Solar Cycle *sic* Maximum
It's Here, Finally

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With input from
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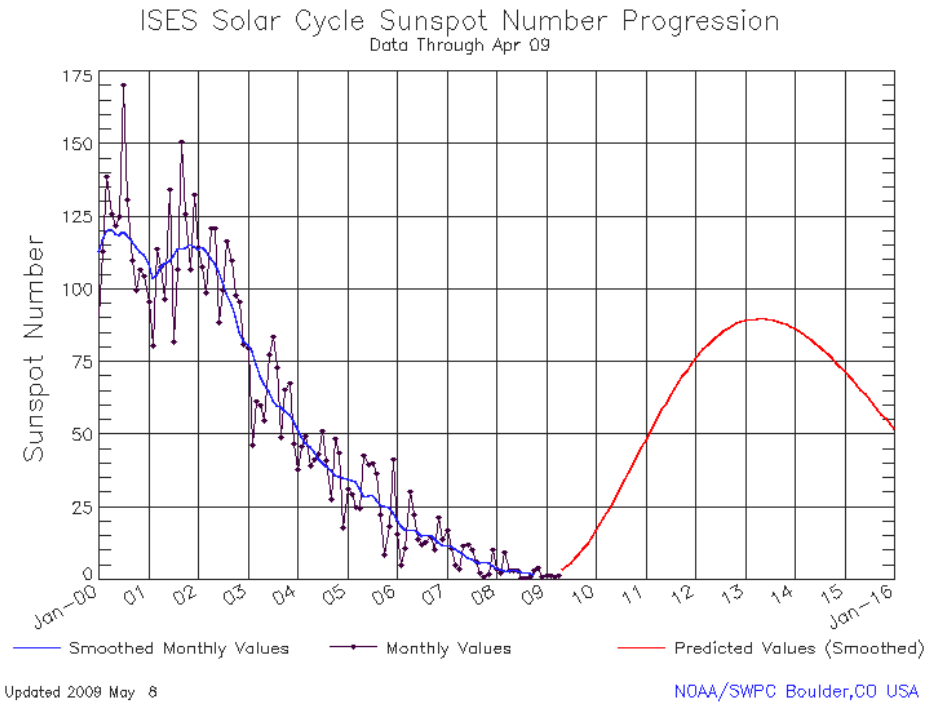
But the heresy is all mine

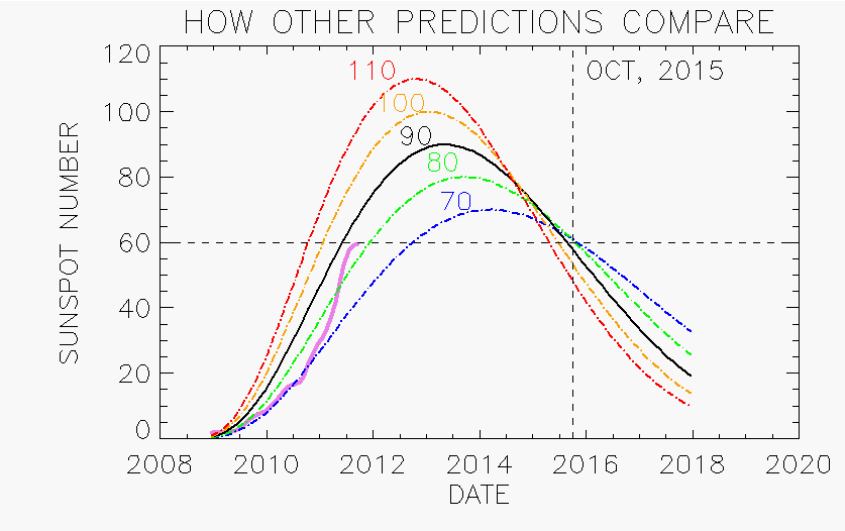
In 2009 we made a prediction

- In 2009, the NASA funded, NOAA chaired, international panel said
  - SSN will peak at 90 in May 2013
  - This is the prediction for the weighted 13-month average



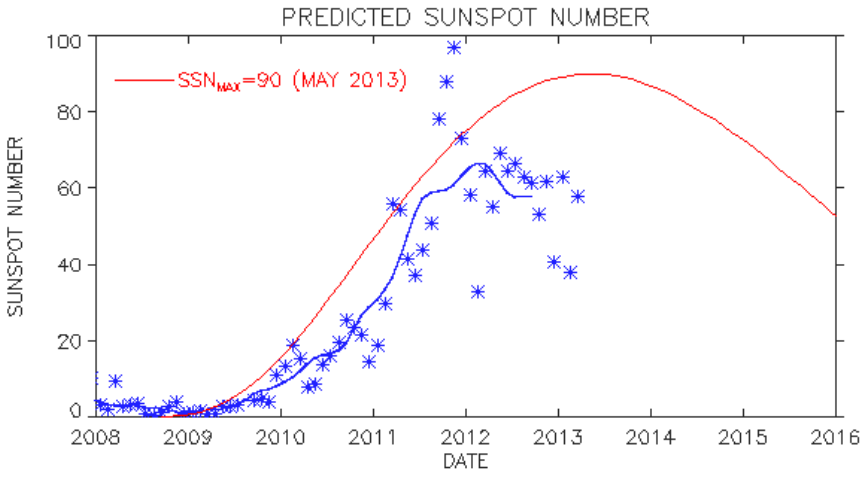
In 2010, 2011, and 2012 we said

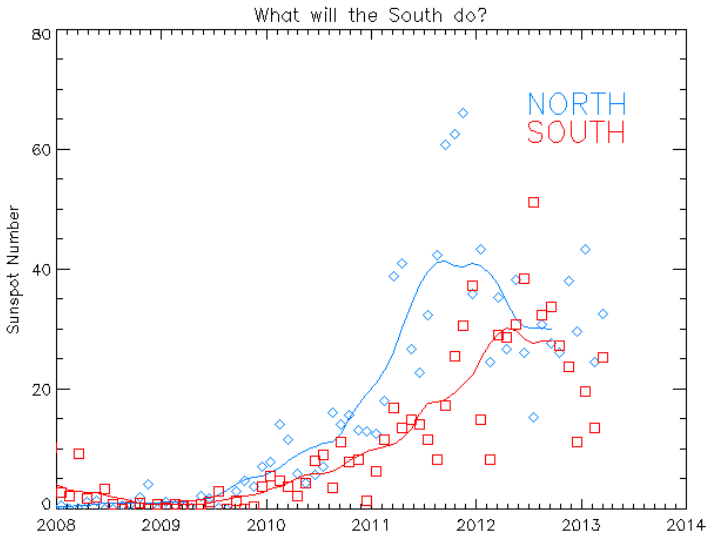
- In 2010, the cycle looked like it would come in lower ~70
- In 2011, the cycle picked up and is a better match for at least 80
  - Within the error of the prediction (±10)
  - We also said, the lag between the solar hemispheres was only 8 months and wouldn't matter too much
- In 2012, we raised the possibility of a double peaked maximum



In 2013

- We asked if solar maximum had already passed
  - It had reached a peak of 67 in February 2012
  - The answer last year was “we don’t know”
    - It all depended on the southern hemisphere



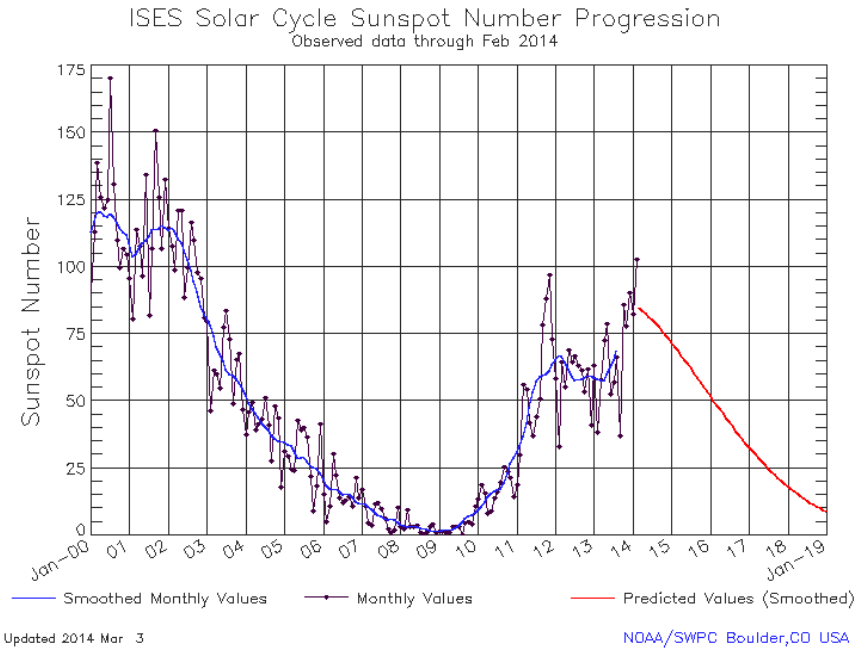


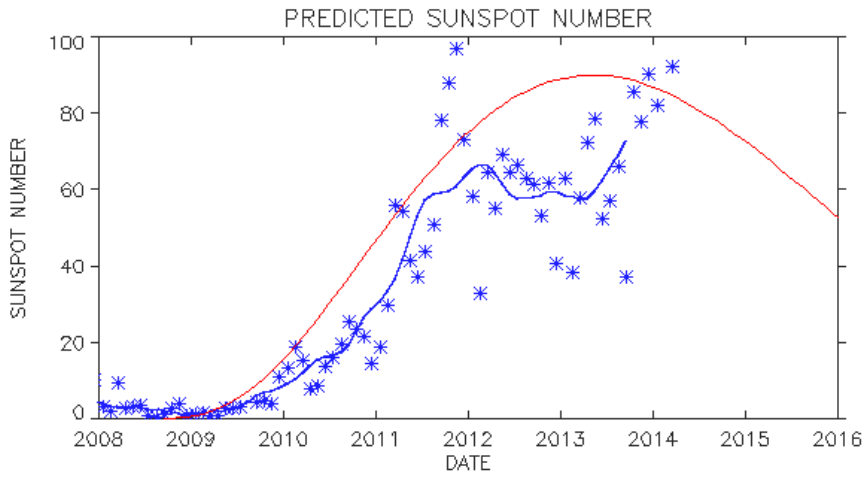
On to 2014

- Where are we now?
- The bi-modality of the solar cycle
  - North v South
- What we really care about is activity
  - How does it compare to recent cycles?

The prediction

- Solar maximum definitely did not occur in 2012
- We are currently at 73 in September, 2013
  - And still going up



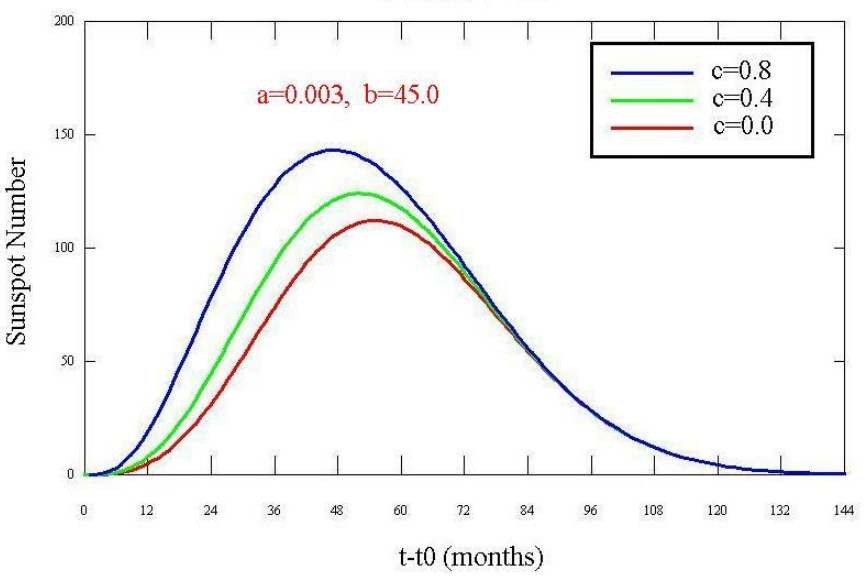


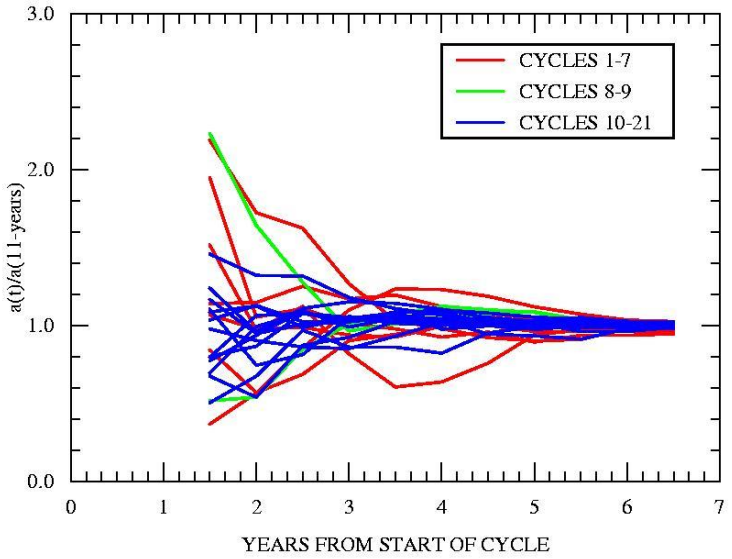
A Functional Form for the Cycle

Fitting the cycle to a functional form with amplitude *a*, starting time t_0, width *b*, and asymmetry *c*, provides a prediction for the current cycle and can account for systematic changes in cycle shape.

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

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

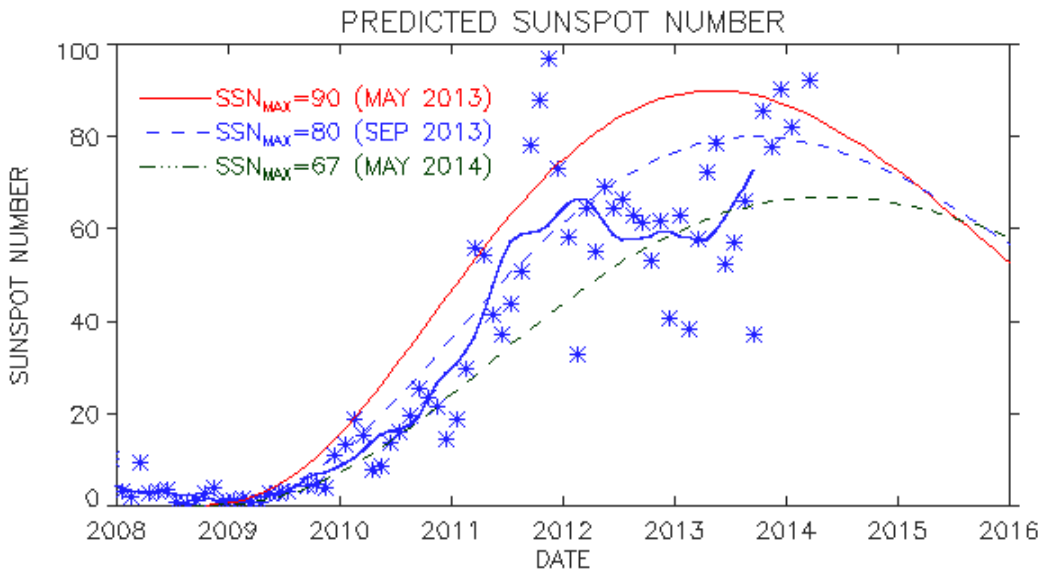




D. Hathaway

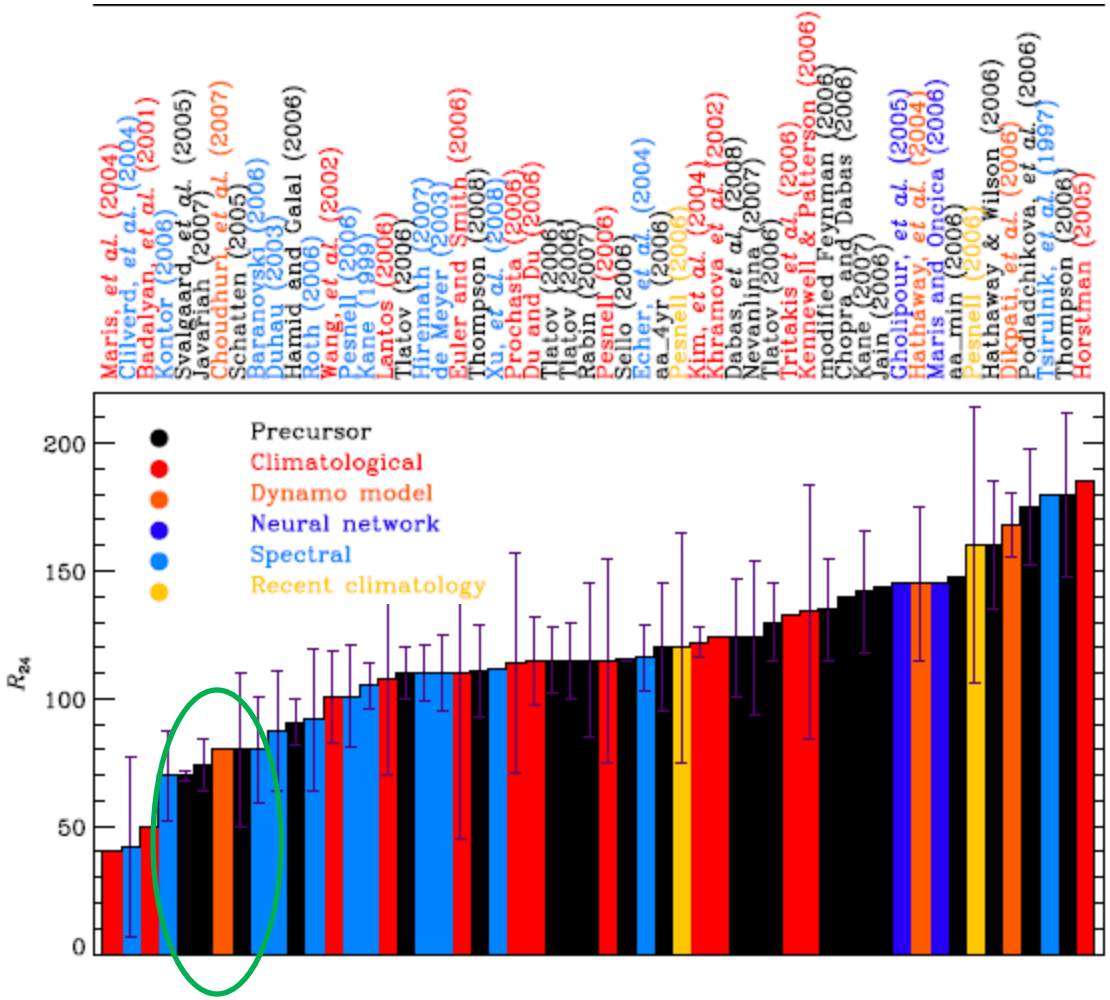
What are we on track for?

- Red:
  - Prediction of 90
- Blue:
  - Prediction of 80
- Green:
  - Prediction of 67



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

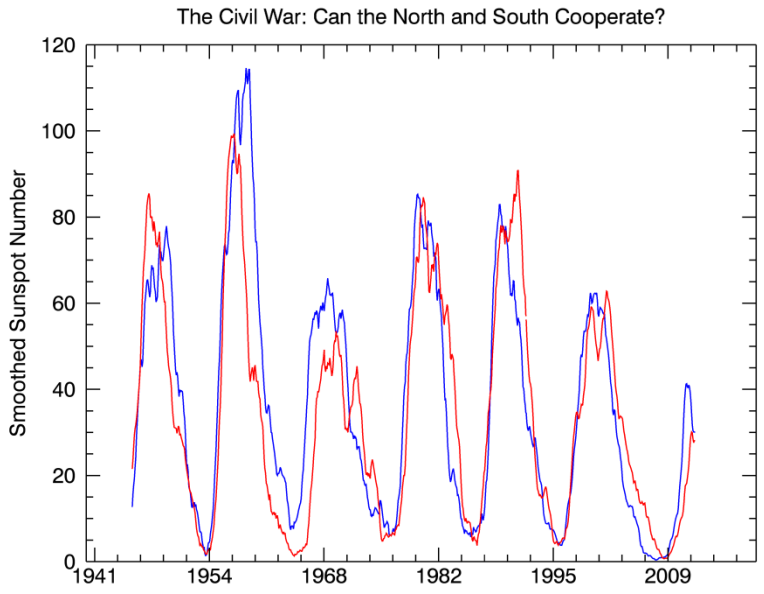
Do we have a winner?

The cycle has reached a local maximum of R=73 in September, 2013

R	Timing	Author	Technique
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

The North/South Divide

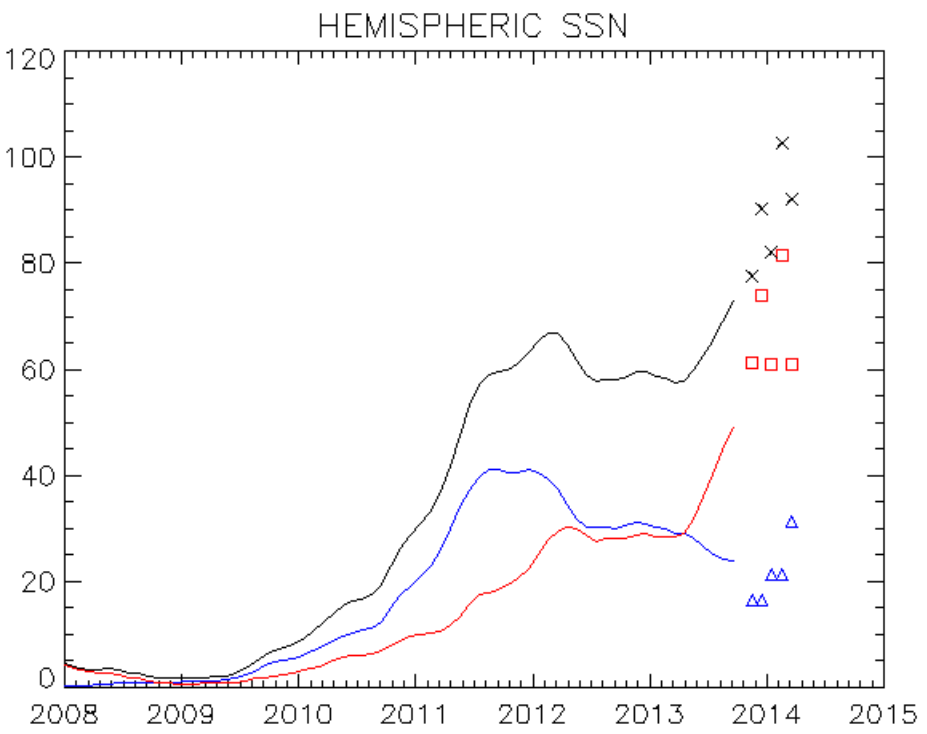
- The two hemispheres generally peak at different times
  - Cycle 24 is no different
- Does this help us figure out where this cycle is headed?



The Divide of Cycle 24

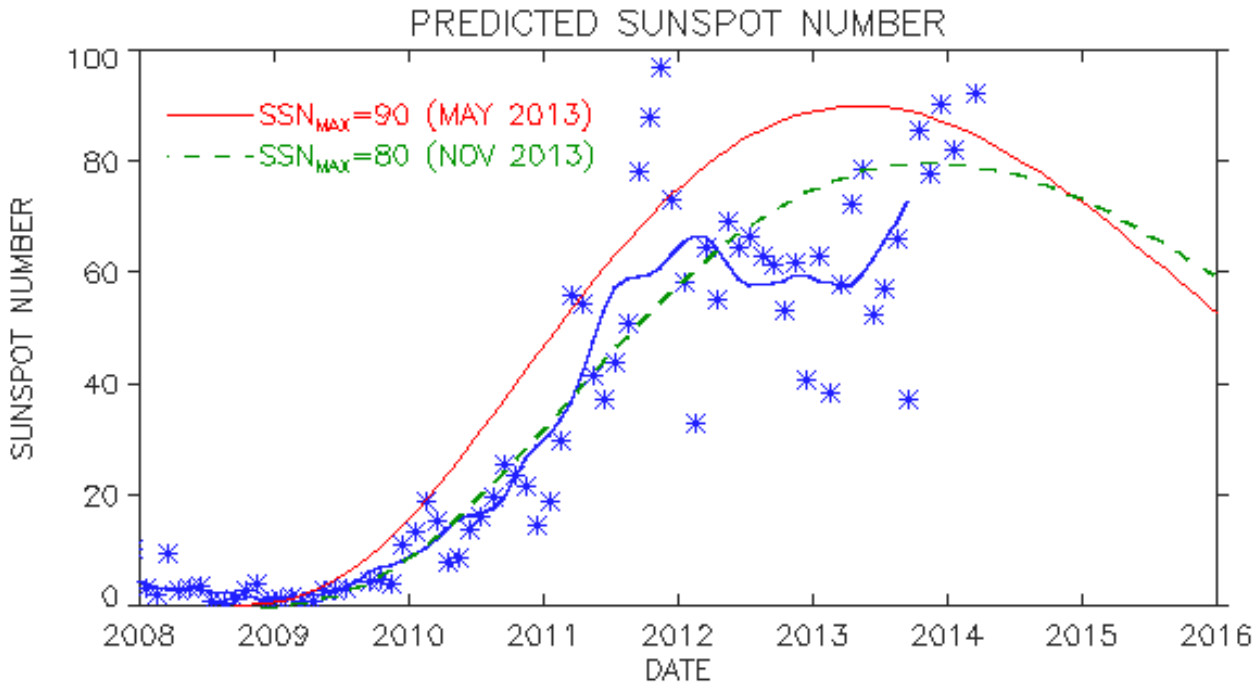
- The North peaked at 41 in Sept & Dec 2011
- Both hemispheres paused for about 1 year
- The South lags the North by about 2 years
  - Peak at 49
    - Higher than the North
- I can't predict the future…
  - the South is rising faster than the North is falling

SSN, North, South



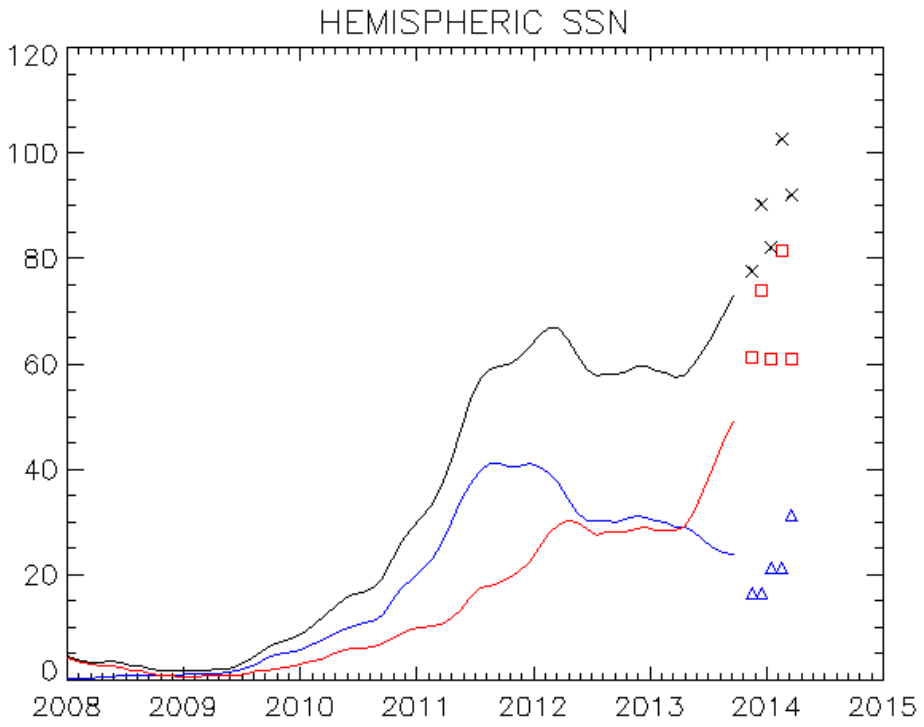
But I'll still try

- A peak of 80 shifted so that solar maximum occurs in November, 2013 doesn't look too bad



Lesson learned

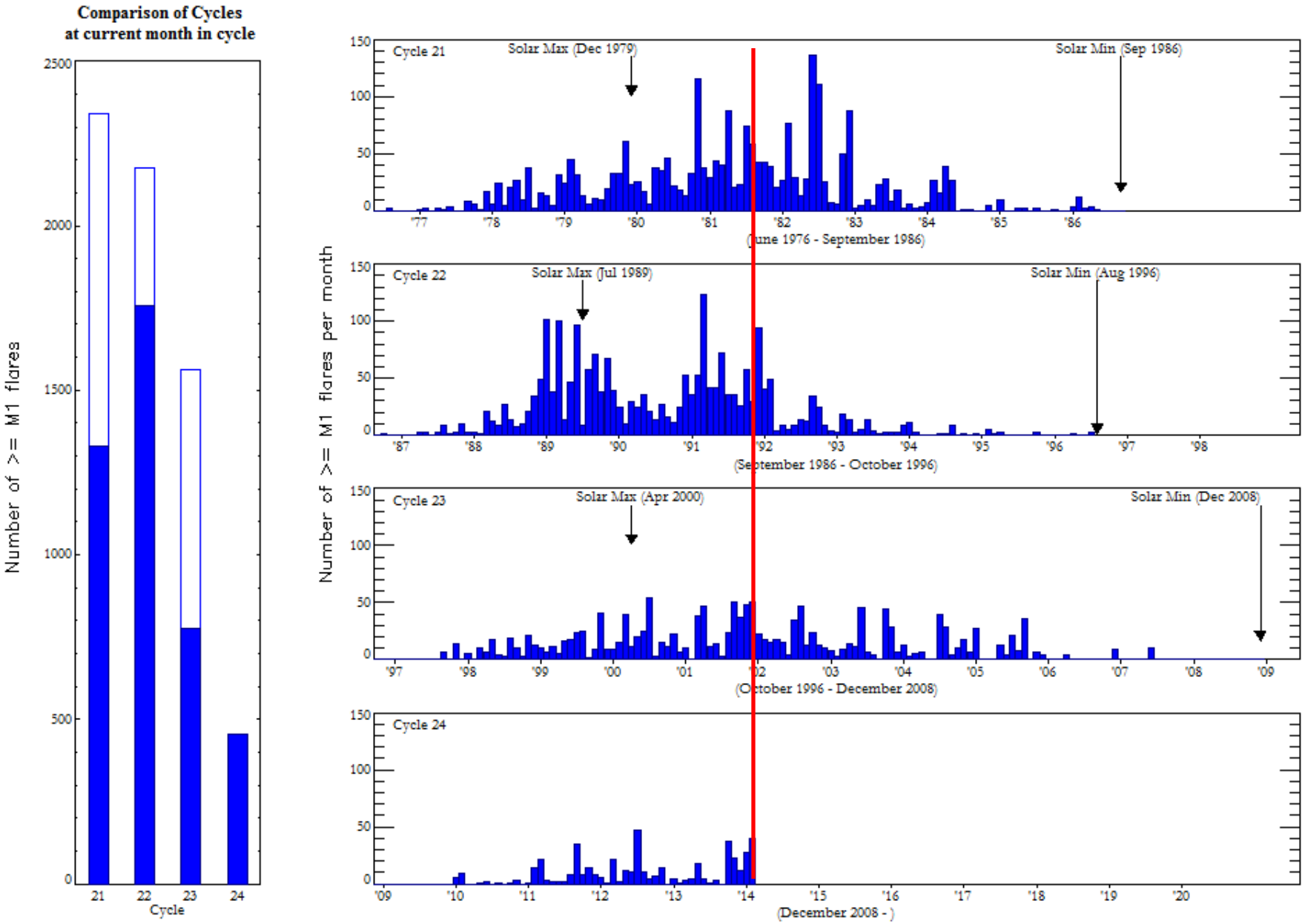
- The Prediction Panel did discuss the need to consider the hemispheres independently
  - But, there was almost nothing in the literature
  - Everyone considers the Sun as a whole
    - Need to consider it as a game of two halves
- If you predict the solar cycle, you better start predicting the hemispheres



X-ray flares >= M1 (R1)

February 2014

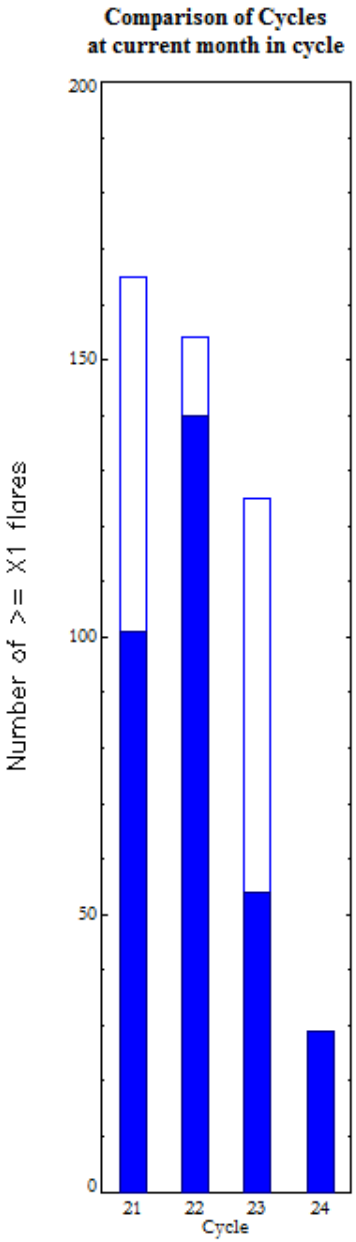
(Month 63)

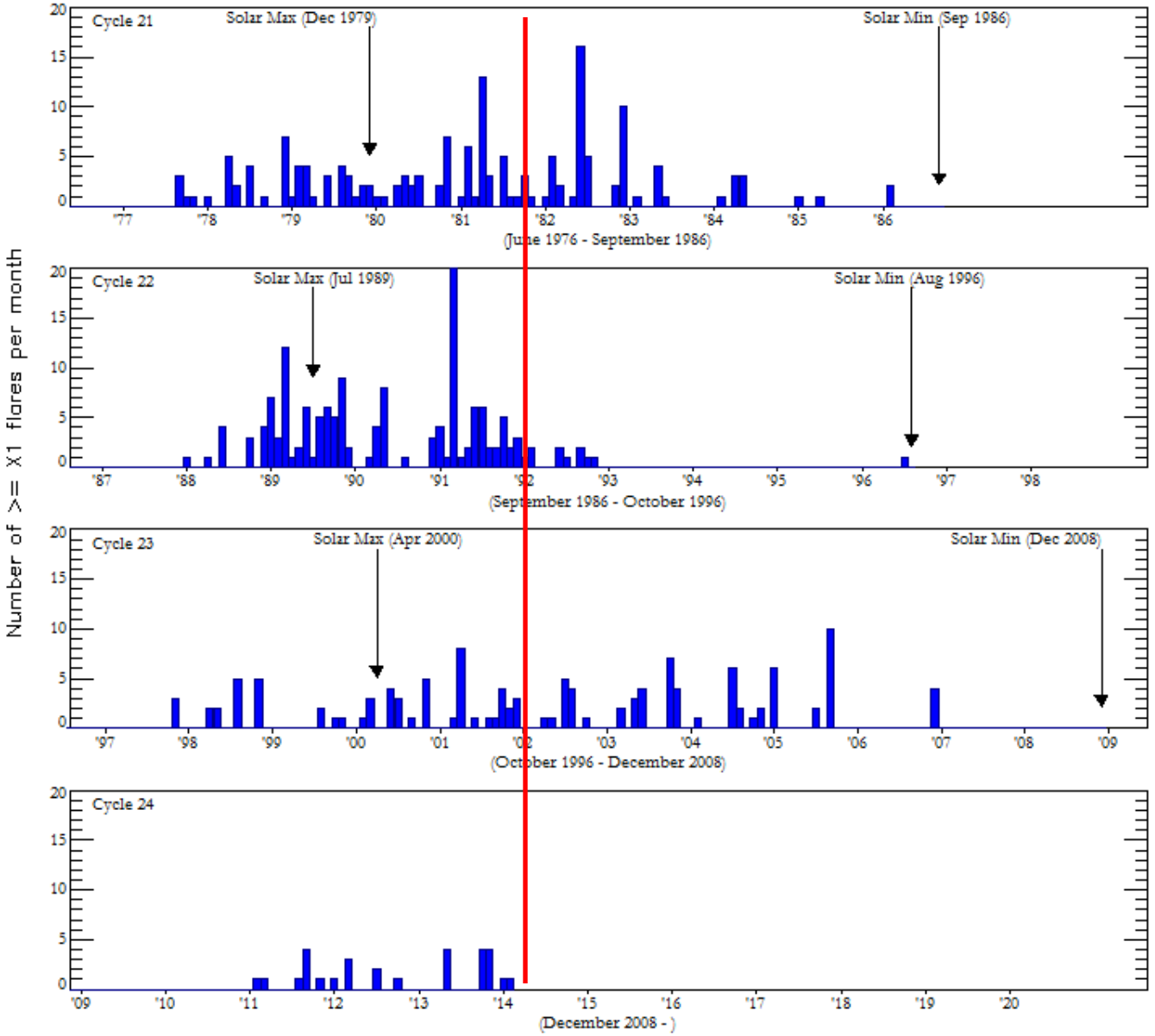


X-ray flares >= X1 (R3)

February 2014

(Month 63)





Periods with Kp >= 5 (G1)

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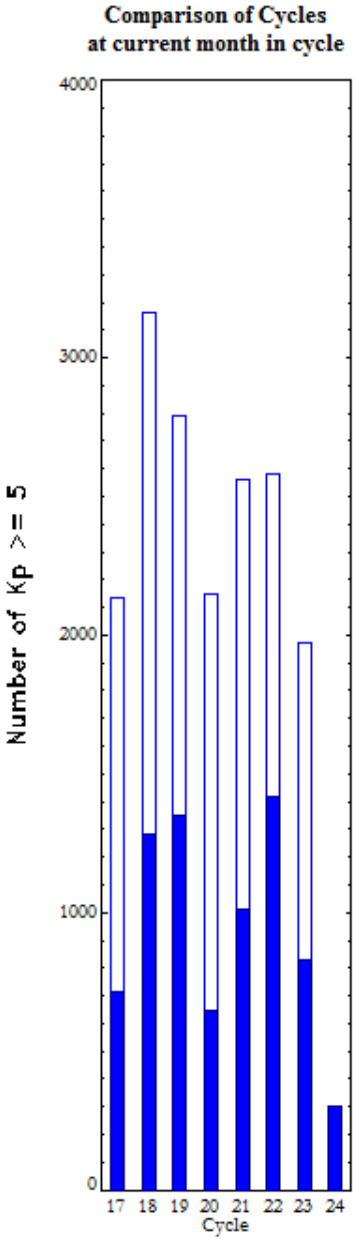

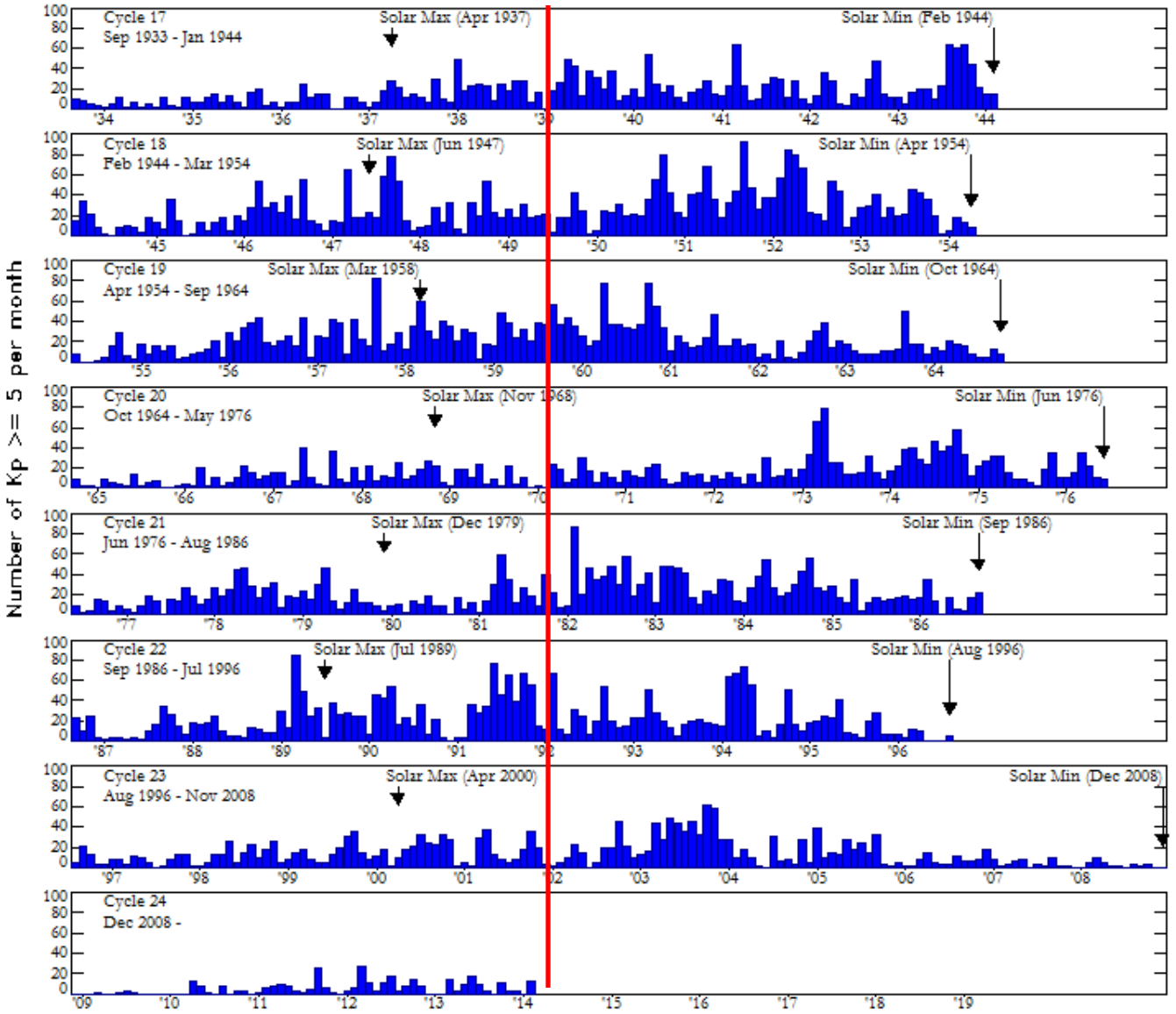

Periods with Kp >= 7 (G3)

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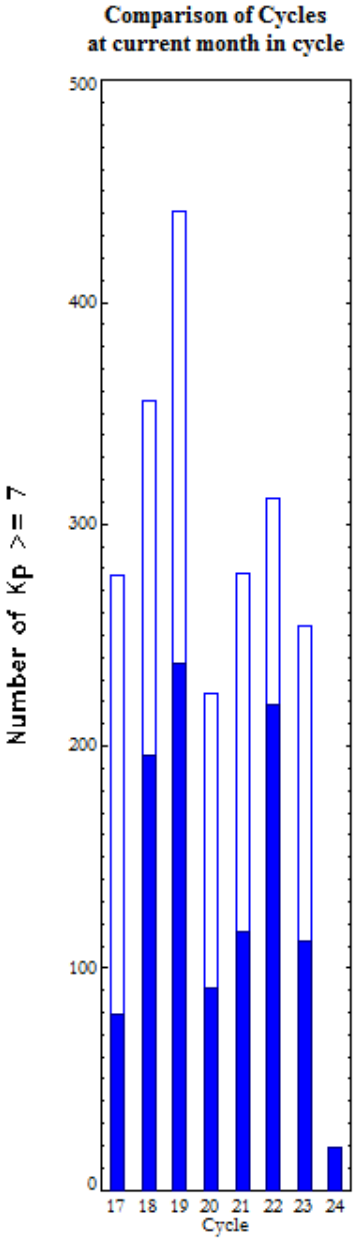

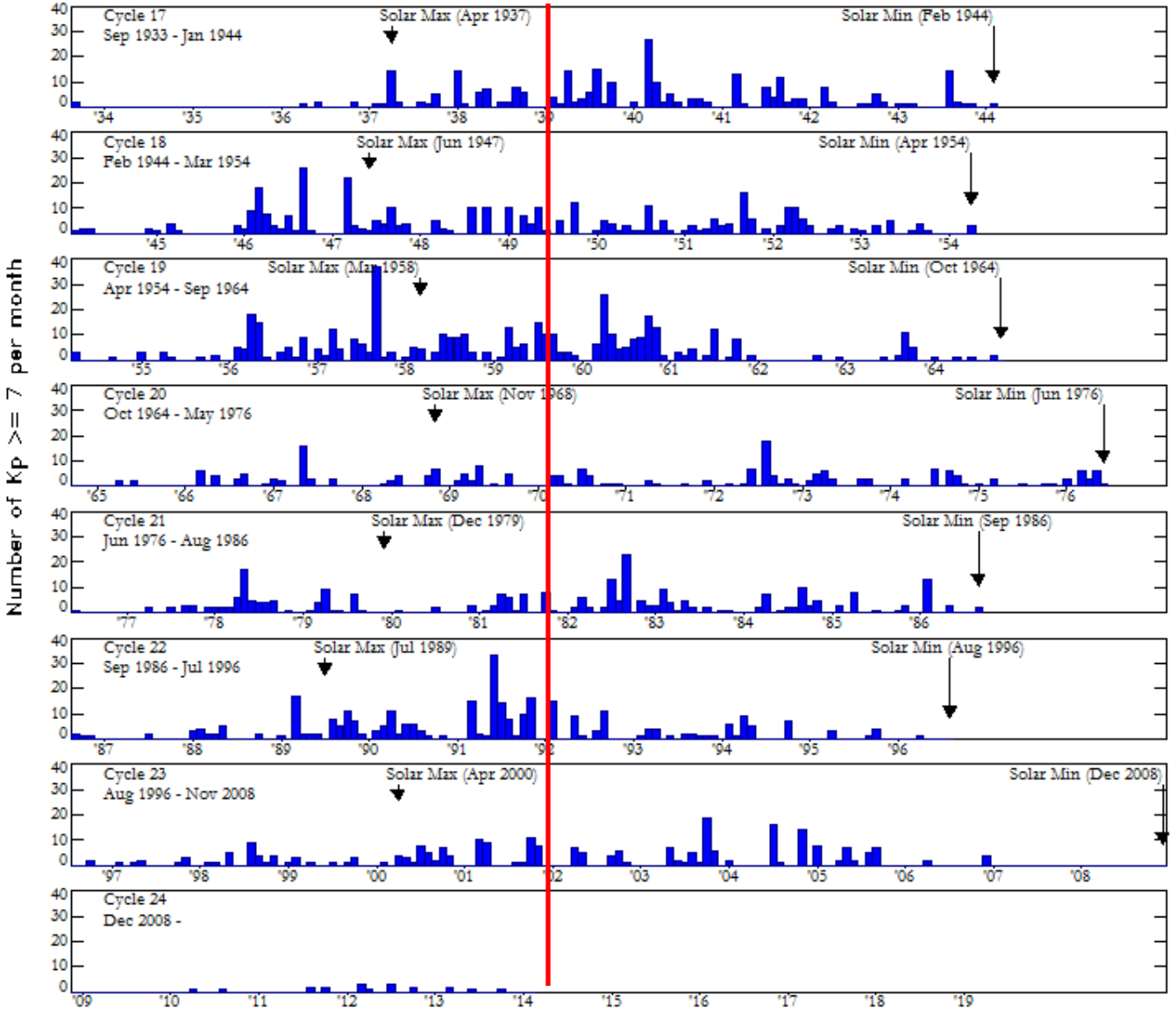

Is it really that bleak?

- Just when it was looking bad…

Periods with Kp >= 9 (G5)

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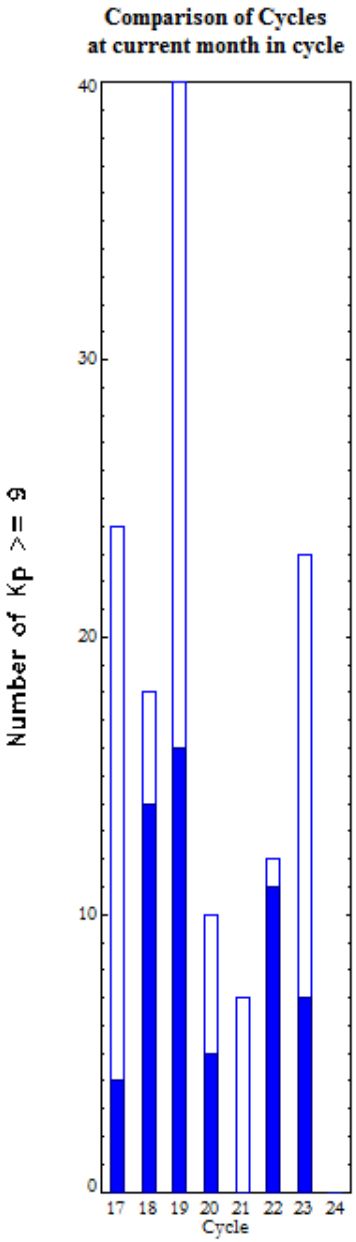
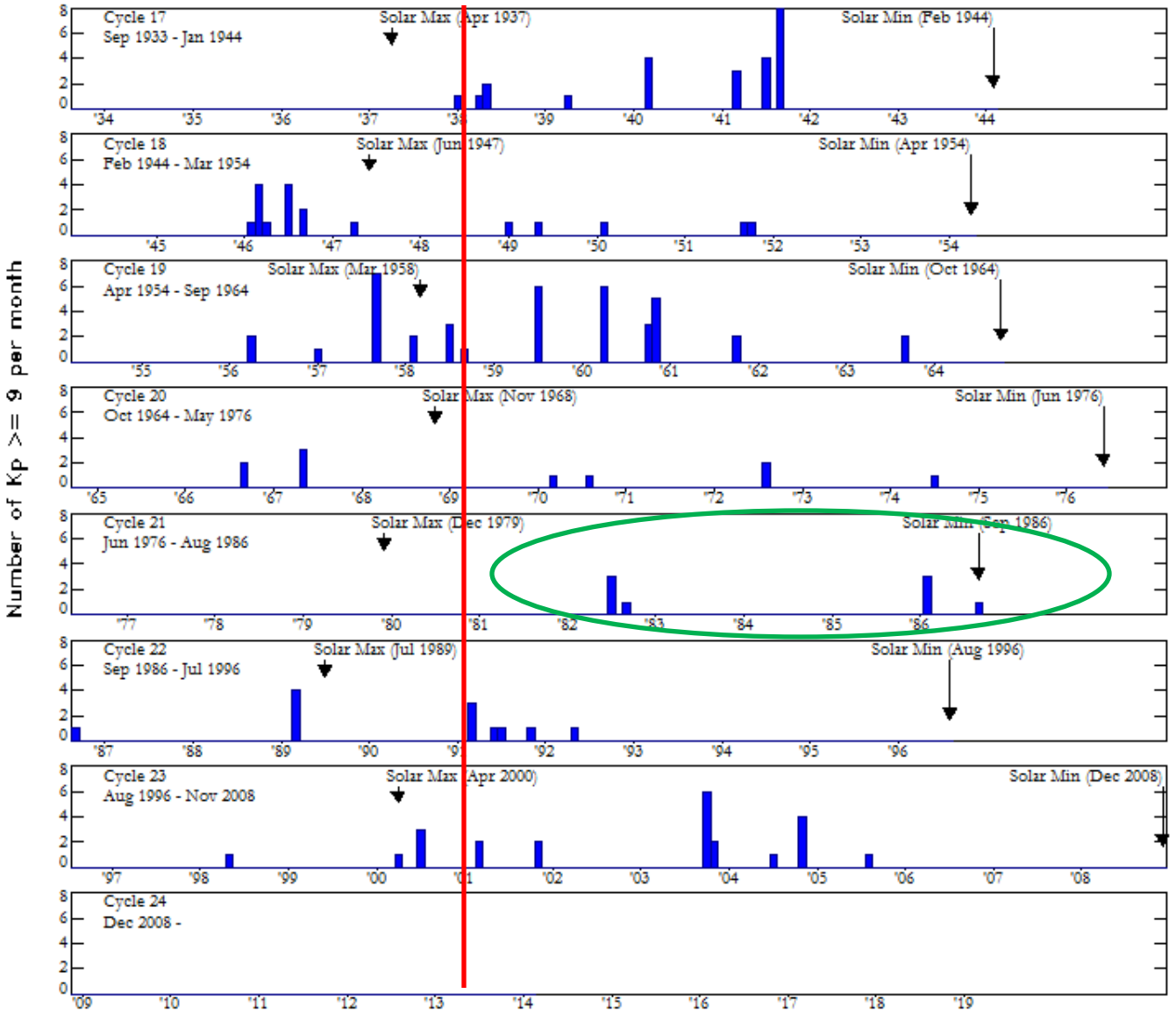
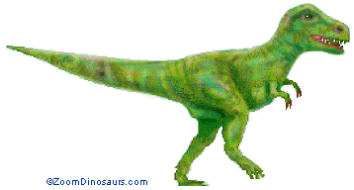




Conclusions

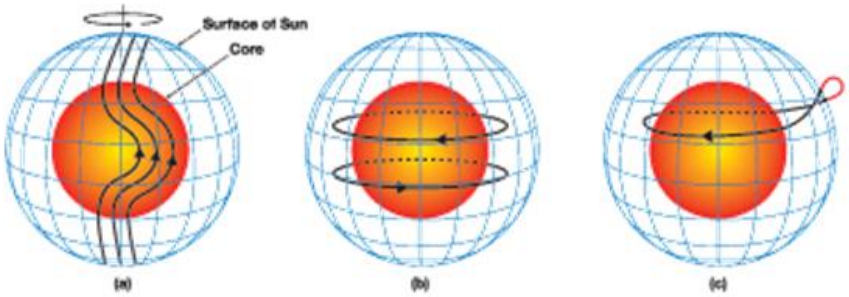
- The panel was right, insofar as a below average cycle was predicted
  - If North and South were in phase, we'd be at 90
    - Then the forecast would have been perfect
  - If we are wrong, it's because Tyrannosaurus Rex ate the solar flares…well that's what the 5th grader I had dinner with last night said.
- We are in the midst of solar maximum
  - Is it just past, is it now, is it soon?
    - Yes

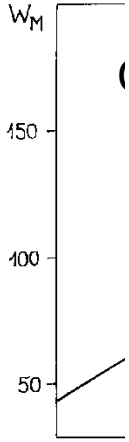


- Forecasting future solar cycles absolutely must consider the hemispheres separately
- IF this cycle behaves like recent cycles, there's still activity to come
  - Maybe we'll be like Cycle 21?

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.**





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

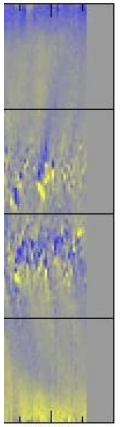
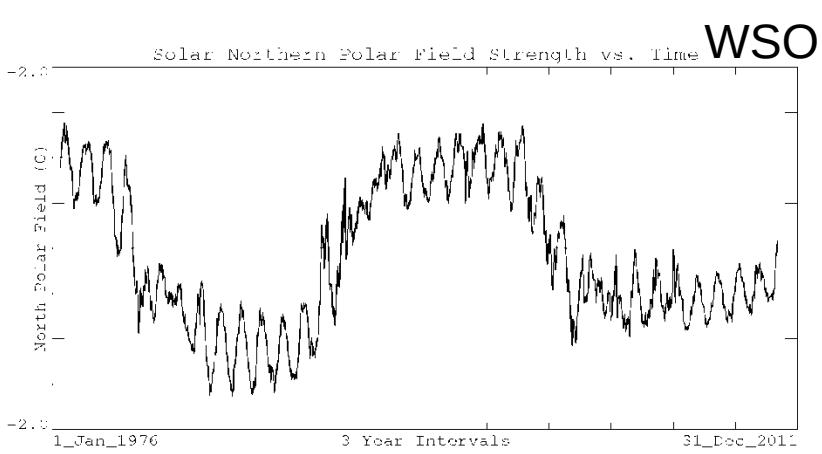


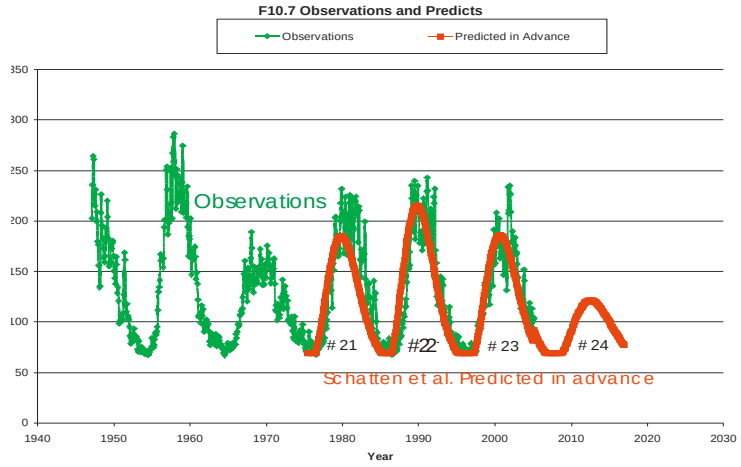
Figure 1 ... in the maximum of the next 11-year cycle.

Courtesy D. Hathaway

Polar Field Precursor Methods

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

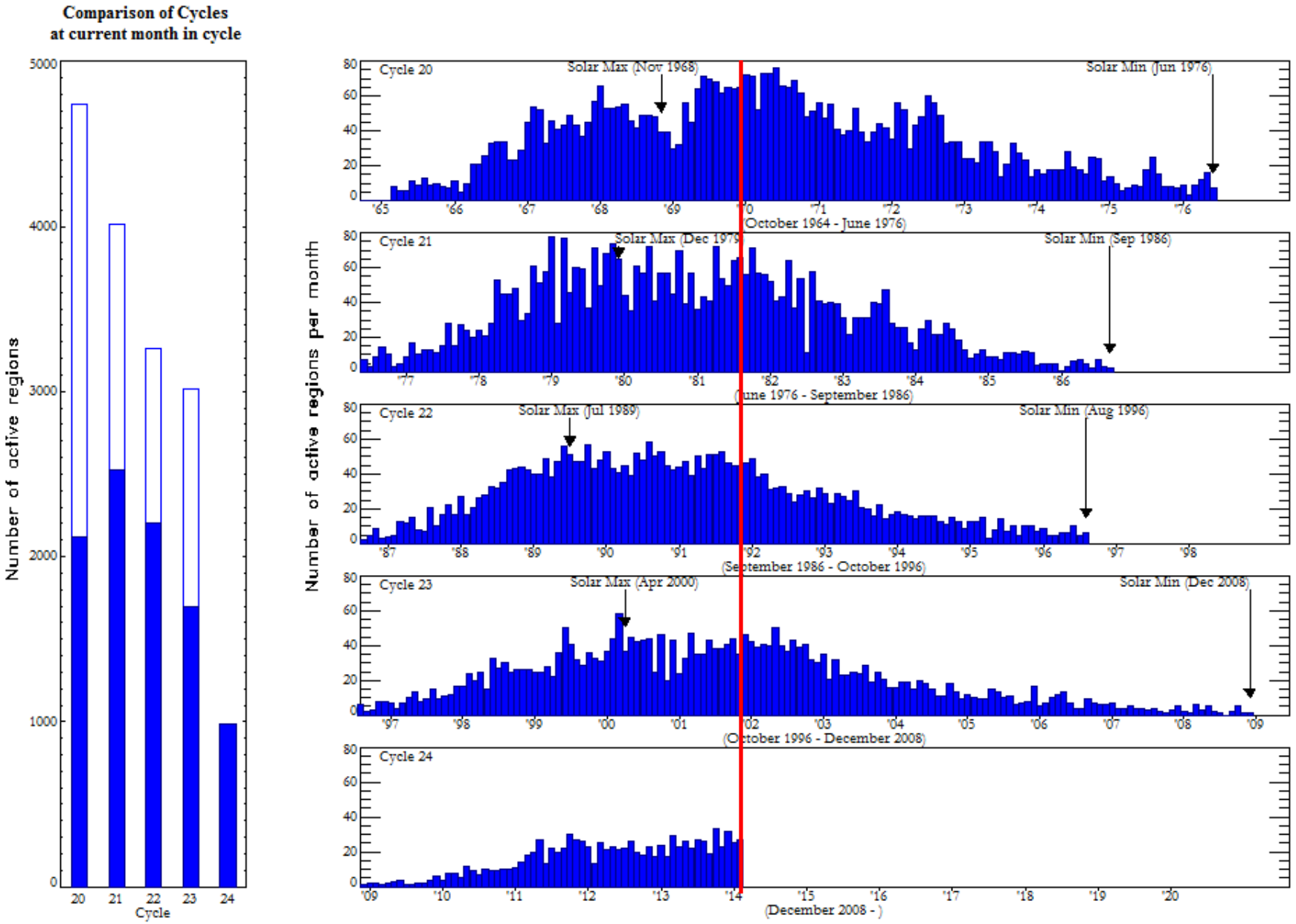




$$\mathrm{SODA} = 60 + 146\left[\left(\frac{B_{pol}}{1.28}\right)^2 + \left(\frac{\mathrm{F10.7} - 60}{146}\right)^2\right]^{1/2}$$

Schatten and Pesnell (1993)

Active Regions

February 2014

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