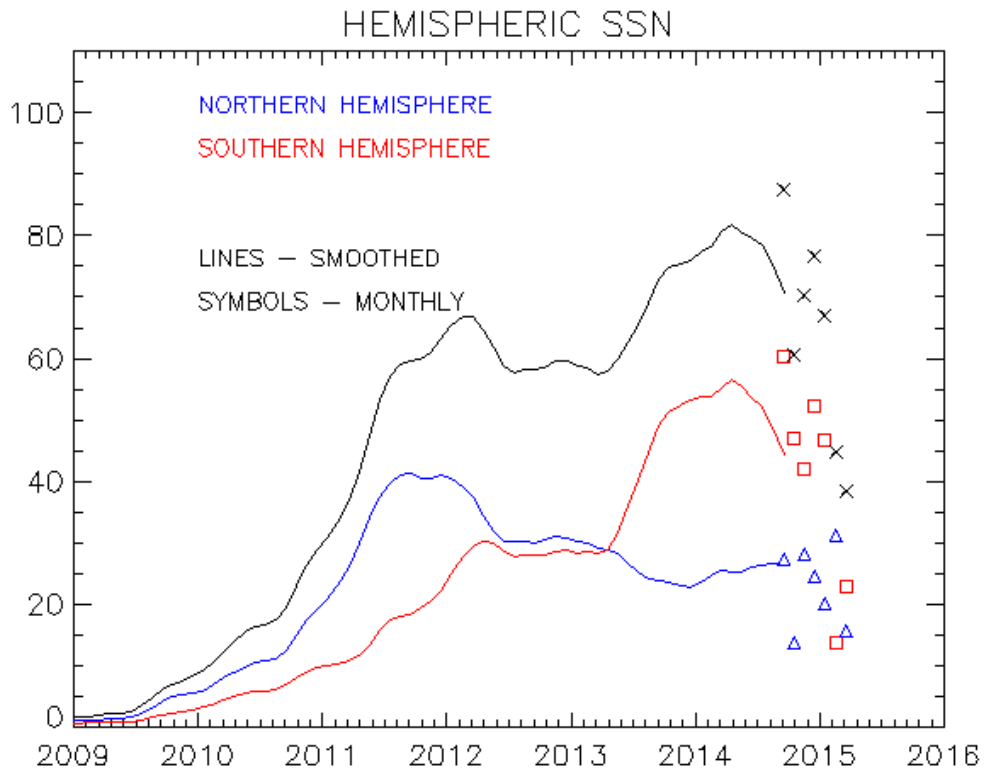
- The purple curve, based on the observed maximum of 81.9 would predict the peak to occur in October, 2013
- Too early but within the prediction panel's error bar (±6 months)
- Fits the rise extremely well, 'misses the peak', but what about the declining phase?
  - Personally, I'm confident about the future.



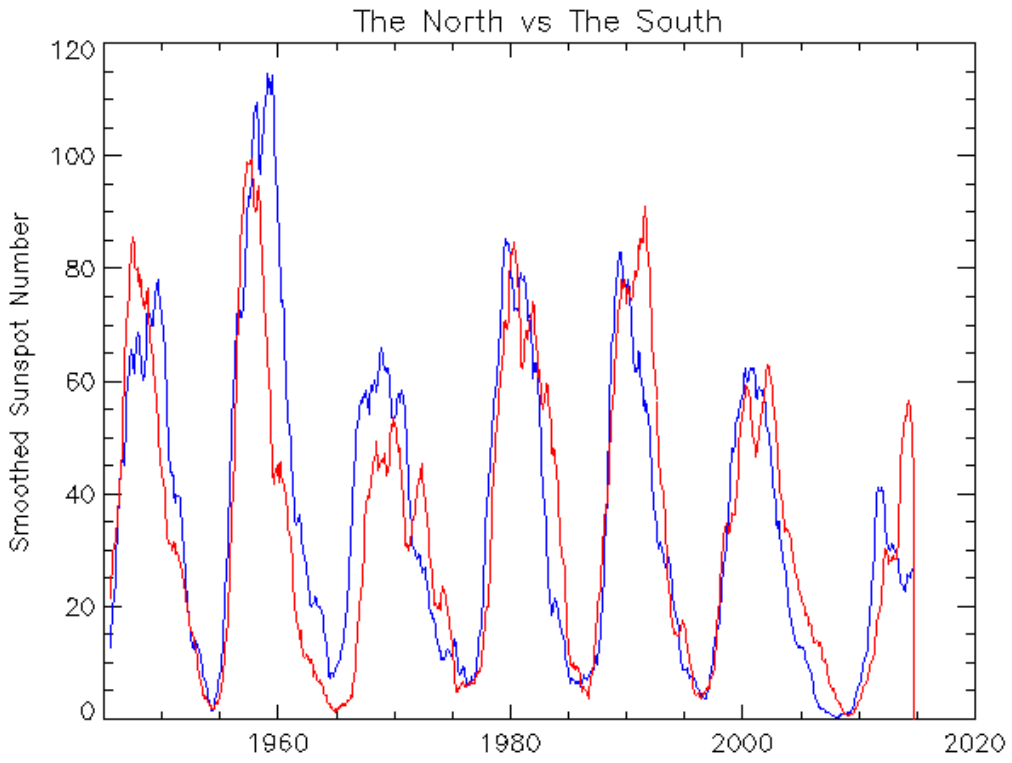
But the forecast assumed one Sun

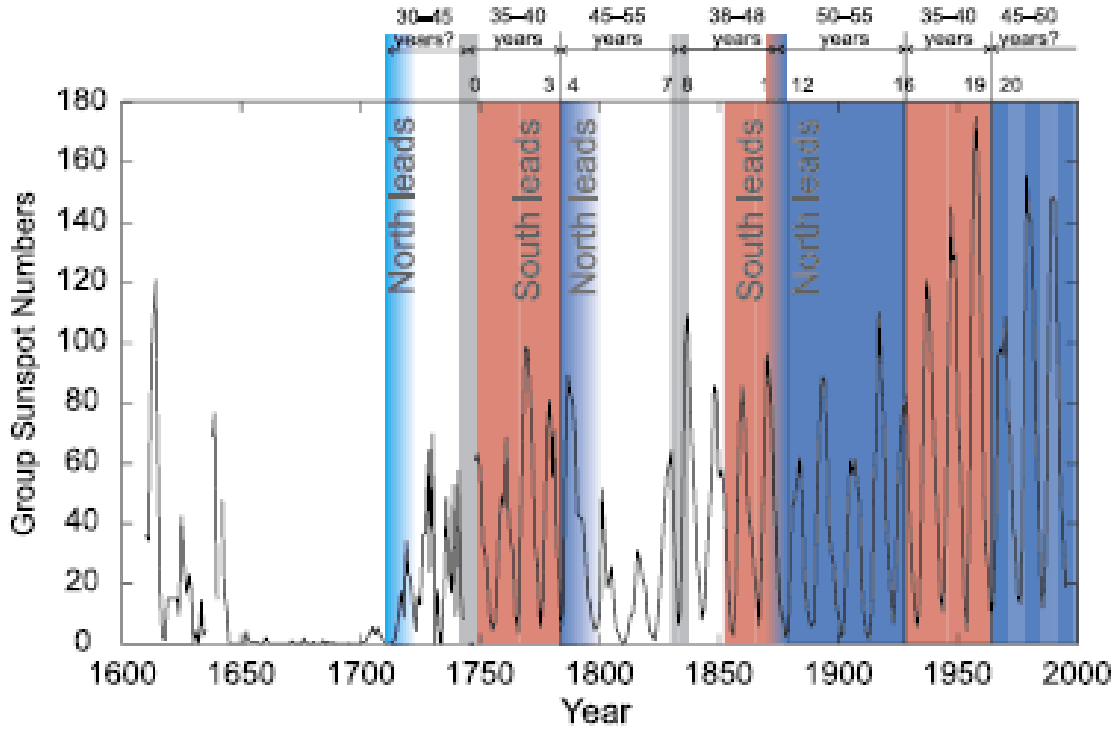
- The panel recognized the hemispheres had to be considered separately
  - Very little data to go on

- Northern hemisphere peak 9/2011 (SSN=41.2)
- Southern hemisphere peak 4/2014 (SSN=56.5)



You have to consider the hemispheres



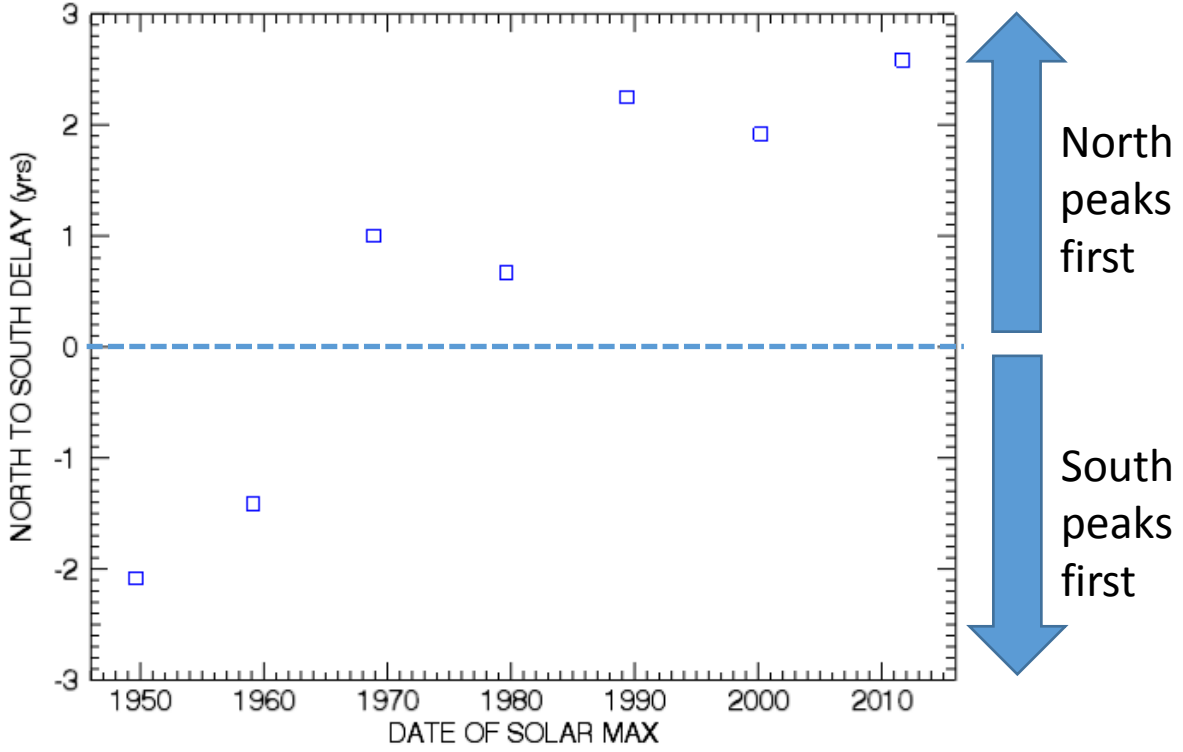


- Apparently the hemispheres can be out of phase rather often.

Zolotova *et al.* 2010

When will the South shift back?

- Plotting difference between maxima of North and South since Cycle 18 shows a relatively constant shift
  - In Cycle 18, South peaked 2 years prior to North
  - In Cycle 24, North peaked 2.5 years prior to South



What Couples the Hemispheres?

- See nice summary in Norton, Charbonneau and Passos (2014)
- Lots of possible mechanisms
  - Magnetic diffusivity
    - Meridional diffusion
  - Transequatorial convective flows
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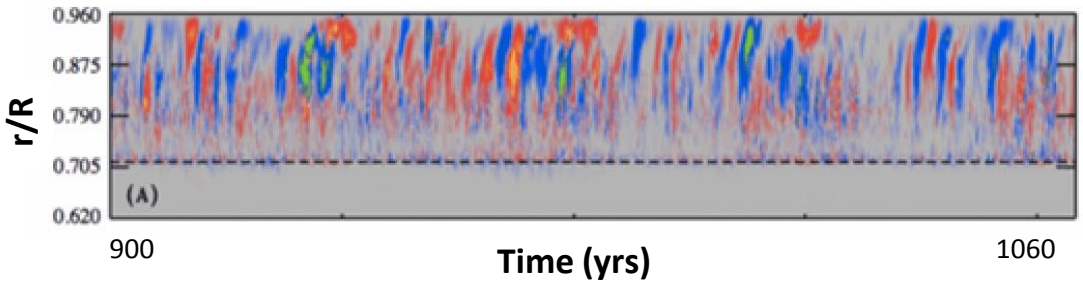
  - Toroidal flux cancellation in the interior across the equator

EULAG-MHD model: Poynting flux



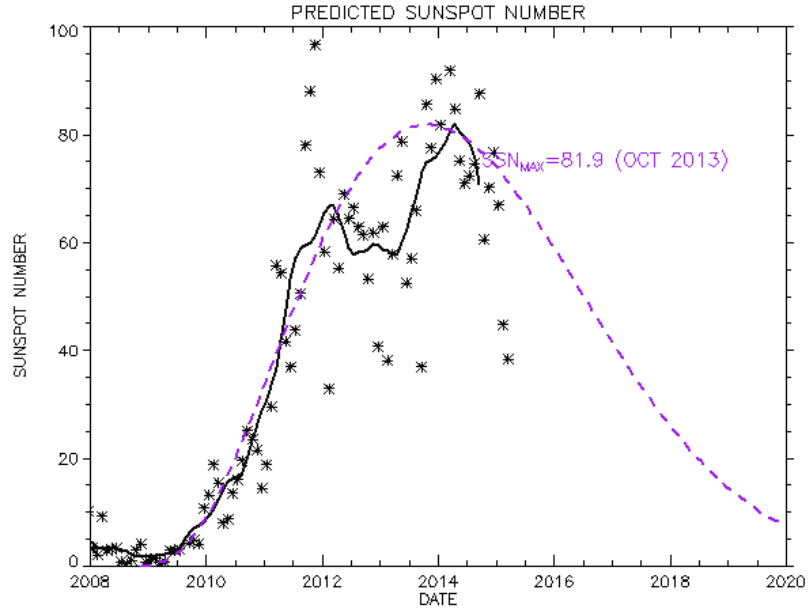
The zonally-averaged latitudinal component of the Poynting flux in the equatorial plane.

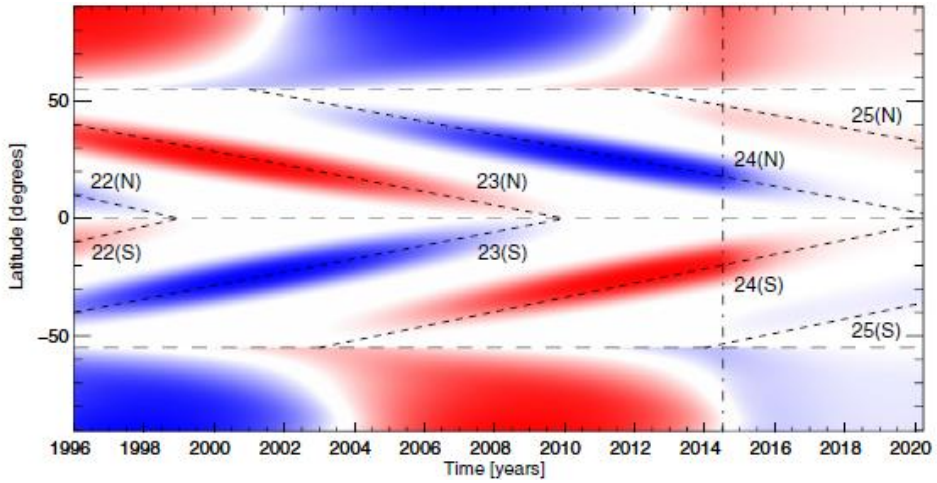
Values (in *red-yellow*) indicates a flux of energy from the southern into the northern hemisphere.

And conversely for negative (in *blue-green*).

What does the future hold?

- Assuming cycle 24 will last 11 years
  - Minimum in Dec 2019
    - we only get down to SSN=8
    - The historical average for sunspot number minimum is 6
- McIntosh and Leamon *2014*
  - Migrating activity bands for Cycle 24 hint at ~2019 for end of cycle
- At least 4.5 more years to Cycle 24?





A Quick Recap

- The solar cycle prediction was pretty good…within error…for peak amplitude.
- Cycle 24 has quite a few years to run
- Predictions of Cycle 25 have to consider it to be a Sun of two halves
  - Can the phase shift be predicted?