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LETTER

Letter to the Editor

Longterm prediction of solar activity using Moscow Neutron Monitor Pressure-Corrected Values

K.J. Li[1,2] **and X.M. Gu**[1,3]

[1] Yunnan Observatory, CAS, 650011 Kunming, P.R. China
[2] National Astronomical Observatories, CAS
[3] United Laboratory of Optical Astronomy, CAS

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Abstract. In this paper, we use a function similar to the Planck function to reproduce the Moscow Neutron Monitor Pressure-Corrected Values of the time January 1958 to December 1998 and then give the predicted values after the year 1998. This kind of the values is found to be anticorrelated with sunspot numbers at a very high level when the value series has a backward phase shift of 7 months. An attempt to predict solar activity of solar cycle 23 has been done. For solar cycle 23, we predict that solar activity should peak at the year 2001.7 with a maximum amplitude of about 151.1 (in terms of smoothed monthly mean sunspot number).

Key words: Sun: sunspots – Sun: activity

1. Introduction

The cyclical behaviour of solar activity, in particular the 11-year sunspot cycle, is now a well-known property of the Sun. Apart from providing information of the physical process inside the Sun, solar activity gives rise to the variations of the solar-terrestrial system, for example, solar activity controls the ion density in the upper portion of the Earth atmosphere and therefore influences the propagation of radio waves, so predictions of solar activity are very important (Hong Qinfang 1984, 1988, 1990).

The first method proposed to predict the sunspot cycle was autoregressive models and since then a great variety of prediction methods have been applied that can be divided into two groups: one relies alone on the sunspot series, the other includes additional external information (Hanslmeier, Denkmayr, and Weiss 1999). For solar cycle 23, Wilson (1992) first gave the prediction values of maximum sunspot number ($R_{\rm m}$) as 198.8 ± 36.5 or 213.9 ± 37.5. Schatten and Pesnell (1993) predicted that $R_{\rm m}$ should be 170±2.5 at the year 1997.7 ± 1. Letfus (1994) predicted that $R_{\rm m}$ should be 195.1$\pm$17.1 and rise time be 3.7 ± 0.5 years. Li (1997) used one component of monthly mean $A_{\rm p}$ indices to predict that $R_{\rm m}$ should be 149.3 ± 19.9 and rise time be 4.2 ± 0.2 years. Bravo and Steward (1997) discussed the correlation between sunspot and coronal hole cycles and found that solar cycle 23 should have a magnitude of about 190 at early time of the year 2001. Shastri (1998) estimated the maximum magnitude of solar cycle 23 as about 152. Lantos and Richard (1998) predicted that the maximum amplitude of solar cycle 23 should be about 168 ± 15, peaking sometime in 1999–2000. Recently, Hanslmeier, Denkmayr, and Weiss (1999) used the combined method to predict maximum of 160, early in the year 2000 for solar cycle 23. In this paper, we use the Moscow Neutron Monitor Pressure-Corrected Values to predict the developing behavior of solar cycle 23.

Send offprint requests to: K.J. Li

2. Solar activity prediction of solar cycle 23

Hathaway, Wilson, and Reichmann (1994) used a function to reproduce both the rise and the decay parts of the sunspot number cycles, the function is similar to the Planck function. Lately, Li (1999) used a function to describe the shape of the sunspot area cycles, which is also similar to the Planck function. Here we attempt to use a function, which is also similar to the Planck function, to reproduce the Moscow Neutron Monitor Pressure-Corrected Values (MNMPCV). The values, which are given by Solar-Geophysical Data (1999a), extend from January 1958 to December 1998. The function used here is of the form:

$$f(t) = \frac{a(t-t_0)^3}{e^{(t-t_0)/b} - c} - d \qquad (1)$$

where parameters a, b, c, d, and t_0 are adjusted to give the best-fit of the observed MNMPCV. Fig. 1 gives comparison of the observed MNMPCV (in terms of smoothed monthly mean values) and their best-fit values. The figure shows that the theoretical values satisfactorily represent the observed MNMPCV except the values of the time 1970 to 1979, from which the both have slight difference. So on the whole, the function can reproduce the observed MNMPCV. We calculate the theoretical values corresponding to the observed values of the period 1990 to 1998 (i.e. the profile marked by the letter D in Fig. 1) many times by

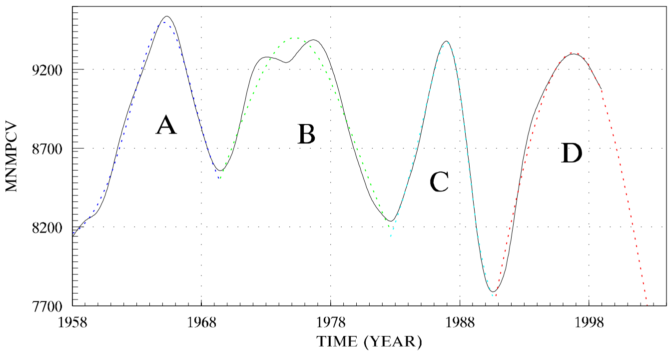

Fig. 1. Comparison of the smoothed Moscow Neutron Monitor Pressure-Corrected Values (MNMPCV) (the solid line) and their best-fit values (the dotted line).

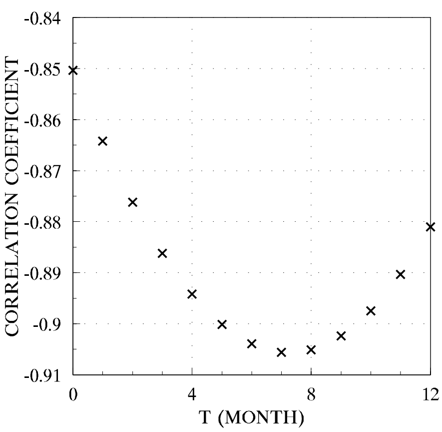

Fig. 2. Cross-correlation coefficient between the total MNMPCV and sunspot numbers for different backward shifts.

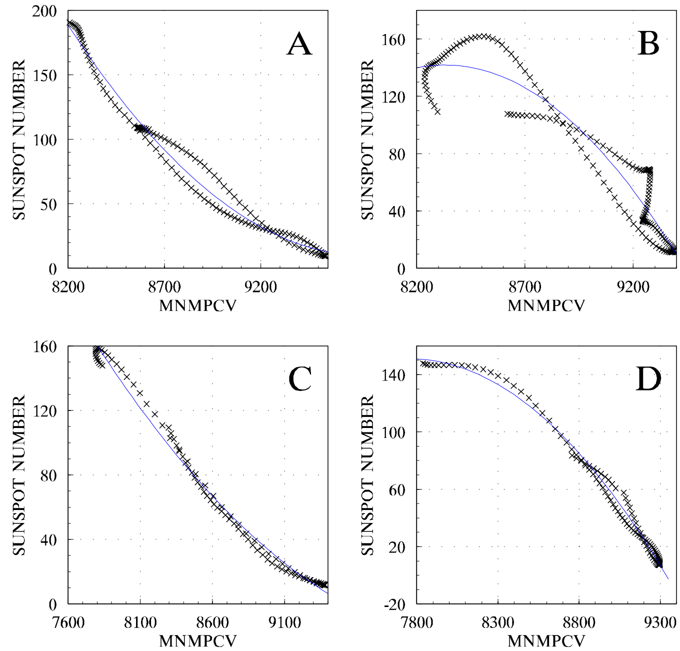

Fig. 3. Results of cross-correlation analysis between sunspot numbers and the MNMPCV of the profiles A, B, C, and D, respectively. The solid lines are the regressive curves of the observed values marked by the symbol '$\times$'.

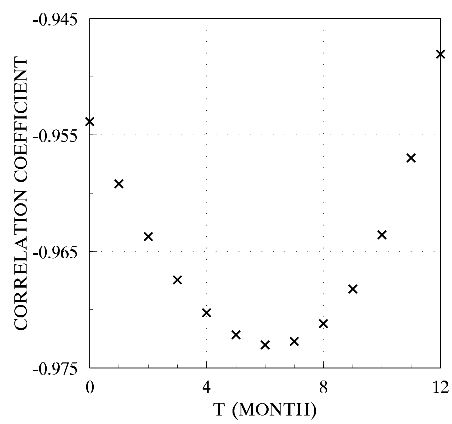

Fig. 4. Cross-correlation coefficient between the MNMPCV of the profile D and sunspot numbers for different backward shifts.

reducing the last one value at one time, and find that the given values of the profile D could already determine the adequate values after the time 1998, i.e. the 'predicted' values.

The result of the cross-correlation analysis of the smoothed MNMPCV and sunspot numbers, which are also given by Solar-Geophysical Data (1999b), is shown in Fig. 2, in which the abscissa T is the backward shift of the MNMPCV versus sunspot numbers. The figure indicates that a very good anticorrelation exists with a shift of 7 months when the correlation coefficient has a value of -0.905613. This should have a clue for us to do a prediction of solar activity by using the MNMPCV.

On the condition of a 7-month shift we calculate the correlation coefficients of sunspot numbers and the four profiles A, B, C, and D respectively and their regressive curves, which are of the form of 2-order polynomial, respectively. Their correlation coefficient are -0.970657, -0.919272, -0.988799, and -0.972742, respectively. Fig. 3 shows the results of the cross-correlation analysis of sunspot numbers and the four profiles respectively. In order to give accurate predicted values we carefully do a cross-correlation analysis for the profile D. The result of the cross-correlation analysis of the profile D is shown in Fig. 4. The figure indicates that a very good anticorrelation exists with a shift of 6 months when the correlation coefficient has a value of -0.973018. In fact, Fig. 3(D) gives the result with a 6-month shift.

According to the four regressive curves, we calculate the 'predicted' values of sunspot numbers through the MNMPCV. Fig. 5 shows the comparison of the observed and the predicted values of sunspot numbers. The figure indicates that solar activity of solar cycle 23 should peak at the year 2001.7 with a maximum amplitude of about 151.1.

3. Conclusions and discussions

In this paper, firstly, we use a function similar to the Planck function to reproduce the Moscow Neutron Monitor Pressure-Corrected Values (MNMPCV) of the time January 1958 to

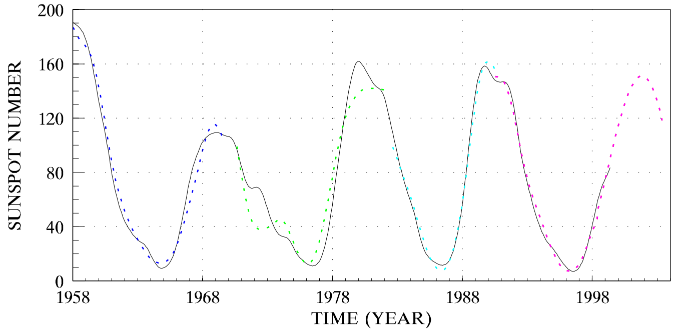

Fig. 5. Comparison of the observed values and predicted ones (the dotted line) of sunspot numbers.

December 1998. Secondly, we analyse the correlation of the MNMPCV and sunspot numbers and find that the both are anticorrelated at a very high level after a 7-month backward shift of the MNMPCV. Then we attempt to do a solar activity prediction of solar cycle 23. For each of the four profiles of the MNMPCV, a regressive curve of 2-order polynomial can represent a very good correlation of the MNMPCV and sunspot numbers. The first three profiles of the MNMPCV are a complete profile, but the fourth profile (profile D) is not. Under the assuptions of that (1) a regressive curve of 2-order polynomial could represent a very good correlation of the MNMPCV and sunspot numbers, which are justified by the first three profiles, (2) the existed values of the fourth profile could already give the accurate regressive curve of the whole profile, we give the developing behavior of solar activity of solar cycle 23. The existed observed values of the fourth profile are much more than half of the whole profile, so we think the second assumption may be approximately acceptable. For solar cycle 23, we predict that solar activity should peak at the year 2001.7 with a maximum amplitude of about 151.1 (in terms of smoothed monthly mean sunspot number).

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