Determination of the sunspot minimum epoch between the cycles No 23 and 24 and prediction of the cycle No 24 magnitude on the base of the "Waldmeier's Rule"

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Abstract. The main purpose of this study is determination of the solar minimum date before the new sunspot cycle No 24. The purpose is realized by using of four types of mean daily data values for the period Jan 1, 2006 – Dec 31, 2009: 1) the solar radioindex $F10.7$; 2) the International sunspot number Ri; 3) the total solar irradiance index (TSI), and 4) the daily number of X-ray flares of classes from "B" to "X" by data of the soft X-ray channel (0.1–0.8 nm) of the GOES satellite. It is found that the mean starting moment of the upward solar activity tendency (the mean solar minimum) is Nov 6, 2008. So, the solar cycle No 23 length is estimated to $\sim$ 12.6 years. A conclusion for a relatively weak general magnitude of solar cycle No 24 is made. Using a relationship based on the "Waldmeier's rule" a near maximal value of the mean yearly sunspot number of $Ri = 72 \pm 27$ has been determined for cycle No 24.

Key words: Sun, solar minimum, solar cycle No 24

Определяне на епохата на слънчевия минимум между цикли №23 и 24 и предсказване на големината на цикъл №24 въз основа на „правилото на Валдмайер"

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Основната цел на това изследване е определянето на датата на слънчевия минимум преди новия слънчев цикъл №24. За тази цел са използвани среднодневните стойности на четири типа данни за периода 1 януари 2006 г. – 31 декември 2009 г.: 1) слънчевият радио-индекс $F10.7$; 2) международното число на слънчевите петна Ri; 3) индексът на пълното слънчево излъчване (TSI); 4) дневното число на рентгеновите слънчеви избухвания от класове от "B" до "X", определени по меката рентгенова емисия в канала 0.1-0.8 nm на сателита GOES. Установено е, че средният начален момент на тенденцията за нарастване на слънчевата активност (средният слънчев минимум) е 6 ноември 2008 г. По този начин дължината на слънчевия цикъл №23 е определена на $\sim$ 12.6 години. Предсказана е относително слаба големина на слънчевия цикъл №24. Чрез използване на взаимовръзка, основаваща се на „правилото на Валдмайер" е определена приблизителна стойност на максималното средно годишно число на слънчевите петна $Ri = 72 \pm 27$ за цикъл №24.

Introduction

There are clear evidences that the last solar minimum (2006–2009 AD) is the deepest one since 1913 AD, when the minimum between the Schwabe-Wolf's

sunspot Zurich numbered cycles 14 and 15 occurred. As a confirmation of that, one could point out the following arguments:

1. There had been about 700 spotless days since Jan 26, 2004 up to Dec 31, 2009.

2. In the middle of 2008 the $F10.7$ radioindex reached lowest levels for the whole period of its observation since 1947 AD (the mean monthly value for July 2008 was 65.7).

3. During the last minimum the solar wind parameters had lowest values for the completely observational period (about 50 years).

4. The radio bursts in 2008 and 2009 in the MHz–range had smallest numbers for the whole period of regular observations (since 1960 AD).

5. The almost total absence of geomagnetic activity during 2008 and 2009 AD.

The first magnetic active region, related to the new Zurich cycle No 24 was observed in Dec 13, 2007, while the first official sunspot group (NOAA 10981) in Jan 4, 2008. These events were followed from a very long period of almost 20 months until Sept 2009, with almost no activity manifestations. A stable slow increase of the new solar cycle began in Sept 2009. This is probably a sign that the minimum between the both cycles is already passed.

The problem for the official initial point of cycle No 24 and the length of the old 23 cycle is still the topic of the day. This paper presents new results for the onset of cycle No 24.

1. Data and methods

The mean daily values of four solar activity indices for the period Jan 1, 2006 – Feb 28, 2010 or total 1521 days are used in this study. These data cover the final downward phase of cycle No 23 up to Apr 2008, the deepest "quiet" phase (Apr 2008–Sept 2009), and the initial significant solar activity increasing after Sept 2009. We use the following selected data.

A. The international daily sunspot number.

B. The radioindex $F10.7$.

C. The daily numbers of soft X-ray (SXR) flares (total for classes B, C, M, and X by data of the soft X-ray 0.1—0.8 nm channel of the GOES satellite).

D. The total solar irradiance (TSI-index).

E. The mean monthly sunspot numbers Ri for solar cycles No 7–23 during the first 18 months after the corresponding minima for prediction of the amplitude of solar cycle No 24.

Thus, our study is based on data, related to solar activity phenomena in different regions of solar atmosphere. The data for series A, B, C, and E are taken from the National Geophysical Data Center (*ftp://ftp.ngdc.noaa.gov/STP*), while those for TSI – from the SORCE satellite web site (*http://lasp.colorado.edu/sorce/*).

The conventional method for detection of the minimal sunspot activity amplitude is based on 13-month smoothed sunspot numbers. The fact that the increasing phase (only 3–4 months up to Feb 2010) is very short suggests that this method could be not enough sensitive on this stage.

A least square procedure for obtaining parabolic full quadratic and cubic polynomial minimized functions of the type $\Psi = at^2 + bt + c$ or $\Psi = at^3 + bt^2 + ct + d$ are used over each one of the studied data series. There t is the number of days since Jan 1, 2006. The both types of trend polynomials for each series have been compared and the better approximation has been chosen by Snedekor-Fisher's F-parameter. Thus, the general trends are expressed by simple non-linear functions, in which only one extreme (minimum) in the studying interval exists. There could be obtained the starting moments of cycle No 24 for every one of these data series searching for the minima of the corresponding mean least square minimized polynomials.

2. The minimum before solar cycle No 24

The calculated minima of the best trend functions are shown in Table 1 where the minima are given in calendar dates. The best-expressed trends are for the sunspot Ri series, as well as for $F10.7$ where the corresponding coefficients of correlation R are 0.53 and 0.66. Both they belong to cubic type. The trend function for TSI correlates satisfactorily well to the original data ($R = 0.49$), while this R-value is very close both to the quadratic and cubic polynomial trend type approximations. For the X-flare events the coefficient of correlation is $R = 0.38$ at cubic approximation. It is important to note that because of the large number of data (1521) all these values of R are statistically significant over 95%. The better cubic trend approximation as the quadratic one for Ri and $F10.7$ data is caused by asymmetry effect of the faster increasing of these indices during the initial upward phase of solar cycle 24 than the decreasing during the downward phase of the solar cycle No 23 before the minimum. This asymmetry is no observable in the TSI dynamics during the same time.

Table 1. The calculated minimum calendar dates before a cycle No 24

Solar index	Calendar date H_α	interval error [days]
Ri	Nov 14, 2008	54
F10.7	Oct 28, 2008	31
SXR flares	Nov 06, 2008	196
TSI	July 04, 2008	77

As it is above shown the most reliable solar cycle minima estimations are made on the base of $F10.7$ and Ri data series, where the half interval error is near or less than two months (54 and 31 days, respectively). The uncertainty of the solar cycle minimum on the base of estimations made by X-flares and TSI series is much higher ($\pm\, 3 - 6$ months with respect to the corresponding calendar dates). The TSI–minimum is earliest – in the middle of 2008. The slight increase of TSI in the second half of 2008 could be related to the corresponding increase of the total area of the bright regions (the faculae regions and the so-called "ephemeral regions" (ER)) at this time.

Such overtaking of the bright ER minimum to the main sunspot one for the last Schwabe-Wolf's cycles is discussed by Krivova et al. [2007].

The mean minimum moment for the solar cycle No 24, based on the results in Table 1 (Ri and $F10.7$) is Nov 6, 2008. It coincided with the X-ray flares minimum. On the other hand, it is close to the results of Didkovsky et al. [2009]. Thus, for the length of the Zurich cycle No 23 started in May 1996 we could obtain $\sim$ 12.6 years.

It is also interesting to compare the mean activity level of cycle No 24 during the first year after its preceding minimum to the corresponding ones of the previous few cycles. The mean monthly numbers of Ri and $F10.7$ during their first year after minima for Zurich cycles 19–24 are shown in Table 2.

If the mean monthly values of these indices during the first year after minimum is taken as a criteria for their starting increase, the cycle No 24 should be the weakest for all last six ones both in Ri and $F10.7$ series. These criteria could be taken as a pre-indicator for a very low near-maximal magnitude of this cycle, which is in good accordance with some other predictions. Such assumption is in the cource of many other forecasts for low amplitude of cycle No 24, as well as for starting of new Dalton-type supercenturial solar minimum (Badalyan, Obridko, and Sykora, [2000]; Komitov and Bonev, [2001]; Komitov and Kaftan, [2003]; Schatten and Tobiska, [2003]; Ogurtsov, [2005]; Clilverd et al., [2006]; Komitov, [2007]). In our opinion, the presented results in Table 2 should not be considered as strong evidence, but only as a possible scenario. This is related to the fact that the trends in Table 2 are obviously not very strong. The strongest cycle No 19 (maximal annual Ri=190 in 1957) has a very moderate behavior during its first year. On the other hand, it is interesting to note that the "starting year" of cycle No 22 (with a maximum in 1989–1990) was characterized by the highest Ri and $F10.7$ in comparison with all others. This could be a possible indication that solar cycle No 22 was "critical" for the long-term solar activity dynamics and it marks the "smoothing" peak of the unusually high solar activity epoch from 1940 to 1996 AD or 2000 AD, which is called at last time as "Modern supercenturial solar maximum".

Table 2. The averaged monthly Ri and $F10.7$ values during the starting first years of solar cycles No 19–24

Cycle No	Ri(first year)	F10.7(first year)
19	7.5	72.7
20	14.2	70.0
21	13.2	73.5
22	23.4	80.3
23	8.8	73.2
24	2.2	69.9

3. Prediction of the solar cycle No 24 amplitude

The estimation of the near maximum value of the annual sunspot number (W_{max}) for solar cycle No 24, is based on so-called "Waldmeier's rule" (Waldemeier, [1935]). That is expressed by the tendency of the increasing sunspot number rate during the upward phase of the Schwabe-Wolf's cycles, which is higher for the more powerful cycles than for the weaker ones.
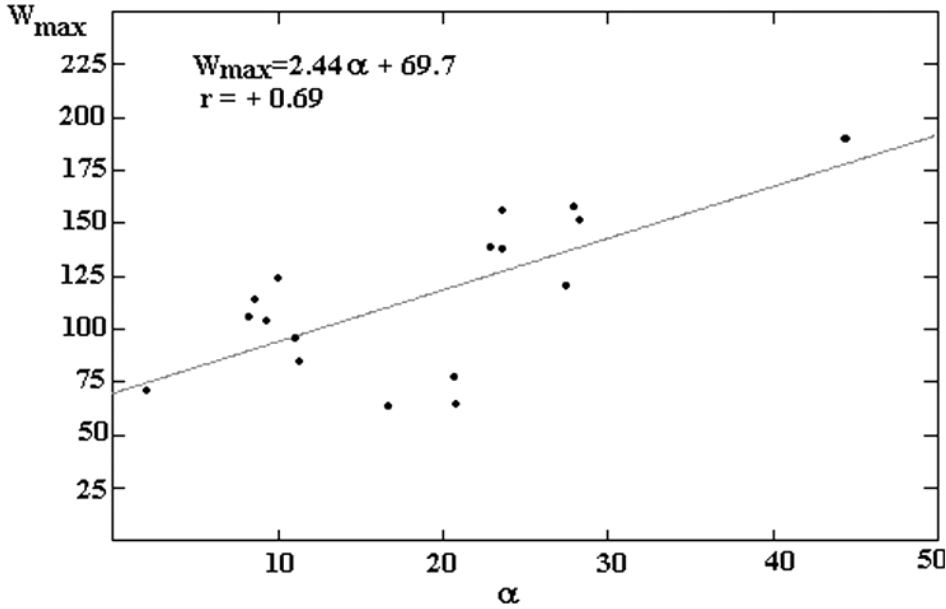

Fig. 1. The relationship between α and W_{max} for solar cycles No 7–23

Up to this moment (June 2010) there are only less than 2 years after the onset of cycle No 24. By this reason, we use information for the sunspot activity rising during the initial 18 months of all solar cycles after 1818 AD, i.e. No 7–23. Using the corresponding mean monthly sunspot numbers Ri , we calculate the mean monthly increasing $\alpha = dRi/dt$ for each solar cycle. The linear correlation relationship between α and W_{max} has been found (Fig. 1). The coefficient of correlation R is +0.69 and the relationship is :

$$W_{max} = 2.44\alpha + 69.7 \tag{1}$$

We calculate the parameter α for the first 18 months after the minimum preceding solar cycle No 24. The result is $\alpha = 0.91$. Thus, on the base of

equation (1) it is found that the magnitude of this cycle should be $W_{max} = 72 \pm 27$. The obtained value is much less than the magnitude of previous cycle No 23 (~ 121) and it is also an other indication about an oncoming Dalton-type long term solar minimum. It is interesting to point out that according a new prediction of Kane [2010], based on Ohl's method, Wmax should be even less (57 ± 25).

Conclusion

The basic results obtained in this study could be summarized in four points:

1. The local smoothed minimum between the solar Schwabe-Wolf's cycles No 23 and 24 occurred at the end of AD 2008. The averaged moment of this event, calculated on the base of four solar indices (Ri, $F10.7$, X-ray flares and TSI) is Nov 06, 2008.

2. The length of solar cycle No 23 is estimated of ~ 12.6 years.

3. The comparison between the mean "first year" values of Ri and $F10.7$ for the Zurich cycles No 19–24 shows that the start of a cycle No 24 is the weakest one among the last six cycles. This special feature of a cycle No 24 could be also an indicator for its weak general magnitude.

4. By using of a relationship based on the "Waldmeier's rule" a near maximal value of mean yearly sunspot number of 72 ± 27 has been obtained for the sunspot cycle No 24.

Acknowledgements

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