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Long-term variations in the north–south asymmetry of solar activity and solar cycle prediction, III: Prediction for the amplitude of solar cycle 25

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HIGHLIGHTS

- We have analyzed the large sunspot group data during 1874–2013.
- We found 9-year and 12-year periodicities in north–south asymmetry of solar activity.
- The activity at 0–10 latitude interval leads that of the whole sphere by 9-year.
- We predicted 50 for the amplitude of the next solar cycle 25.
- Solar cycle 25 may be 31% smaller than solar cycle 24.

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ABSTRACT

The combined Greenwich and Solar Optical Observing Network (SOON) sunspot group data during 1874–2013 are analysed and studied the relatively long-term variations in the annual sums of the areas of sunspot groups in 0°–10°, 10°–20°, and 20°–30° latitude intervals of the Sun's northern and southern hemispheres. The variations in the corresponding north–south differences are also studied. Long periodicities in these parameters are determined from the fast Fourier transform (FFT), maximum entropy method (MEM), and Morlet wavelet analysis. It is found that in the difference between the sums of the areas of the sunspot groups in 0°–10° latitude intervals of northern and southern hemispheres, there exist ≈9-year periodicity during the high activity period 1940–1980 and ≈12-year periodicity during the low activity period 1890–1939. It is also found that there exists a high correlation (85% from 128 data points) between the sum of the areas of the sunspot groups in 0°–10° latitude interval of the southern hemisphere during a Qth year (middle year of 3-year smoothed time series) and the annual mean International Sunspot Number (R_Z) of $(Q+9)$th year. Implication of these results is discussed in the context of solar activity prediction and predicted 50 ± 10 for the amplitude of solar cycle 25, which is about 31% lower than the amplitude of cycle 24.

1. Introduction

Solar activity varies on many timescales (from decades to stellar evolutionary timescales, Rozelot, 2001; Hathaway, 2010; Ahluwalia and Ygbuhay, 2012). Fig. 1 shows the long-term varitions in the annual mean monthly Zürich or International Sunspot Number (R_Z) taken from the website, `ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-indices/sunspot-numbers`. The study of variations in the solar activity is important for understanding the basic mechanism of solar cycle and for predicting the level of solar activity.

It is well believed that interactions of solar convection, magnetic field, rotational and meridional flows responsible for solar activity and solar cycle. It is known that solar activity, rotation rate, and merdional velocity are latitude and time dependent. Studies on latitude and time dependent variations of these phenomena are important for understanding the mechanism behind solar cycle, which is not yet fully understood. The latitude and time dependencies in these large-scale flows may cause the magnetic fields at different heliographic latitudes during different time-intervals of a solar cycle for contributing (/relating) the activity at the same or different heliographic latitudes during its following cycle (s). These different latitude bands of activity could produce correlations useful in predictions. Recently, by using the sunspot group data during the period 1874–2006, we have found the following results (Javaraiah, 2007, 2008, hereafter Paper I, Paper II).

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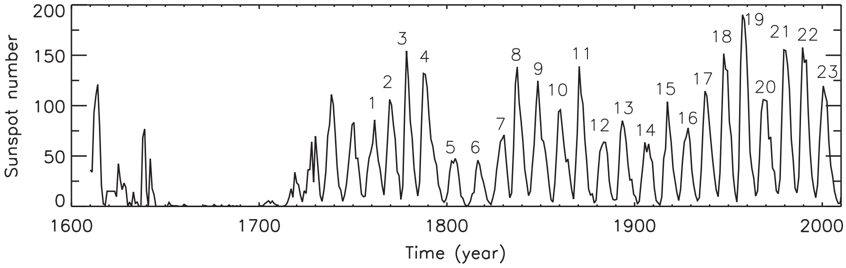

Fig. 1. Plots of annual mean international sunspot number (R_Z) against time. Near the peaks of the cycles corresponding Waldmeier solar cycle numbers are shown.

1. REL1–The sum of the areas of the sunspot groups in 0°–10° latitude interval of the Sun's northern hemisphere and in the time-interval of -1.35 year to $+2.15$ year from the time of the preceding minimum of a solar cycle n correlate well (correlation coefficient $r = 0.947$) with the amplitude (largest 13-month running smoothed sunspot number) of the next cycle $n + 1$. The correlation between the north–south difference of the corresponding area sums in these latitude and time intervals and the amplitude of cycle $n + 1$ is found to be even much higher ($r = 0.968$).
2. REL2–The sum of the areas of the sunspot groups in 0°–10° latitude interval of the southern hemisphere and in the time-interval of 1.0 year to 1.75 year just after the time of the maximum of the cycle n correlate very well ($r = 0.966$) with the amplitude of cycle $n + 1$.

The following are the abbreviations and their corresponding meanings that were used in Papers I and II, which are also used (or mentioned) in the present paper.

- n – the Waldmeier solar cycle number,
- $T_{\rm m}$ – the preceding minimum epoch of a solar cycle,
- $T_{\rm M}$ – the maximum epoch of a solar cycle,
- $R_{\rm m}$ – the value of 13-month smoothed R_Z at $T_{\rm m}$,
- $R_{\rm M}$ – the value of 13-month smoothed R_Z at $T_{\rm M}$,
- $T^*_{\rm m}$ – the time-interval of -1.35 year to $+2.15$ year from $T_{\rm m}$,
- $T^*_{\rm M}$ – the time-interval of 1.0 year to 1.75 year just after $T_{\rm M}$,
- $A_{{\rm N},n}(T^*_{\rm m})$ - the sum of the areas of the sunspot groups in 0°–10° latitude interval of the northern hemisphere during $T^*_{\rm m}$ of a cycle n,
- $A_{{\rm S},n}(T^*_{\rm m})$ – the sum of the areas of the sunspot groups in 0°–10° latitude interval of the southern hemisphere during $T^*_{\rm m}$ of a cycle n,
- $A_{{\rm N},n}(T^*_{\rm M})$ – the sum of the areas of the sunspot groups in 0°–10° latitude interval of the northern hemisphere during $T^*_{\rm M}$ of a cycle n,
- $A_{{\rm S},n}(T^*_{\rm M})$ – the sum of the areas of the sunspot groups in 0°–10° latitude interval of the southern hemisphere during$T^*_{\rm M}$ of a cycle n,
- $\delta A_n(T^*_{\rm m})$ – the difference, $A_{{\rm N},n}(T^*_{\rm m}) - A_{{\rm S},n}(T^*_{\rm m})$, and
- $\delta A_n(T^*_{\rm M})$ – the difference, $A_{{\rm N},n}(T^*_{\rm M}) - A_{{\rm S},n}(T^*_{\rm M})$.

The following equations correspond to REL1, obtained in Papers I and II (there are minor/negligible changes in the values of coefficients due to some minor data corrections):

$$R_{\rm M,\ n+1} = (1.7 \pm 0.2) A_{{\rm N},n}(T^*_{\rm m}) + (74 \pm 7), \qquad (1)$$

and

$$R_{\rm M,\ n+1} = (1.6 \pm 0.1) \delta A_{\rm n}(T^*_{\rm m}) + (100 \pm 4). \qquad (2)$$

The following equation correspond to REL2, obtained in Paper I:

$$R_{{\rm M},n+1} = (1.5 \pm 0.1) A_{{\rm S},n}(T^*_{\rm M}) + (22 \pm 10). \qquad (3)$$

It should be noted that the difference in the temporal dependence in the correlations between $R_{\rm M}$ and the sums of the areas of the sunspot groups in the latitude intervals of the northern and southern hemispheres is due to (or it implies) the temporal dependence in the north–south (N–S) asymmetry of the sunspot activity (for details on the N–S asymmetry of solar activity see Javaraiah and Gokhale, 1997; Chang, 2009, Papers I and II, and references therein). Although both the relations REL1 and REL2 are based on almost equal high correlations, they yielded a substantial different values for the amplitude of solar cycle 24, *viz.* 103 ± 10 and 74 ± 10, respectively. The current trend (not shown in Fig. 1) of 13-month smoothed monthly R_Z indicates two peaks (Gnevyshev peaks) for the current solar cycle ~24: one with value 66.9 in February, 2012 and another with value 75 in October, 2013. Obviously the prediction based on the REL1 is failed. The value 74 ± 10 predicted from the REL2, i.e., by using Eq. (3), within its uncertainty limits is close to the observed $R_{\rm M}$.

In the present analysis we determined the long-term periodicities in the differences (N–S asymmetries) between the sums of the areas of the sunspot groups in different 10° latitude intervals of the northern and southern hemispheres by using FFT and MEM. The time-dependencies in the periodicities are checked by using the Morlet-wavelet analysis. We checked whether REL1 and REL2 are connected to long-term periodicities in the N–S asymmetry of sunspot activity. By using REL2 it is possible to predict only the amplitude of a cycle with a good accuracy by about 9-year advance. Therefore, here we have also checked whether it is possible to predict the annual mean R_Z, by determining the cross-correlations between the annual mean R_Z and the annual sum of the areas of sunspot groups in different 10° latitude intervals. That is, we checked whether it is possible to predict the shape and length of a solar cycle, and also the epoch and the strength of its minimum. In addition, by using REL1 and REL2 (mainly), we predicted the amplitude of solar cycle 25.

It should be noted here that, for the first time in the solar cycles history, in the case of solar cycle 24 the second peak is larger than the first peak. REL2 seems to be related to the Gnevyshev gaps as well as the epoch of change in the sign of global magnetic field. In the current cycle the polarities of north-pole magnetic fields are already changed. Therefore, although the epoch of maximum of cycle ~24 may be October 2013, we have made a tentative prediction for the amplitude of cycle ~25 by using REL2 with reference to the first peak at February 2012.

In the next section we will describe data and method of analysis. In Section 3 we will present results, and in Section 4 we will present conclusions and a brief discussion.

2. Data and method of analysis

In Papers I and II we have used the Greenwich sunspot group data during 1874–1976 and the SOON sunspot group data during 1977–2006. Now SOON sunspot group data are used for seven more years, 2007–2013 (the data are available up to date) and