# Has the maximum of Solar Cycle 23 appeared?

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**Abstract** **In this note, we define firstly a compositive parameter as an index describing the level of solar activity in a solar cycle. The parameter is derived from a combination of the smoothed monthly mean sunspot number with the fluctuation of the associated monthly mean sunspot numbers to the smoothed one. Then, a method is developed for estimating the time of the appearance of a solar maximum based on the conception of similar cycles. An application of the method to the 23rd solar cycle shows that the maximum of the cycle should have appeared in the period from April to August 2000, and the descending phase of Cycle 23 has come.**

**Keywords: solar cycle, sunspot number, estimate of peak time, 23rd solar cycle.**

Smoothed monthly mean sunspot numbers (smoothed numbers hereafter) are widely used to describe levels of solar activity and decide characteristics such as phases and extrema of a solar cycle. However, we cannot decide the peak value and peak time of a solar cycle from observational data until at least the eighth month after the appearance of the maximum, due to the need of 13 monthly mean sunspot numbers for calculating a smoothed number (see eq. (1)). Now, it is not far to or from the maximum of Cycle 23, but we are still not able to know the precise time of the cycle's maximum. On the other hand, predictions of the time of the 23rd cycle's maximum published before or during the minimum of the cycle at the beginning show a large dispersion to each other: the time range of the appearance of the cycle's maximum covers a long period from June 2000 to June 2006[1]. While predictions published recently show a common tendency: the peak time of the cycle is in A.D. 2000— 2001[2−5],1). Thus, whether the maximum of Cycle 23 has appeared is still an open question at present.

In this note, we try to develop a method for estimating the appearance time of a cycle's maximum when it is not far to or from the maximum. Firstly, we define a compositive parameter derived from a smoothed sunspot number and a fluctuation of 13 associated monthly mean sunspot numbers to the smoothed number as a new index, indicating the solar activity level. Then, we study the possible trace of the index of a certain cycle around its maximum, and give an estimation of the peak appearance time of the cycle. An application of this method to Cycle 23 shows that the maximum of Cycle 23 should have appeared in the period from April to August 2000. Namely, the maximum of Cycle 23 has appeared, and it is in the descending phase of the cycle even if there might be a sub-peak in the phase.

## 1 The trace of the level of solar activity near a maximum

The definition of a smoothed monthly mean sunspot number, $R(M, n)$, for the month $n$ and cycle $M$ and the fluctuation $D(M, n)$ of the associated 13 monthly mean sunspot numbers to $R(M, n)$ are given in eqs. (1) and (2), respectively. The former is an indicator of the mean level of solar activity, while the latter can be used to reflect the possible deviation of the observed activity level to the mean one.

$$R(M,n)=\frac{1}{12}\left\{\frac{1}{2}[r(M,n-6)+r(M,n+6)]+\sum_{j=n-5}^{n+5}r(M,j)\right\}, \tag{1}$$

$$D(M,n)^2=\frac{1}{12}\left\{\left\{\frac{1}{2}[r(M,n-6)+r(M,n+6)]-R(M,n)\right\}^2+\sum_{j=n-5}^{n+5}[r(M,j)-R(M,n)]^2\right\}, \tag{2}$$

where $r(M, n)$ is the monthly mean sunspot number of the month $n$, cycle $M$. The relation of $R(M, n)$ with $D(M, n)$ near the maximum of cycle $M$ can then be studied if $r(M, n)_s$ is taken around the maximum of cycle $M$.

For a month by month comparison of the level of solar activity, a compositive parameter, $A(M, n)$, is derived from $R(M, n)$ and $D(M, n)$ given in eq. (3). One may see from eq. (3) that $A(M, n)$ not only represents a combination of $R(M, n)$ and $D(M, n)$ but also makes $R(M, n)$ the dominant component in the index. Meanwhile, $A(M, n)$ is of the same magnitude as a sunspot number which is traditionally known in many fields.

1) Space Environment Center NOAA U.S., Dept. of Commerce, Predicted sunspot number and radio flux. Gopher://sec.noaa.gov/00/weekly/predict.txt, 2000, October.

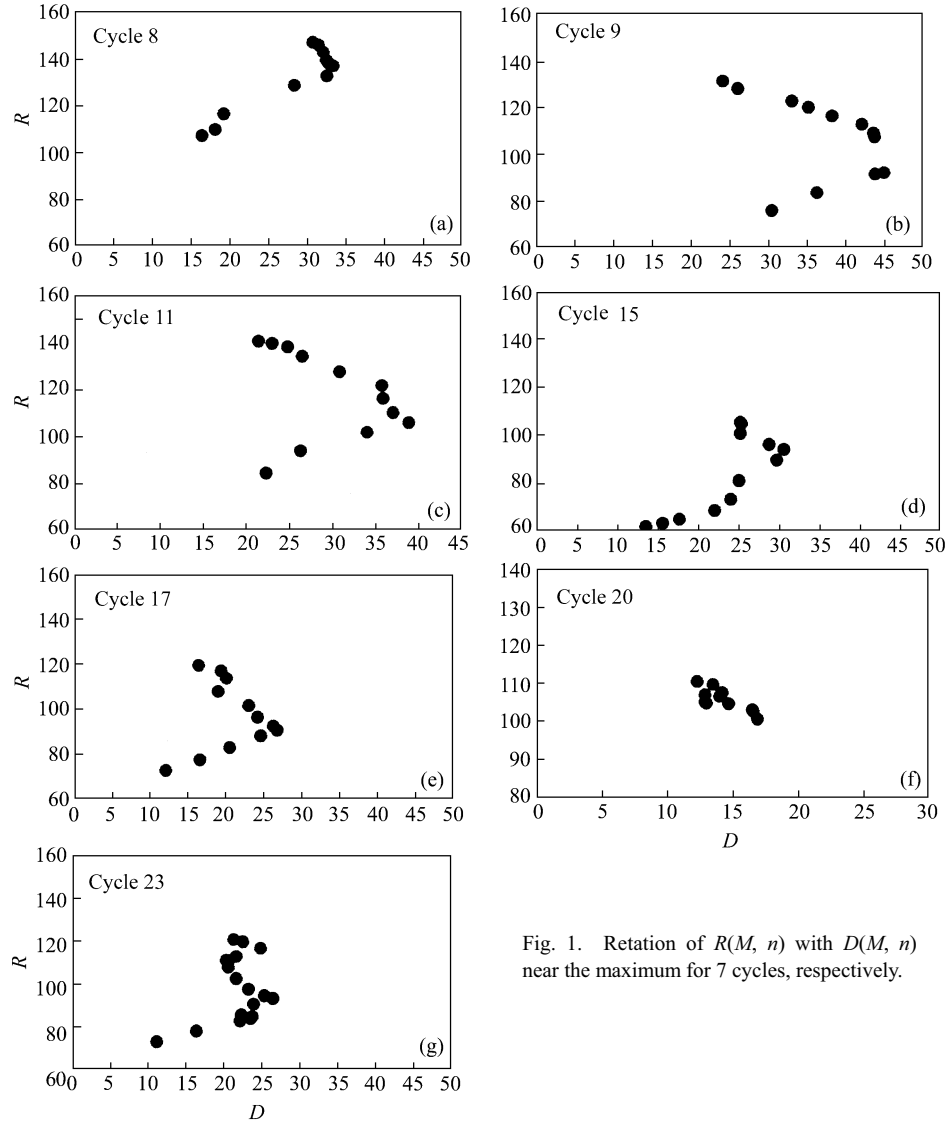


Fig. 1. Retation of $R(M, n)$ with $D(M, n)$ near the maximum for 7 cycles, respectively.

$$A(M,n)=\left[R(M,n)^2+D(M,n)^2\right]^{\frac{1}{2}}. \qquad (3)$$

Obviously for a certain cycle, e.g. cycle $M$, the relation of $A(M, n)$ with $n$ should show the variation of $A(M, n)$ with time, namely the trace of $A(M, n)$.

## 2 Decision of the 23rd cycle's maximum

We will decide the time of the 23rd cycle's maximum by means of finding the possible limits of the trace of $A(M, n)$ near the maximum. According to the observational data and predictions we have already had for Cycle 23, among the past 15 cycles (from the 8th to the 22nd cycle), several cycles satisfying the following three conditions are selected to be similar cycles to Cycle 23. The three conditions are: (i) its maximum of the smoothed number is in the range of 100—150, (ii) its ascending phase is not less than 3 years, and (iii) the shape of the relation of the $R(M, n)$ with $D(M, n)$ is morphologically similar to that of Cycle 23. We have 6 cycles which satisfy conditions (i) and (ii), and relations of $R(M, n)$ with $D(M, n)$ for these cycles and for Cycle 23 are respectively shown in fig. 1. It is easy to find that Cycle 20 does not satisfy condition (iii). Finally, we have Cycles 8, 9, 11, 15 and 17, which satisfy all of the three conditions.

In eqs. (4) and (5), an average of $A(M, n)$, written as $\overline{A}(M,n)$, and the standard error of $\overline{A}(M,n)$, written as $\Delta\overline{A}(M,n)$, can be deduced for the selected 5 cycles, using observational data and taking $n_s$ around the five maxima.

$$\overline{A}(n)=\frac{1}{5}\sum_{M}A(M,n),$$
$$M=8,9,11,15,17, \qquad (4)$$

$$\Delta\overline{A}(n)=\left\{\frac{1}{4}\sum_{M}\left[A(M,n)-\overline{A}(n)\right]^2\right\}^{1/2},$$
$$M=8,9,11,15,17. \quad (5)$$

Results obtained in this way mentioned above are shown in fig. 2, where black points and pairs of short bars represent respectively $\overline{A}(M,n)_{\mathrm{s}}$ and $\Delta\overline{A}(M,n)_{\mathrm{s}}$ for the 5 cycles. One can see that $\overline{A}(M,n)_{\mathrm{s}}$ and $\Delta\overline{A}(M,n)_{\mathrm{s}}$ in fig. 2 unitedly and clearly describe the range of the 23rd cycle's trace. Then, using 15 groups of observational data taken from the latest 15 months (Feburary 1999—April 2000) of Cycle 23, we get 15 values of $A(23, n)$, labeled by circles in fig. 2. By moving these circles in the way parallel to axis $n$ and considering the error bars, we may find two extreme cases outlining the most possible limits of the trace of Cycle 23 by two lines of circles (fig. 2), and can conclude that the maximum of Cycle 23 would have appeared in the period from April to August 2000, and it is now in the descending phase of the cycle.

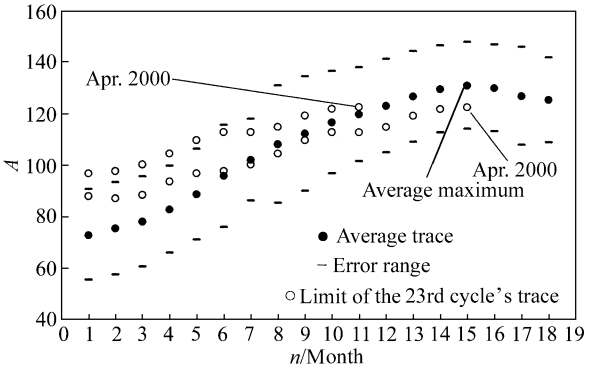


Fig. 2. Average path around the maximum for 5 cycles similar to Cycle 23 and decision of the time of maximum of Cycle 23.

## 3 Discussion

The time estimation of the maximum of a certain cycle given by the method developed in this note is strongly related to the selection of similar cycles. The more strictly the similar conditions are used in the method, the less errors may be obtained but the larger risk must be faced and *vice versa*. Although the time span of our result is 5 months, from April to August 2000, we may definitely state that the maximum of Cycle 23 has appeared.

A similar idea was successfully proposed to forecast the beginning minimum of the 23rd cycle in 1996[6]. Comparably, in this note, we not only use the widely accepted smoothed numbers instead of the one used in 1996, but also extend the forecasting object of our study from minima to maxima of solar cycles.

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