Solar Maximum... We Hardly Knew Ye

Douglas Biesecker
NOAA/SWPC

Image courtesy of Yohkoh SXT
Start with the 2009 Prediction

• Forecast was for peak of 90 in May, 2013
• Actual was a peak of 82 in April, 2014
  • Within the ±10 error bar
  • Outside the ±6 month error bar
• Subjectively, the forecasted curve does a reasonably, maybe even very good job, of ‘fitting’ the smoothed sunspot number
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>
</tr>
<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>
</tr>
<tr>
<td>Gleissberg Cycle</td>
<td>-80.4</td>
<td>18.5</td>
<td>-51.6</td>
<td>-51.1</td>
<td>-9.6</td>
<td>49.4</td>
</tr>
<tr>
<td>Even-Odd</td>
<td>-59.3</td>
<td></td>
<td>-22.3</td>
<td></td>
<td>61.1</td>
<td>50.8</td>
</tr>
<tr>
<td>Amplitude-Period</td>
<td>-74.1</td>
<td>0.3</td>
<td>-61.2</td>
<td>-25.3</td>
<td>9.7</td>
<td>44.7</td>
</tr>
<tr>
<td>Maximum-Minimum</td>
<td>-83.9</td>
<td>21.6</td>
<td>-22.9</td>
<td>-15.0</td>
<td>1.8</td>
<td>40.6</td>
</tr>
<tr>
<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>
</tr>
<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>
</tr>
<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>

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. A relation between the indexes of recurrent magnetic disturbances and Wolf's number Ww in the maximum of the next 11-year cycle.
Polar Field Precursor Methods

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

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

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

<table>
<thead>
<tr>
<th>SSN</th>
<th>Timing</th>
<th>Author</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>91.9</td>
<td>1/2011</td>
<td>Roth (2006)</td>
<td>Spectral</td>
</tr>
<tr>
<td>87.5</td>
<td>-</td>
<td>Duhau (2003)</td>
<td>Spectral</td>
</tr>
<tr>
<td>80</td>
<td>2012</td>
<td>Baranovski (2006)</td>
<td>Spectral</td>
</tr>
<tr>
<td>80</td>
<td>2012</td>
<td>Schatten (2005)</td>
<td>Precursor (polar fields)</td>
</tr>
<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>
A Functional Form for the Cycle

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

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

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).

Hathaway *et al.* 1994
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
  • Transequatorial meridional flow
  • Toroidal flux cancellation in the interior across the equator

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?