

# Solar Cycle 24

Overview of predictions on the start and  
amplitude of a new solar cycle

Jan Janssens  
Belgian Solar Section

# Summary

- The coming solar cycle minimum
- The coming solar cycle maximum
- Current Conclusions *(05 Mar 2005)*

# Solar Minimum

- Ahnert's formula

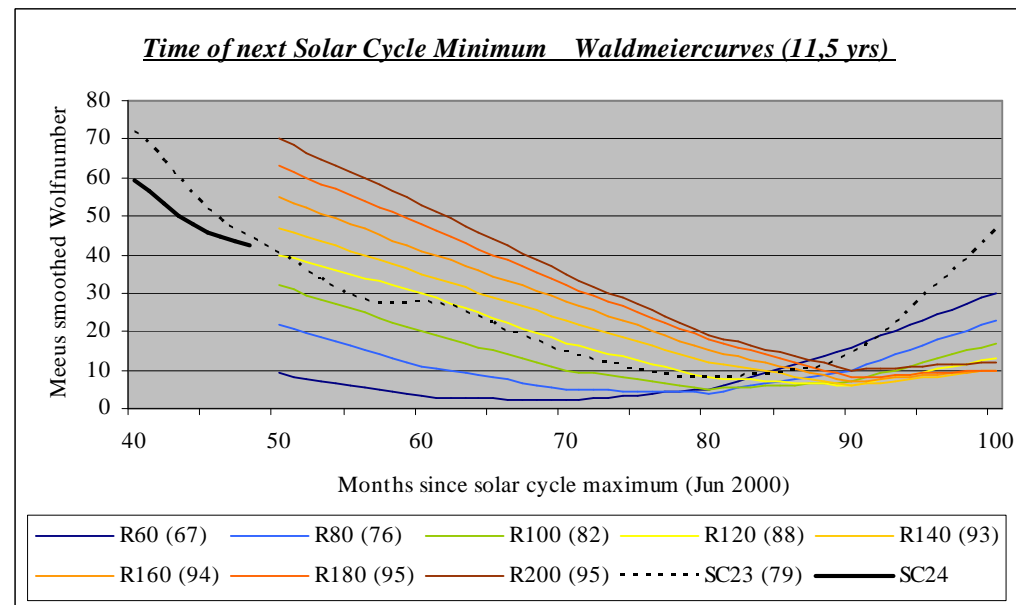
- $T_{min} = 1701,4 + 11,0 \cdot (N+5) + 2,2 \cdot \sin(144,0^\circ + 16,36^\circ \cdot (N+5))$ ,  
with N the cycle number

SC#	Min Ahnert	Min Meeus	$\Delta$	SC#	Min Ahnert	Min Meeus	$\Delta$
<b>0</b>	Oct 1754	Mei 1755	-7	<b>12</b>	May 1890	Feb 1890	3
<b>1</b>	May 1765	Aug 1766	-15	<b>13</b>	Jul 1901	Sep 1901	-2
<b>2</b>	Mar 1776	Jun 1775	9	<b>14</b>	Aug 1912	Jun 1913	-10
<b>3</b>	Feb 1787	Mei 1784	33	<b>15</b>	Jun 1923	Apr 1923	2
<b>4</b>	Apr 1798	Jun 1798	-2	<b>16</b>	Feb 1934	Sep 1933	5
<b>5</b>	Aug 1809	Jul 1810	-11	<b>17</b>	Sep 1944	Apr 1944	5
<b>6</b>	Jan 1821	Apr 1823	-27	<b>18</b>	Feb 1955	Apr 1954	10
<b>7</b>	Aug 1832	Aug 1833	-12	<b>19</b>	Jun 1965	Aug 1964	11
<b>8</b>	Mar 1844	Jul 1843	8	<b>20</b>	Nov 1975	Mar 1976	-4
<b>9</b>	Nov 1855	Jan 1856	-2	<b>21</b>	Apr 1986	Sep 1986	-5
<b>10</b>	Jun 1867	Apr 1867	2	<b>22</b>	Oct 1996	Mei 1996	5
<b>11</b>	Dec 1878	Dec 1878	0	<b>23</b>	<i>Jun 2007</i>	<i>+/- 12</i>	

- Onset of SC 24 expected for **June 2007**, +/- 12 months!

# Solar Minimum

- Waldmeiercurves
  - Statistics based on ideal curve
  - Additional data required
  - Currently follows R120 => SC min at **Feb 2007 +/- 8 months**



# Solar Minimum

- First spotless day (*after SC-maximum*)
  - Assuming SC24 will mimick SC16 to 23, SCmin can be expected between 28 and 38 months after month with first spotless day.
  - For SC24, first spotless day occurred in Jan 2004
    - SCmin to be expected **between May 06 and Mar 07**
    - Total spotless days to be expected = 362 +/- 134

SC	Month 1st R=0	Begin SC	Delta	Total R=0
10	Apr 1850	Jan 1856	69	654
11	Oct 1861	Apr 1867	66	406
12	May 1873	Dec 1878	67	1028
13	Jan 1885	Feb 1890	61	736
14	Nov 1895	Sep 1901	70	938
15	Mar 1908	Jun 1913	63	1019
16	Apr 1920	Apr 1923	36	534
17	Sep 1930	Sep 1933	36	568
18	Nov 1941	Apr 1944	29	269
19	Dec 1950	Apr 1954	40	446
20	Nov 1961	Aug 1964	33	227
21	Jul 1973	Mar 1976	32	272
22	Nov 1983	Sep 1986	34	273
23	Apr 1994	Mei 1996	25	309
24	Jan 2004	Oct 2006 +/- 5	33	362 +/- 134

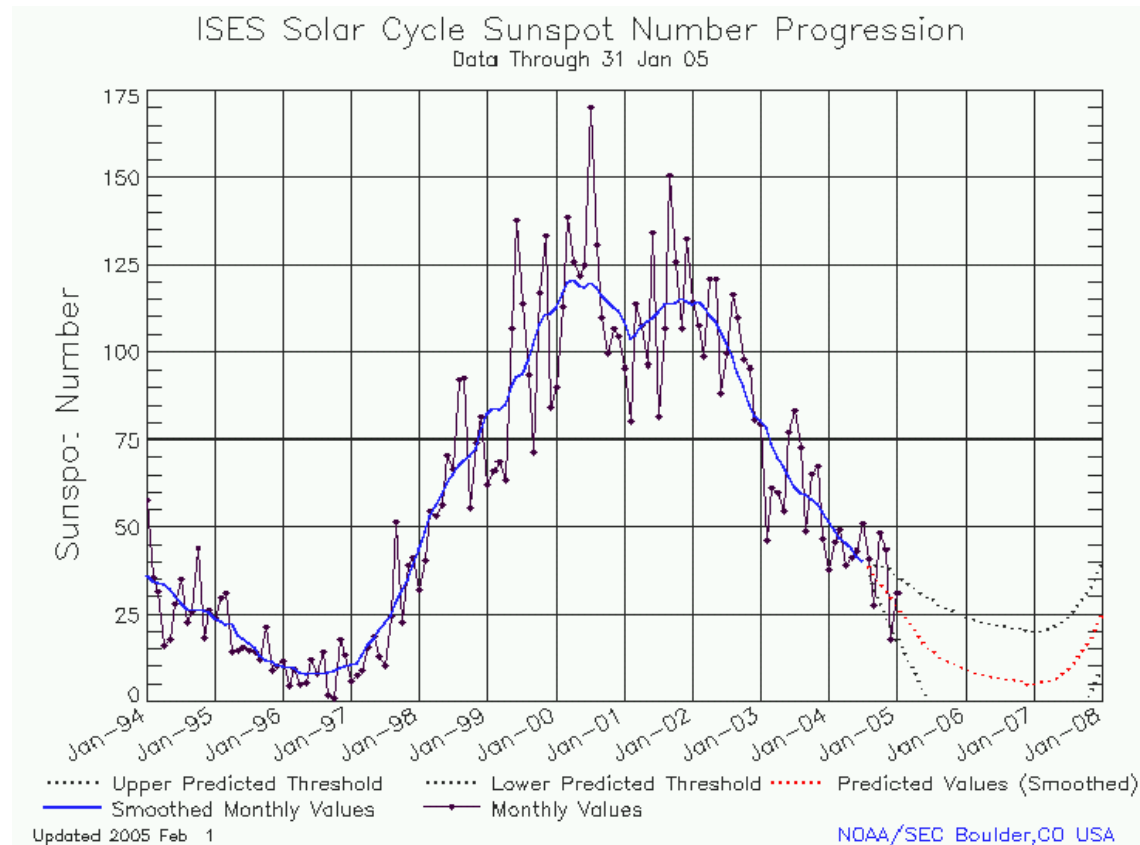
# Solar Minimum

- Appearance of 1st high latitude group
  - Between 10 to 18 months prior to Rmin, at latitudes higher than +/- 20°, AND *with reversed magnetic polarity*
    - Problematic cycle 23
  - **If** SC24 starts in Oct 2006, first such spots can be expected as from **Apr 2005**

SC	Date	Grwch / NOAA	Latitude	Longitude	SC Minimum	Delta
20	Sep 1963	14720200	S20	239	Aug 1964	11
21	Nov 1974	16210700	N37	239	Mar 1976	16
22	Mar 1985	4640	S26	150	Sep 1986	18
	May 1995	7872	N13	321	May 1996	12
23	Jul 1995	7893	S18	125	May 1996	10
	Aug 1995	7899	S20	215	May 1996	9
	May 1996	7963	N25	244	May 1996	0
	May 1996	7965	S38	74	May 1996	0

# Solar Minimum

- NOAA predicts SC min at **Dec 06 – Jan 07** +/- 3 months



# Solar Maximum

- Ahnert's formula
  - Similar to his formula for cycle minima
  - $T_{\max} = 1706,0 + 11,0 \cdot (N+4) + 2,2 \cdot \sin(155,6^\circ + 16,36^\circ \cdot (N+4))$ , with N the cycle number
  - $T_{\max}$  SC24 at **Nov 2011 +/- 12 months** (*SC since 1850*)
- Correlation between time of rise T en Rmax:
  - $R_{\max} = 244,18 - 2,49 \cdot T$  ( $r^2 \sim 80\%$ )
  - IF SCmin in Oct 06, then  $T = 61 +/- 12$  months
    - $R_{\max} = 92,3 +/- 29,9$
    - The later SCmin, the higher Rmax (according to this reasoning)

# Solar Maximum

- Badalyan, Obridko & Sykora
  - Based on coronal green line (530,3 nm)
  - Cyclical variation of this line's brightness is about 10 years ahead of variation of Wolfnumber
  - Good prediction of Wolfnumber in SC23 ( $R_{\max}=110-122$ )
  - Minimum first half of 2007
  - **Maximum SC24 in 2010-2011 with  $R_{\max} \sim 50$  (?!)**
  - Ref: <http://helios.izmiran.rssi.ru/hellab/Obridko/69688393.pdf>

# Solar Maximum

- Wang et al. (2002)
  - Distinction between low rising (LRV) and high rising velocity (HRV) groups of solar cycles
  - Coupling between times of SCmax and time of descending branch (between Rmax and subsequent Rmin)
  - Using concept of similar cycles:
    - Rmax to be expected between March 2011 and March 2013
    - Rmax amplitude between 83,2 and 119,4
  - Ref: [http://www.chjaa.org/2002/2002\\_2\\_6p557.pdf](http://www.chjaa.org/2002/2002_2_6p557.pdf)

# Solar Maximum

- Myung-Hee et al. (2004)
  - Statistical model based on
    - Split up of even and odd solar cycles
    - Split up of rising and declining phases of each solar cycle
    - Relatively high correlations found; but problems persist
  - SC24 predictions
    - Tmin: Dec 2006
    - Tmax: Nov 2010 +/- 13 months
    - Rmax: 122 +/- 6 (annual)
  - Ref: <http://ston.jsc.nasa.gov/collections/TRS/techrep/TP-2004-212070.pdf>

# Solar Maximum

- Hathaway & Wilson (2003)
  - Statistical cross-correlations based on daily, monthly and yearly Wolfnumbers
  - SC24 starts prior to 2007
  - SC24 should have larger than average amplitude
  - Ref: <http://trs.nis.nasa.gov/archive/00000650/01/tp212927.pdf>

# Solar Maximum

- Niehuss & Owens (1999); Euler & Smith (2004)
  - Modified McNish-Lincoln (MSAFE)
    - Dynamical statistics based on previous solar cycles
  - Predictions (95% percentile)
    - SCmin in Jan 2007 (Rmin = 15,9)
    - SCmax in Mar 2011 (Rmax = 195,8)
  - Ref: [http://sail.msfc.nasa.gov/solar\\_report\\_archives/Aug2004Rpt.pdf](http://sail.msfc.nasa.gov/solar_report_archives/Aug2004Rpt.pdf)

# Solar Maximum

- Svalgaard et al. (2005)
  - Strength of the polar field during the decline of a solar cycle is an indication of the sunspot activity of the following cycle (past 4 SC)
  - Prediction SC24:
    - $R_{\max} = 75 \pm 8$
  - Ref: <http://www.agu.org/pubs/crossref/2005/2004GL021664.shtml>

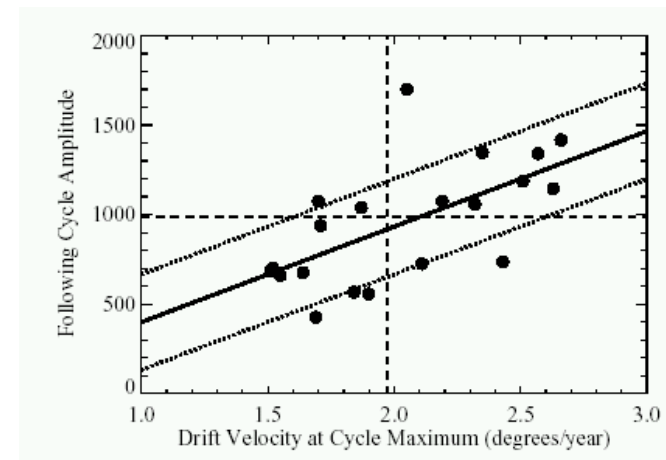
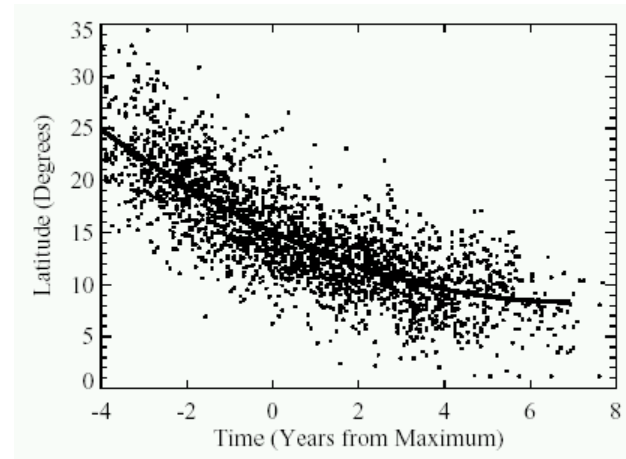
# Solar Maximum

- Schatten et al. (2004)
  - SODA-index
    - SOLar Dynamo Amplitude – index
    - Based on linear relationship between polar magnetic field strength and SC amplitude
    - Continuously optimised using solar flux and toroidal magnetic field
    - Good predictions of SC22 (high) and SC23 (moderate) amplitudes
  - Prediction SC24
    - Tmax = mid 2011
    - **Rmax = 100 +/- 30** (below average SC)
  - Ref: [http://ai-solutions.com/Resources/Papers/cospar-schatten-D1.1-D2.1-E3.1-0001-05\\_final.pdf](http://ai-solutions.com/Resources/Papers/cospar-schatten-D1.1-D2.1-E3.1-0001-05_final.pdf)
  - Ref: <http://www.usra.edu/hq/meetings/scw/Schatten/Schatten.ppt>

# Solar Maximum

- Hathaway et al. (2003)
  - Deep meridional plasma flow drives sunspot cycle
    - Hemispheres with faster drift rates have shorter periods
    - Drift rate at maximum correlates with amplitude of next SC
  - Ref:

<http://solar.physics.montana.edu/nandi/papers/nandy03a.pdf>

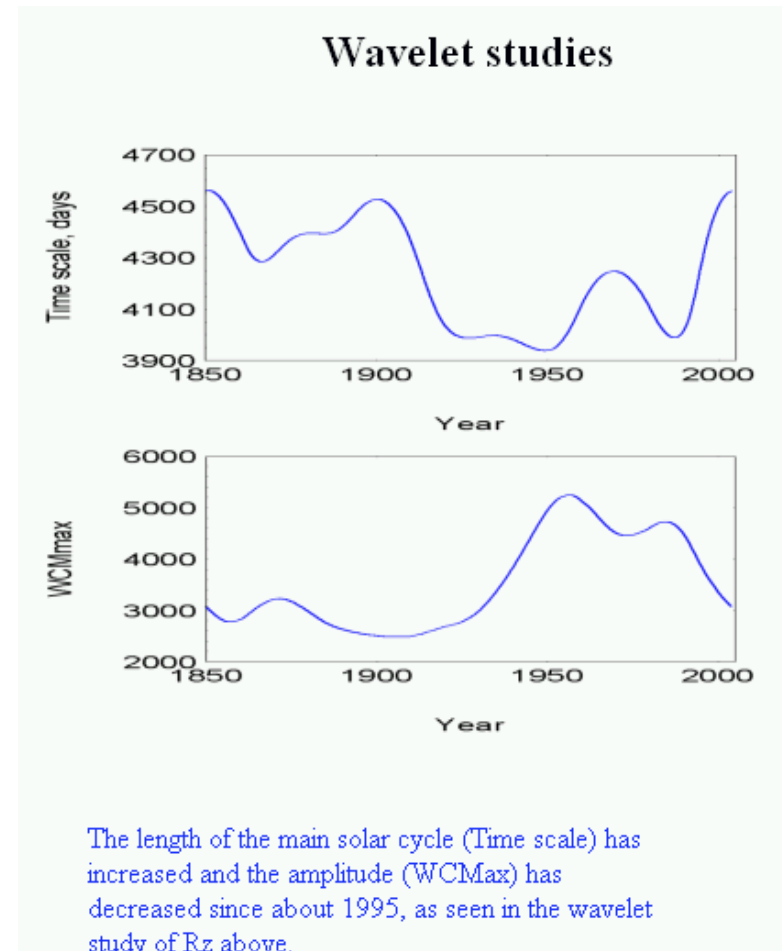


# Solar Maximum

- Dikpati et al. (2004)
  - Advanced calculus of meridional flow
    - Uses solar differential rotation, meridional flow (observed), poloidal magnetic field (observed), tachocline field quencher (theory) and solar interior theory
    - Mimicks very well peculiar features in solar cycle 23
    - At least 2 previous cycles determine amplitude of next cycle
  - Current meridional flow speed is low
    - Next SC min will be +/- 12 months later than current expectations
      - Tmin = last half of 2007 or first half of 2008
      - Rmax : Work in progress
  - Ref: <http://download.hao.ucar.edu/pub/dikpati/dynamopredi.pdf>

# Solar Maximum

- Lundstedt et al. (2004)
  - Lund Solar Activity Model
    - Uses Solar data
    - Statistics (Wavelet)
    - Solar activity theory
    - Neural (selfeducating)
  - Current conditions similar to the 1900's
    - SC24 may be lower than average ( $R_{max} = 85 \pm 25$ ?)
  - Ref: <http://flare.lund.irf.se:16080/rwc/cycle24/>
- Le & Wang (2003)
  - Similar results
  - Ref: [http://www.chjaa.org/2003/2003\\_3\\_5p391.pdf](http://www.chjaa.org/2003/2003_3_5p391.pdf)



# Solar Maximum

- Duhau (2003)
  - Nonlinear coupling between sunspot maxima and aa minima (from wavelet analysis)
  - Stepwise increase (less than 30 years) in Rmax
    - Between 1844 and 1923: around 90
    - After 1923: around 140
  - Evidence solar activity is in declining phase
  - Prediction SC24
    - $R_{\max} = 87,5 \pm 23,5$
  - Ref:  
<http://springerlink.metapress.com/app/home/contribution.asp?wasp=78u409whmn2ktg4yrqau&referrer=parent&backto=issue,13,13;journal,19,94;linkingpublicationresults,1:100339,1>

# Solar Maximum

- Post-minimum predictions
  - $R_{\max} = 63,84 + 16,36 \cdot v18$  , with  $v18$  the rise in  $R$  between months 17 and 18 since smoothed  $R_{\min}$
  - $R_{\max} = 48,65 + 1,16 \cdot R25$  , with  $R25$  the smoothed Wolfnumber 25 months after smoothed  $SC_{\min}$
  - $T_{\max}$  occurs +/- 1,9 years (+/- 8 m) after smoothed  $R=50$ 
    - $R_{\max}$  from:  $R_{\max} = 244,18 - 2,49 \cdot Trise$
  - $R_{\max} = -0,85 \cdot aa + 364,44$  , with  $aa$  the number of geomagnetically quiet days ( $aa < 20$ ) the year after the year of  $SC_{\min}$  (Ref: Mendoza et al. , <http://www.copernicus.org/EGU/annales/17/ag17/639.pdf> )
  - McNish-Lincoln method (dynamical statistics of previous SC)

# Current Conclusions *(05 Mar 05)*

Solar Cycle 24 - Predictions

Name	Technique	Start	Margin	Tmax	Margin	Rmax	Margin	Remarks
Ahnert	Statistics	Jun 2007	12 months					Own extrapolation
Waldmeier	Ideal Curves	Feb 2007	8 months					Own extrapolation
Observation	1st day R=0	Oct 2006	6 months					Own extrapolation
Observation	High-Latitude spots							May occur as from Apr 05
NOAA	Statistics	Dec 2006	3 months					
Ahnert	Statistics + Trise-Amplitude relation			Nov 2011	12 months	92,3	29,9	Own extrapolation
Badalyan	Coronal Green line			Jan 2011	12 months	50	?	
Wang	Low and high rising velocity groups			Mar 2012	12 months	101,3	18,1	
Myung-Hee	Statistics + Odd-even cycles			Nov 2010	13 months	122	6	Annual R max
Hathaway	Statistics on daily, monthly, yearly R	< 2007				Larger than average		
Euler	MSAFE	Jan 2007		Mar 2011		195,8		95% percentile
Svalgaard	Polar magnetic field					75	8	
Schatten	SODA-index			Mid-2011		100	30	
Dikpati	Meridional flow	Dec 2007	6 months					Calcul. Rmax in progress
Lundstedt	Lund Solar Activity Model					85	25	Own extrapolation
Duhau	Non-linear model on Rmax en aa-min					87,5	23,5	

- SC24 starts late 2006 – early 2007
- SC24 maximum
  - Time: 2011
  - Amplitude: 100 +/-20