Where is Solar Cycle 24?
Did it happen already?
Is there more to come?

Douglas Biesecker
NOAA/SWPC

With help from
Chris Balch (NOAA/SWPC) and Scott McIntosh (NCAR/HAO)
Agenda

• The panel prediction
  – What was it and where are we?
  – Is it still numerology?

• The bi-modality of the solar cycle
  – North v South
  – We will see a second peak (I think)

• What we really care about is activity
  – How does it compare to recent cycles?
The prediction

- In 2009, the NASA funded, NOAA chaired, international panel said – SSN will peak at 90 in May 2013

- Is there any chance we can still salvage some respectability?
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.

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

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

D. Hathaway
Trying different curves

- **Red**: Prediction of 90
  - Doesn’t look likely
- **Blue**: Prediction of 80
  - Still seems possible
- **Green**: Prediction of 67
  - Did it come two years too soon?
Do we have a winner?

- The cycle has reached a local maximum of $R=67$ in February, 2012
- Is that all we’ve got? If so, who was right?

<table>
<thead>
<tr>
<th>R</th>
<th>Timing</th>
<th>Author</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>-</td>
<td>Javariah (2007)</td>
<td>Precursor (sunspot area)</td>
</tr>
<tr>
<td>70</td>
<td>-</td>
<td>Svalgaard et al (2005)</td>
<td>Precursor (polar fields)</td>
</tr>
<tr>
<td>70</td>
<td>12/2012</td>
<td>Kontor (2006)</td>
<td>Spectral</td>
</tr>
</tbody>
</table>
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
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.

<table>
<thead>
<tr>
<th>Prediction Method</th>
<th>Cycle 19</th>
<th>Cycle 20</th>
<th>Cycle 21</th>
<th>Cycle 22</th>
<th>Cycle 23</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Cycle</td>
<td>-94.8</td>
<td>-9.1</td>
<td>-53.5</td>
<td>-48.6</td>
<td>-10.1</td>
<td>53.7</td>
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<tr>
<td>Secular Trend</td>
<td>-91.6</td>
<td>8.7</td>
<td>-36.2</td>
<td>-25.3</td>
<td>17.8</td>
<td>46.3</td>
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<td>Gleissberg Cycle</td>
<td>-80.4</td>
<td>18.5</td>
<td>-51.6</td>
<td>-9.6</td>
<td>49.4</td>
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<tr>
<td>Even-Odd</td>
<td>-59.3</td>
<td>-22.3</td>
<td>61.1</td>
<td>40.8</td>
<td></td>
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<tr>
<td>Amplitude-Period</td>
<td>-74.1</td>
<td>0.3</td>
<td>-61.2</td>
<td>9.7</td>
<td>44.7</td>
<td></td>
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<tr>
<td>Maximum-Minimum</td>
<td>-83.9</td>
<td>21.6</td>
<td>-22.9</td>
<td>1.8</td>
<td>40.6</td>
<td></td>
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<td>Ohl's Method</td>
<td>-55.4</td>
<td>19.1</td>
<td>21.8</td>
<td>4.4</td>
<td>22.2</td>
<td>29.7</td>
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<tr>
<td>Feynmann's Method</td>
<td>-42.8</td>
<td>9.6</td>
<td>26.9</td>
<td>3.6</td>
<td>41.1</td>
<td>29.5</td>
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<tr>
<td>Thompson's Method</td>
<td>-17.8</td>
<td>8.7</td>
<td>-26.5</td>
<td>-13.6</td>
<td>40.1</td>
<td>24.1</td>
</tr>
</tbody>
</table>

Figure 1: Magnetic observations and Ohl's number $W_M$ 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)

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

Schatten and Pesnell (1993)
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

• It seems likely the North peaked at R=41 in 2011
• The South lags the North by about 8 months
  – Did it peak in early 2012 at R=30?
  – If so, this cycle is pretty much done
• But, I can’t predict the future...
What if they had been in phase?

- If the two hemispheres were in phase, we wouldn’t even be having this conversation
- 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
Enough of those spots, what about the activity?

Solar flares: Be glad you're on Earth, not Mars (+video)

The recent solar flares provide a dramatic backdrop for a study that shows Mars gets far more of its atmosphere stripped away by solar storms than does Earth. Thank you, magnetosphere.

Sun Erupts With Major Solar Flare

FOLLOW US

This story was updated at 11:42 a.m. EST.

A major solar flare erupted from the sun late last night (March 4) sending an explosion of plasma and charged particles hurtling toward Earth.

The flare was an X1.1-class solar flare and exploded from the surface of the sun at 11:13 p.m. EST (0413)

Solar Flares Knock Out LightSquared Satellite As Run of Bad Fortune Continues

by Karl Bode 7 hours ago tags: satellite · business · wireless · alternatives · bandwidth · trouble · wireless

Tipped by viperadamr Earlier this week we noted that recent solar flares managed to knock HughesNet's Spaceway 3 satellite offline for a significant part of Tuesday. User viperadamr writes in to note that the flares also took out LightSquared's Skyterra 1 satellite, which has been out of service since the original solar flare on March 7. The last update from the company was on March 9 insisting they'd have the satellite operational again by last night.

HughesNet SPACEWAY HN9000 service is currently unavailable. We have engineering teams working to restore service to these customers as quickly as possible. We apologize for the inconvenience. Please check back for updates.

Non-Spaceway customers are not affected. Your system model number on the front of your unit will tell you if you are an HN9000 customer.

The nearest remedy for high energy solar data from Spaceway spacecraft is the Space Network. The Space Network's 16 heliostations are ground-based solar observatories, having been located in selected places for the obstruction of the sun. The heliostations are controlled by the Space Network's Solar Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's Space Network's SPACEWAY 3 satellite offline for a significant part of Tuesday. User viperadamr writes in to note that the flares also took out LightSquared's Skyterra 1 satellite, which has been out of service since the original solar flare on March 7. The last update from the company was on March 9 insisting they'd have the satellite operational again by last night.
Active Regions
March 2013
(Month 52)

Comparison of Cycles at current month in cycle

(October 1964 - June 1976)

Cycle 21  Solar Max (Dec 1979)  Solar Min (Sep 1980)
(June 1976 - September 1980)

(September 1986 - October 1990)

(October 1996 - December 2001)

Cycle 24  
(December 2008 - )
X-ray flares $\geq$ M1 (R1)

March 2013
(Month 52)

Comparison of Cycles at current month in cycle

- Cycle 21: Solar Max (Dec 1979)
  - (June 1976 - September 1986)
  - Solar Min (Sep 1986)

- Cycle 22: Solar Max (Jul 1989)
  - (September 1986 - October 1996)
  - Solar Min (Oct 1996)

- Cycle 23: Solar Max (Apr 2007)
  - (October 1996 - December 2008)
  - Solar Min (Dec 2008)

- Cycle 24
  - (December 2008 - )

Number of $\geq$ M1 flares per month.
X-ray flares $\geq X1$ (R3)

March 2013
(Month 52)

Comparison of Cycles at current month in cycle

Cycle 21
Solar Max (Dec 1979)
Solar Min (Sep 1986)

Cycle 22
Solar Max (Jul 1989)
Solar Min (Oct 1996)

Cycle 23
Solar Max (Apr 2007)
Solar Min (Dec 2008)

Cycle 24

Number of $\geq X1$ flares per month
Comparison of Cycles at current month in cycle

Number of Kp >= 5 per month

Periods with Kp >= 5
March 2013
(Month 52)
Periods with Kp >= 7
March 2013
(Month 52)

Comparison of Cycles at current month in cycle

Number of Kp >= 7 per month
As of mid-April, 2013, the cycle 24 fluence is trailing cycle 23 by a factor of ~2.
Conclusions

• I can’t predict where the solar cycle will be
• The panel was right, insofar as a below average cycle was predicted
• A second peak in 2013 is possible, if the South chooses to participate
  – If not, then this will be an unusual maximum
• Forecasting future solar cycles absolutely must consider the hemispheres separately

• IF this cycle behaves like recent cycles, there’s still lots of activity to come.