A method to predict amplitude and date of maximum sunspot number

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Abstract A method to predict the amplitude and date of the maximum sunspot number is introduced. The regression analysis of the relationship between the variation rate of monthly sunspot numbers in the initial stage of solar cycles and both of the maximum and the time-length of ascending period of the cycle showed that they are closely correlative. In general, the maximum will be larger and the ascending period will be shorter when the rate is larger. The rate of sunspot numbers in the initial 2 years of the 23rd cycle is thus analyzed based on these grounds and the maximum of the cycle is predicted. For the smoothed monthly sunspot numbers, the maximum will be about 139.2 ± 18.8 and the time-length of ascending period will be about 3.31 ± 0.42 years, that is to say, the maximum will appear around the spring of the year 2000. For the mean monthly ones, the maximum will be near 170.1 ± 22.9 and the time-length of ascending period will be about 3.42 ± 0.46 years, that is to say, the appearing date of the maximum will be later.

Keywords: **solar activity, prediction, sunspot number, 23rd solar cycle.**

The prediction of solar activity level is necessary for the studies and services of the solar terrestrial environment and the research of some natural disasters. Although there is not enough physical base to take the sunspot numbers as the index of the solar activity, it is often used to describe the overall level

of the solar activity since the sequence of sunspot number is long and continuous[1]. In general, making an accurate prediction of sunspot numbers is difficult at present since the variation feature of sunspot numbers is very complex. Many scholars are continuously studying the rule of solar activity in order to find better methods to predict the activity. Many predictions of the maximum sunspot number of the 23rd cycle have been done, but there are many obvious differences in the predictions based on different methods[2-6]. A summary that includes about 28 predictions of smoothed sunspot number is done by Joselyn[1]. In summary, the predicted maximum ranges from 115 ± 40 to 200 ± 35, and 130—190 is considered the consensus prediction. The appearing date of the maximum is predicted to be from January 1999 to June 2001. So it is necessary to study and predict the maximum of sunspot number of the 23rd cycle continuously. In this note, the variation rule of monthly sunspot numbers in the initial 2 years of solar cycles and the relationship between the variation and both of the maximum sunspot number and the time-length of ascending period are studied. The possible amplitude and date of maximum sunspot number of the 23rd solar cycle are predicted by analyzing the variation of monthly sunspot numbers in the initial 2 years of the cycle.

1 Variation rate of monthly sunspot numbers in the initial stage of cycles

Certain variation rules of sunspot numbers are often used to predict the solar activity level. The variation rate of sunspot numbers mentioned in this note is the slope, b, which is derived from the regression for the variation of monthly sunspot numbers in the initial stage of a solar cycle. The thought, which uses the variation rate to predict the amplitude and date of maximum sunspot number for a future solar cycle, is from the investigation of the variation feature of the past 22 cycles. We find that the maximum is larger and the ascending period is shorter generally when the variation rate of monthly sunspot numbers in the initial stage of a cycle is larger.

Of course, if we use the variation rate to predict the amplitude and date of maximum sunspot number, we should analyze monthly sunspot numbers within a certain period, for example, about 2 years in the initial stage of the cycles. The variation rate of a shorter data sequence cannot describe the variation feature of the solar cycle very well. But if the period is too long, such as more than 3 years, the practical value will be reduced since the predicting time-lead is small. At present, the smoothed monthly sunspot numbers in the initial 2 years of the 23rd solar cycle have been obtained by smoothing observations and they are presented by R_{13} in this note. The author emphatically studied the variation feature of the smoothed monthly sunspot numbers in the initial 2 years of the past 22 cycles. If the variation feature of monthly sunspot numbers is highly correlative to the amplitude and date of maximum, the amplitude and date of the maximum of the 23rd cycle will be predicted by this method.

The analysis of mean monthly sunspot numbers, which is non-smoothed numbers, is very difficult since the undulation in data is large. Usually it is not used to predict the sunspot numbers. However, users need the mean monthly values. The author tried to analyze another kind of smoothed monthly sunspot numbers. This kind of numbers is obtained by averaging non-smoothed monthly numbers in 3 months and are presented by R_3. The result of the regression of the data may be able to show the variation trend of mean monthly sunspot numbers. The prediction of the sequence will be useful for estimating the maximum amplitude and date of non-smoothed sunspot numbers.

The results of regression of the variation of monthly sunspot numbers along the time for the 2 data sequences of the past 22 cycles showed that their interrelation is close. The result showed that, for the R_{13} sequence, the 22 cycles have remarkable linear correlation at 99% confidence level. The interrelation coefficients of 19 cycles are found to be larger than 0.9. For the R_3 sequence, the interrelation coefficients of 21 cycles are found to be larger than 0.8 and they also have remarkable linear correlation at 99% confidence level. Only the 5th cycle does not show linear correlation at 95% confidence level since there was anomalous undulation in the initial 2 years of the cycle.

So we can say that the sunspot number variation rate b is able to describe the variation tendency of sunspot numbers in the initial 2 years of the cycles. Especially, the feature is more obvious for R_{13} sequence with high correlation.

1) Joselyn, J. A. et al., Solar Cycle 23 Project: Summary of Panel Findings, 1996, 11.8, http://www.sel.noaa.gov/info/cycle23.html.

2 Amplitude and date of maximum sunspot number and b

We analyzed the relationship between the variation rate b of the sunspot numbers in the initial 2 years of the past 22 cycles and both of the amplitude of maximum R_M and the time-length of ascending period Lr for the two sequences. By means of correlation analysis for b and R_M, we obtained equations of the regression:

$$R_{M\text{-}13} = 53.98 + 28.98\, b_{13}, \quad (1)$$

$$R_{M\text{-}3} = 67.99 + 31.35\, b_3, \quad (2)$$

where $R_{M\text{-}13}$ and $R_{M\text{-}3}$ are the amplitudes of R_{13} and R_3 sequences, b_{13} and b_3 are their variation rates, respectively. Their correlation coefficients are 0.90 and 0.88. This indicates that the correlation between the variation rate values of monthly sunspot numbers in the initial 2 years and the variation of sunspot maximum R_M of the 22 cycles is remarkable at 99% confidence level. The two equations well describe the relationship between R_M and b of sunspot numbers in the initial stage of the past 22 solar cycles. The mean square errors are about ± 18.8 and ± 22.9 for the two sequences. The regression straight lines are shown in figs. 1 and 2 respectively.

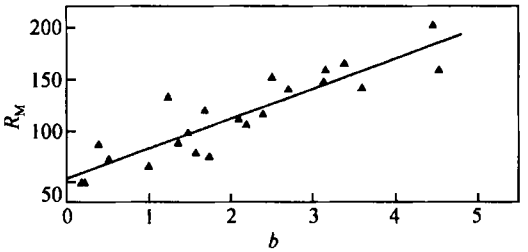

Fig. 1. The linear relation between $R_{M\text{-}13}$ and b of R_{13} sequence in the initial stage of the past 22 cycles.

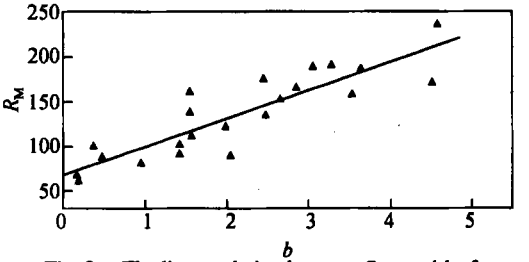

Fig. 2. The linear relation between $R_{M\text{-}3}$ and b of R_3 sequence in the initial stage of the past 22 cycles.

Through the linear regression analysis for the variation rate b and the time-length of ascending period L_r in each cycle for 2 data sequences, we obtained the correlation coefficients which are about -0.85 and -0.79 respectively. The regression straight lines are shown in figs. 3 and 4.

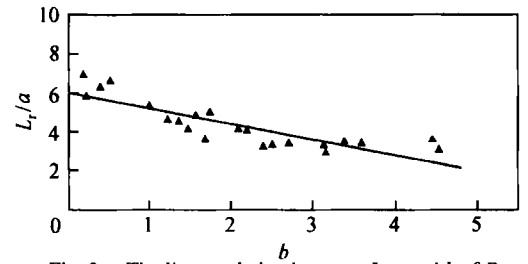

Fig. 3. The linear relation between $L_{r\text{-}13}$ and b of R_{13} sequence in the initial stage of the past 22 solar cycles.

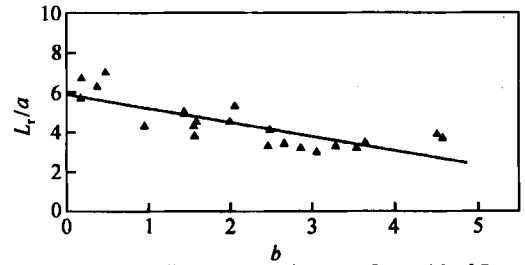

Fig. 4. The linear relation between $L_{r\text{-}3}$ and b of R_3 sequence in the initial stage of the past 22 solar cycles.

However, we found that it may be better to describe the relationship between L_r and b by parabolic equations. The equations derived from the polynomial regression analysis are

$$L_{r\text{-}13} = 6.98 - 2.10\, b_{13} + 0.29\, b_{13}^2, \quad (3)$$

$$L_{r\text{-}3} = 6.85 - 1.94\, b_3 + 0.27\, b_3^2, \quad (4)$$

in which the unit of $L_{r\text{-}13}$ and $L_{r\text{-}3}$ is year. Their complex correlation coefficients are 0.94 and 0.89, and the mean square errors are about ± 0.42 year and ± 0.46 year respectively. These show that the time-length of ascending periods and the rate of monthly sunspot numbers in the initial stage are highly correlated at 99% confidence level. Eqs. (3) and (4) may be able to describe the relationship between $L_{r\text{-}13}$ and $L_{r\text{-}3}$ and b in the past 22 solar cycles. The regression curves are shown in figs. 5 and 6 respectively.

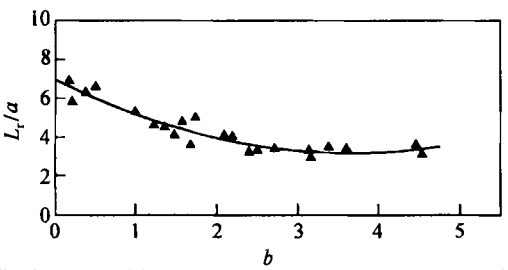

Fig. 5. The quadric correlation curve between $L_{r\text{-}13}$ and b of R_{13} sequence in the initial stage of the past 22 solar cycles.

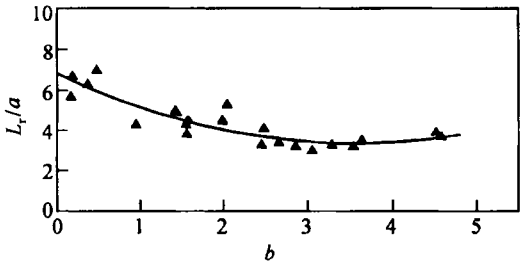

Fig. 6. The quadric correlation curve between $L_{r\text{-}3}$ and b of R_3 sequence in the initial stage of the past 22 solar cles.

3 Prediction for the 23rd solar cycle

Using observations of monthly mean sunspot numbers in the initial 2 years and more of the 23rd cycle, which are issued by SGD[7], we obtained smoothed monthly sunspot numbers for R_{13} and R_3 sequences, $R_{23\text{-}13}$ and $R_{23\text{-}3}$. The equations of linear regression for their variation are

$$R_{23\text{-}13} = -2.30 + 2.94\ t,$$

$$R_{23\text{-}3} = -6.21 + 3.26\ t,$$

where t is the monthly number from the beginning of the 23rd cycle. The correlation coefficients of the two sequences are about 0.98 and 0.95 respectively. The variation of the monthly sunspot numbers shows an obvious correlation with time at 99% confidence level in the first 2 years of the solar cycle. The rates 2.94 and 3.26 may be able to describe the variation tendency of monthly sunspot numbers very well. We may make the prediction for the 23rd cycle through plugging the two rates into eqs. (1)—(4) respectively.

From the above-mentioned result, we got that the amplitude and date of maximum of the 23rd cycle for R_{13} sequence are about 139.2 ± 18.8 and 3.31 ± 0.42 years, so the maximum will appear around the spring of the year 2000 possibly. For R_3 sequence, the values are about 170.1 ± 22.9 and 3.42 ± 0.46 years, so the appearing date of the maximum will be later than date of R_{13} sequence. The values of mean monthly sequence should be near to the values of R_3 sequence.

4 Discussion

Although some methods to predict solar activity have been obtained, it is hard to make an accurate prediction of sunspot numbers at present since the variation feature of sunspot numbers is very complex and the mechanism of the activity has not been understood thoroughly. The method in this note is also a kind of statistic prediction. However, the probability which the predictions are close to the actual values may be larger since the method is based on the regression analysis of monthly sunspot numbers in the initial 2 years and there is high interrelation among related qualities, especially for the cycle in which the undulate of monthly sunspot numbers is not large. The reason why the amplitude and date of maximum sunspot number are related to the variation rate of the initial stage of solar cycle should be studied deeply. The explanation of the relationship may be useful for the study of mechanism of solar activity.

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