

# **On the prediction of solar cycle maxima using solar cycle minimum parameters: Handle with care!**

Jan Janssens  
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**Abstract** – In many discussions on internet forums and blogs, it is stated that SC24 will be low because of the currently low solar activity, i.e. low Wolfnumber R, long solar cycle 23, large number of spotless days, and long inactive period ( $R < 20$ ). Though these relationships seem to exist, the uncertainty in them is very high, making the uncertainty in the predicted amplitude really big and hardly of any practical use. The purpose of this article is to put this in perspective by applying it on the upcoming SC24.

## **The individual relationships**

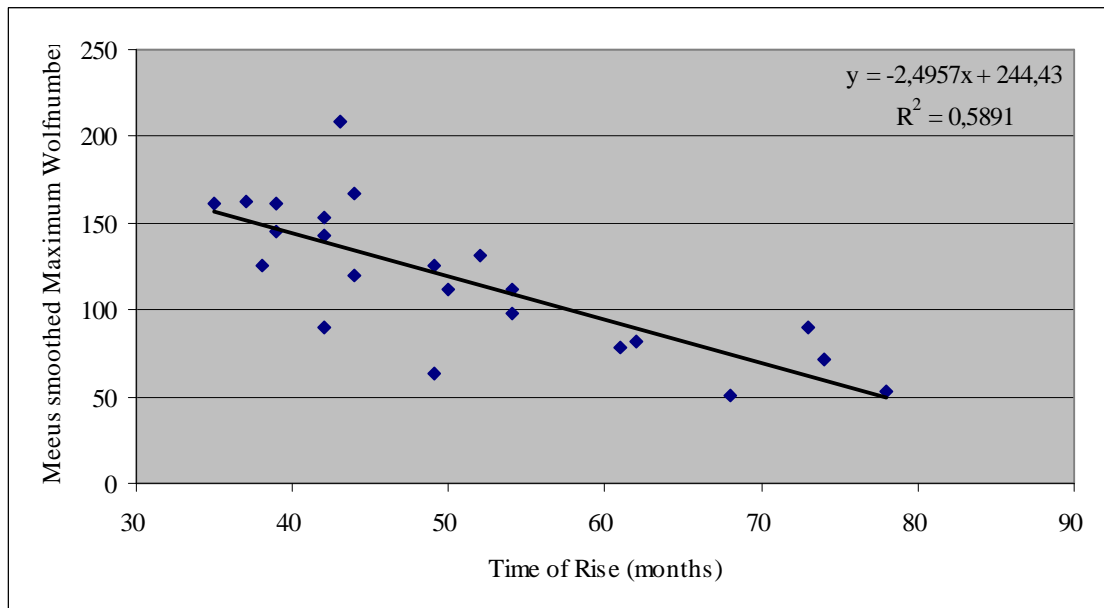
Table<sup>1</sup> underneath shows for each solar cycle the length in months of the previous solar cycle (LengthSC-1), the Meeus smoothed<sup>2</sup> minimum Wolfnumber Rmin, the number of months that the Wolfnumber was beneath 20 ( $R < 20$ ) during cycle transition, the number of spotless days ( $\#R=0$ ) during the solar cycle transit, the time of rise between the minimum and subsequent maximum of the solar cycle (T-rise), and the Meeus smoothed maximum Wolfnumber Rmax. The data for SC24 are conservative or current values. As can be readily seen, there are significant differences in these parameters between the individual solar cycles. For the purpose of this article, the last two rows in the table are of importance. They show for each parameter how well it correlates with the maximum Wolfnumber Rmax (“(-)” means an inverse correlation), and the standard deviation on the maximum Wolfnumber predicted by this parameter.

| SC                        | LengthSC-1 | Rmin  | R<20    | #R=0    | T-rise  | Rmax SC |
|---------------------------|------------|-------|---------|---------|---------|---------|
| SC 1                      | -          | 6,8   | 39      | -       | 73      | 90,4    |
| SC 2                      | 135        | 9,6   | 16      | -       | 38      | 125,3   |
| SC 3                      | 106        | 7     | 23      | -       | 35      | 161,8   |
| SC 4                      | 107        | 9,1   | 20      | -       | 42      | 143,4   |
| SC 5                      | 169        | 2,8   | 54      | -       | 78      | 52,5    |
| SC 6                      | 146        | 0     | 96      | -       | 68      | 50,8    |
| SC 7                      | 153        | 0,1   | 68      | -       | 74      | 71,5    |
| SC 8                      | 124        | 7,4   | 26      | -       | 42      | 152,8   |
| SC 9                      | 119        | 10,7  | 22      | -       | 52      | 131,3   |
| SC 10                     | 150        | 3,3   | 33      | 654     | 54      | 98,5    |
| SC 11                     | 135        | 4,3   | 22      | 406     | 39      | 144,8   |
| SC 12                     | 140        | 2     | 58      | 1028    | 61      | 78,1    |
| SC 13                     | 134        | 4     | 53      | 736     | 42      | 89,5    |
| SC 14                     | 139        | 2,8   | 53      | 938     | 49      | 63,9    |
| SC 15                     | 141        | 1,1   | 54      | 1019    | 50      | 112,1   |
| SC 16                     | 118        | 5,6   | 29      | 534     | 62      | 82      |
| SC 17                     | 125        | 2,9   | 44      | 568     | 44      | 119,8   |
| SC 18                     | 127        | 6,5   | 21      | 269     | 39      | 161,2   |
| SC 19                     | 120        | 3,2   | 25      | 446     | 43      | 208,4   |
| SC 20                     | 124        | 8,5   | 22      | 227     | 54      | 111,6   |
| SC 21                     | 139        | 12,4  | 26      | 272     | 44      | 167,1   |
| SC 22                     | 126        | 12,8  | 27      | 273     | 37      | 162,1   |
| SC 23                     | 116        | 7,9   | 26      | 309     | 49      | 125,6   |
| SC 24                     | > 138      | < 4,8 | > 36    | > 450   | -       | -       |
| Corr. r <sup>2</sup> Rmax | (-)0,39    | 0,32  | (-)0,55 | (-)0,43 | (-)0,59 | -       |
| StDev Pred                | 32,9       | 34,2  | 27,9    | 31,0    | 26,6    | -       |

<sup>1</sup> Raw daily and monthly data from Daily Wolfnumbers from SIDC, RWC Belgium, World Data Center for the Sunspot Index, Royal Observatory of Belgium, 1749-2008. <http://sidc.oma.be/sunspot-data/>

<sup>2</sup> The Meeus smoothed Wolfnumber  $R_{si}$  for the month “i” is calculated as follows:  $R_{si} = (11 \cdot R_i + 10 \cdot (R_{i-1} + R_{i+1}) + 9 \cdot (R_{i-2} + R_{i+2}) + 7 \cdot (R_{i-3} + R_{i+3}) + 5 \cdot (R_{i-4} + R_{i+4}) + 3 \cdot (R_{i-5} + R_{i+5}) + R_{i-6} + R_{i+6}) / 81$ .  $R_{i \pm x}$  is the Wolfnumber of the month “x months” prior or after the month “i” for which  $R_{si}$  is calculated.

Let's start by focusing on the first and well-known Waldmeier law (1935), which states that the shorter the time of rise  $T_{\text{rise}}$ , the higher the maximum<sup>3</sup>. This inverse relation has a correlation  $r^2$  of 0,59, "... an assured relation". Graph underneath shows this relationship well. However, it may be immediately clear that there is a large uncertainty in the prediction of the subsequent maximum Wolfnumber: The standard deviation is a huge 26,6! This means in practice that if we would measure a time of rise of 42 months, the predicted maximum Wolfnumber would be 140. However, due to the uncertainties of the method used, the true Wolfnumber can be expected anywhere between 113 and 167! In other words, from a maximum lower than that of SC23 to one higher than that of the very active SC22...



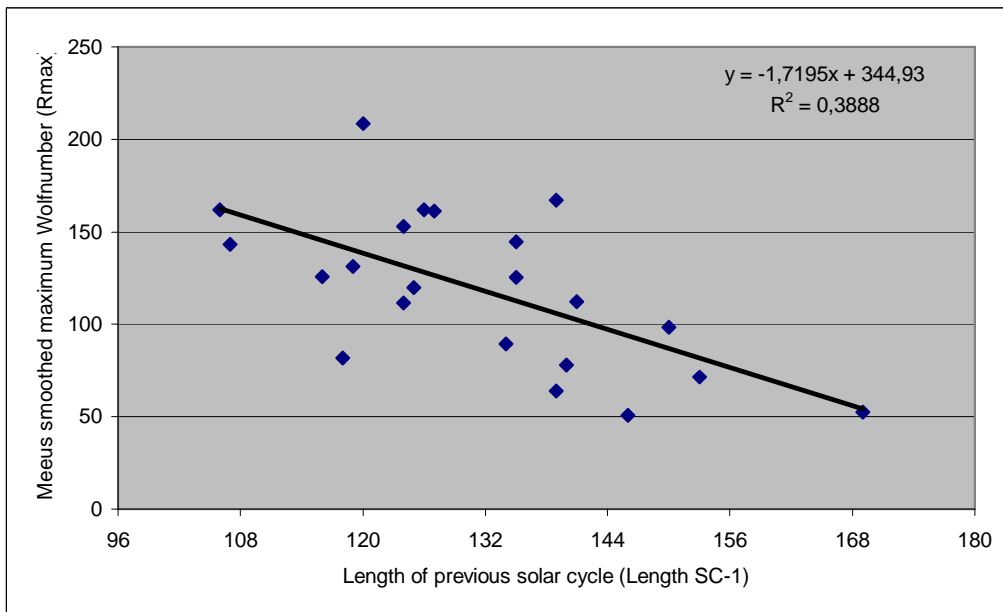
It gets even worse! Some solar cycle maxima are even well outside the error margin band. For example, take a look at cycles 19 and 13 which have both a  $T_{\text{rise}}$  of about 42. For the predicted  $R_{\text{max}} = 140 \pm 27$ , the corresponding true  $R_{\text{max}}$  arrives at respectively 208 and 89! This is the very reason why NASA and other spaceweather depending operators are looking for prediction methods with a much lower error margin.

Now, all considered cycle minimum parameters have correlations with  $R_{\text{max}}$  that are even lower than  $T_{\text{rise}}$ , and thus have even bigger standard deviations. The correlation obtained with the parameter  $R_{<20}$  (0,55) comes closest to that with  $T_{\text{rise}}$ . With 0,43, the parameter  $\#R=0$  is already much less correlated. All these parameters use data from the new solar cycle, which may in part explain their somewhat higher correlations.

The length of the previous solar cycle, as well as the minimum Wolfnumber, correlate with  $R_{\text{max}}$  at 0,39 and 0,32, and have a standard deviation of about 33. As the graph underneath shows, the relation is apparently there, but predicting from these parameters the next cycle amplitude is quite a different story. The uncertainty remains very big. For example, the cycles preceding SC 14 and 21 both had lengths of 139 months (comparable to the length of the current, though not yet finished SC23). However, for the predicted  $R_{\text{max}} = 106 \pm 33$ , the

<sup>3</sup> Beck et al., Solar Astronomy Handbook, page 206, Willmann-Bell, 1995

corresponding true Rmax is respectively 63,9 and 167,1! This is again well outside the standard deviation.



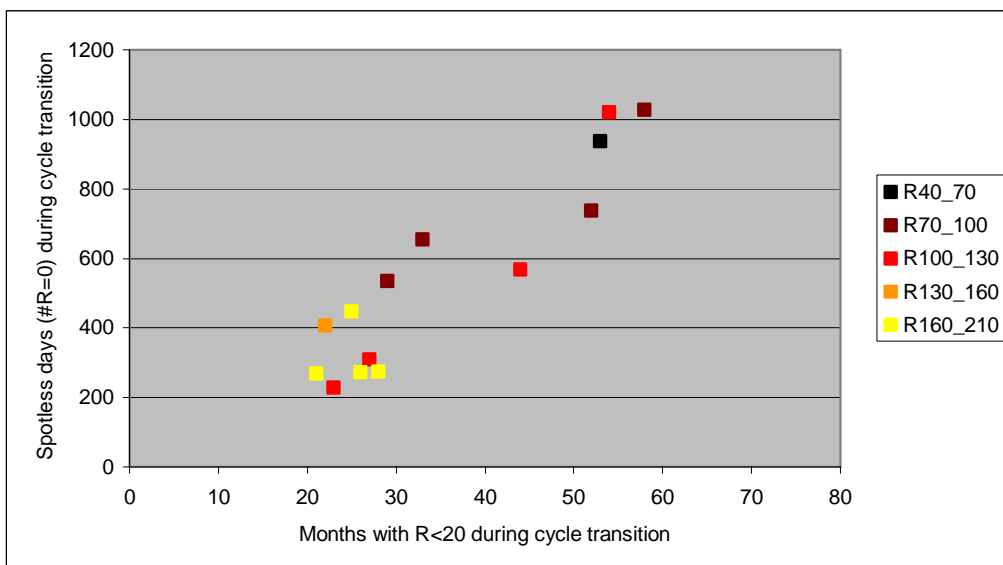
### Combining 2 minimum parameters

From the previous analysis, it is clear that with only one parameter, the uncertainty in the predicted maximum Wolf number is very big. Therefore, one could consider to combine 2 minimum parameters in order to get a better fit with the subsequent amplitude.

In the graph underneath, the two parameters having the best correlation with Rmax, i.e.  $R < 20$  and  $\#R=0$ , were combined. The cycle amplitudes were put in “baskets” of 30 starting at 40 (so 40-70, 70-100, ..., >160). Each basket was given a different colour, with yellow the most active cycles and black the least active.

As can be seen, there are 2 areas with active cycles ( $R_{max} > 130$ ) and inactive cycles ( $R_{max} < 100$ ), but unfortunately both areas contain cycles with intermediate amplitudes (red dots,  $R_{max}$  between 100 and 130). This increases the uncertainty even more.

Combining other minimum parameters leads to similar results.



## Multiple regression

Using the regression tool in Excel's data-analysis package, one can combine several parameters and get their significance and combined correlation to Rmax.

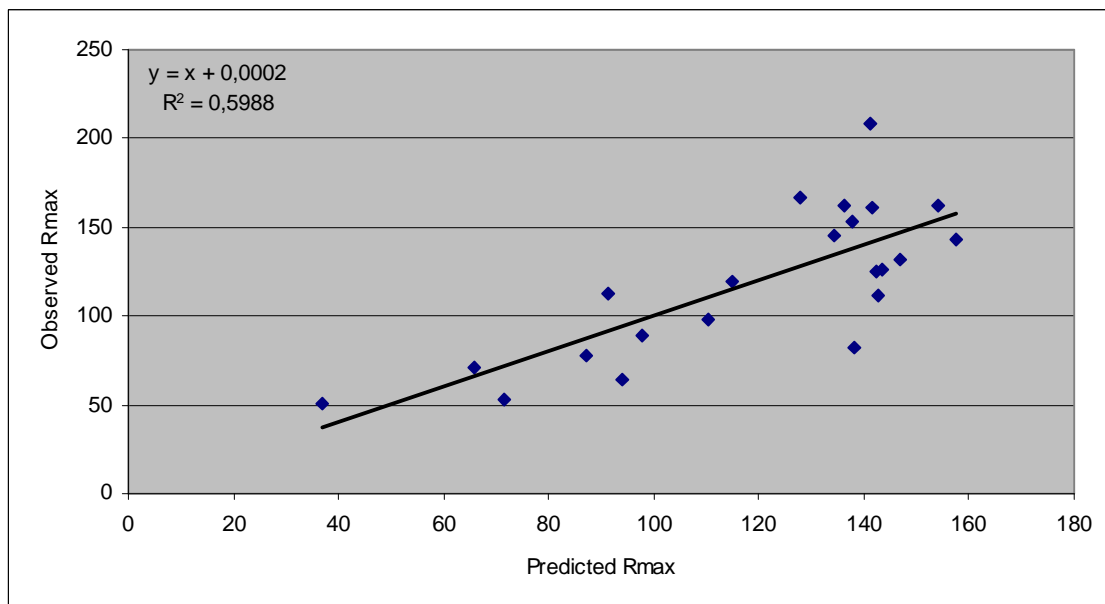
The tool was applied to two data-series. The first contain all 4 minimum parameters, but are only available for 14 solar cycles. The second series contain only 3 parameters (no early data for #R=0), but are available for 22 cycles<sup>4</sup>.

In the first series, all parameters have a significant contribution. Unfortunately, the correlation with Rmax is only 0,46, and the resulting standard deviation is 30,2. Moreover, the length of the previous SC and the minimum Wolfnumber anti-correlate with the previously found relationships.

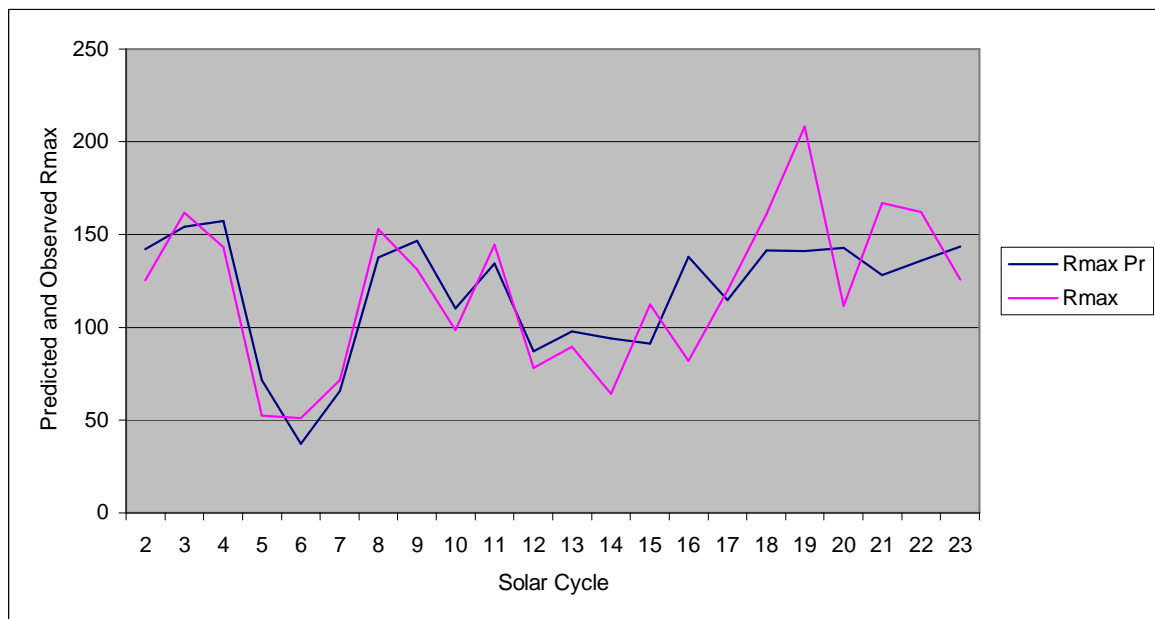
In the second series, the correlation with Rmax is 0,60 (slightly better than T-rise!), and the resulting standard deviation is 26,7. According to the tool, the contribution of the parameter R<20 is not significant. Coefficients for all parameters are given in table underneath.

| Series | #SC | LengthSC-1 | #R=0    | Rmin    | R<20    | Constant | r <sup>2</sup> | StDev |
|--------|-----|------------|---------|---------|---------|----------|----------------|-------|
| I      | 14  | 0,2965     | -0,0875 | -1,8274 | -0,676  | 166,2    | 0,46           | 30,2  |
| II     | 22  | -0,7107    | -       | 0,1659  | -1,1984 | 255,9    | 0,6            | 26,7  |

The graphs underneath illustrate the correlation between the predicted and observed amplitude of the solar cycle for series II. The uncertainty-problem persists. It is also interesting to see that the correlation holds up quite well until about SC13. Apparently, there is one (or more) parameter missing in this statistical analysis.



<sup>4</sup> 22 cycles and not 23, because the length for SC 0 can not be deduced from the SIDC-data. The official monthly Wolfnumbers go back "only" to 1749.



### **Predicting the amplitude of SC24**

From the above results, it may be clear that there is a big uncertainty in predicting SC24 maximum based on cycle minimum parameters alone, regardless of the method applied. Assuming the current<sup>5</sup> predicted values and timing for Rmin (4,0 in February 2008) and R<20 (last in Feb 2009), and a linear fading out of the number of spotless days (from 20 to 0 starting May 2008, each month 1 day less), table underneath provides the predicted values for the SC24-maximum. From these values and especially due to the corresponding standard deviations, SC24-amplitude can range from 70 to 160. Therefore, statements based on these results need to be handled with care.

| Parameter   | SC24-current | Rmax Pred | StDev |
|-------------|--------------|-----------|-------|
| Length SC-1 | 141          | 102,5     | 32,9  |
| Rmin        | 4            | 106,9     | 34,2  |
| R<20        | 37           | 118,0     | 27,9  |
| #R=0        | 530          | 124,9     | 31,0  |
| Series I    | -            | 129,4     | 30,2  |
| Series II   | -            | 112,0     | 26,7  |

<sup>5</sup> Data source: SWPC - <http://www.swpc.noaa.gov/ftplib/weekly/Predict.txt>