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PREDICTION OF THE AMPLITUDE OF 25[TH] SOLAR CYCLE USING THE RATE OF INCREASE OF SOLAR ACTIVITY

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ABSTRACT. A prediction of the amplitude of the 25th cycle of solar activity is proposed based on the analysis of data on 24 previous solar cycles, which relate to the statistical relationship between the rate of increase in the number of sunspots in the phase of the growth curve and the amplitude of the cycle. It turned out that the forecasting result depends on which section of the growth curve is taken as the basis for forecasting, as well as whether all 24 cycles are taken into account, or only the odd ones. The prediction result is also affected by the initial assumption about monotonicity or non-monotonicity of the growth phase. A comparison of the rates of sunspot growth in different parts of the growth phase of different cycles shows that the current cycle #25 does not show early signs of non-monotonic growth similar to those observed in the 24th cycle. It was concluded that, most likely, the maximum smoothed number of sunspots in the 25th cycle W_{max} (25) should be equal to 185 ± 18 units in the new system, which corresponds to the average power of the solar cycle, with the implementation of the Hnievyshev-Ohl rule. However, if cycle #25 will still have a non-monotonic curve of the growth phase, similar to such a curve in the previous cycle #24, then W_{max} (25) ≈ 130. With such parameters of this cycle, there are no signs of approaching the deep minimum of the age cycle in the middle 21st century. This does not exclude the fact that this deep age minimum can occur suddenly and sharply immediately after the 25th cycle, as was the case, for example, in the Dalton minimum.

Keywords: Sun, solar activity, number of sunspots, amplitude forecast of the 25th cycle, Gnievyshev-Ohl rule, minimum of the age cycle.

АНОТАЦІЯ. Запропоновано прогноз амплітуди 25-го циклу сонячної активності на основі аналізу даних про 24 попередні сонячні цикли, які стосуються статистичного зв'язку між швидкістю наростання числа сонячних плям на фазі кривої росту і амплітудою циклу. Виявилось, що результат прогнозування залежить від того, яку ділянку кривої росту взяти за основу для прогнозування, а також від того, приймати до уваги всі 24 цикли, чи лише непарні. На результат прогнозування впливає також вихідне припущення про монотонність чи немонотонність фази росту. Порівняння швидкостей наростання числа сонячних плям на різних ділянках фази росту різних циклів показує, що поточний цикл № 25 не виявляє ранніх ознак немонотонності росту, подібних до спостережених у 24-му циклі. Зроблено висновок, що, найімовірніше, максимальне згладжене число сонячних плям у 25-му циклу W_{max} (25) має дорівнювати 185 ± 18 одиниць у новій системі, що відповідає середньому по потужності сонячному циклу, з виконанням правила Гнєвишева-Оля. Однак, якщо все-таки цикл №25 буде з немонотонною кривою фази росту, подібною до такої кривої у попередньому циклі №24, то тоді W_{max} (25) ≈ 130. При таких параметрах цього циклу, немає ознак наближення глибокого мінімуму вікового циклу в середині XXI ст. Це не виключає того, що цей глибокий віковий мінімум може наступити раптово і різко одразу після 25-го циклу, як це було, наприклад, у мінімум Дальтона.

Ключові слова: Сонце, сонячна активність, число сонячних плям, прогноз амплітуди 25-го циклу, правило Гнєвишева-Оля, мінімум вікового циклу.

1. Introduction

Solar activity is a rather complex phenomenon in the Sun's atmosphere, which has a magnetic nature and cyclical changes over time. The most famous and visible is the 11-year cycle of solar activity, although there are also other cycles, including the 22-year, 44-year, and the age cycle with a duration of 70-100 years. Among specialists, the greatest attention is paid to forecasting the 11-year cycle, since it is this cycle that is associated with the most significant changes in the near-Earth space and geosphere. At present, reliable methods of forecasting solar activity have not yet been created, although there are quite a lot of scientific works on this topic. A comparison of the latest forecasts of solar activity in the new 25th cycle, which began in December 2019, is given in the work of Petrovay (2020). It follows from this comparison that even the most modern forecasting methods give significantly different results. For example, the neural network method gives the amplitude of the 25th cycle at the level of 57-91 units (Attia et al., 2013), and the attractor analysis - about 103 units. For comparison, it is worth recalling that in the previous 24th cycle, solar activity reached 116 units (in 2014). At the same time, the wavelet analysis predicts the height of the maximum of the 25th cycle at the level of 132 units (Rigozo et al., 2011), and the method of internal precursors – 175 units (Li et al., 2015). Thus, in general, the situation with the maximum of this cycle, which is expected in 2024-2026, remains unclear. However, the situation was exactly the same before, when the previous 24th cycle of solar activity was predicted (see, e.g., Lozitsky & Efimenko, 2012, 2014; Attia et al., 2013; Pishkalo, 2014; Rigozo et al., 2011; Tsirulnik et al., 1997).

The current 25th cycle attracts attention because it can be used to conclude that the long-awaited minimum of the age cycle of solar activity is approaching, which falls around the middle of the 21st century. Zharkova and Shepherd (2022) note in the recently published paper that the major solar minimum should occur in cycles No. 25-27. The purpose of present work is to obtain a predictive estimate of the amplitude of the 25th cycle, based on the rate of increase in the number of sunspots during the growth phase of this cycle.

2. Observational data and their analysis

For our analysis, we used the data posted on the site http://www.solen.info/solar/. New, revised data on the number of sunspots are presented here based on the results of a revision made by International Data Center at the Royal Belgian Observatory (Clette et al., 2014). The main changes are that Alfred Wolfer's observational series, rather than Rudolf Wolff's, is used as a basis, which increases the earlier values by a factor of about 1.67, making them commensurate with modern estimates. In addition, the values were corrected after 1947, when M. Waldmayer, in determining the relative number of sunspots, introduced weighting factors according to the size of the spots. A variable trend was also found and eliminated in the observations of the Locarno observatory, which was a reference observatory after 1980.

Cycle No. 25 began in December 2019. From this month, the months of the 25th cycle were counted, and the rate of increase in the number of sunspots $\Delta W/\Delta T$ was compared with other cycles, as well as with the maximum smoothed number of sunspots W_{max} at the top of the cycle. Similar approach was applied by Lozitsky and Efimenko (2012) but for sunspot numbers of old system.

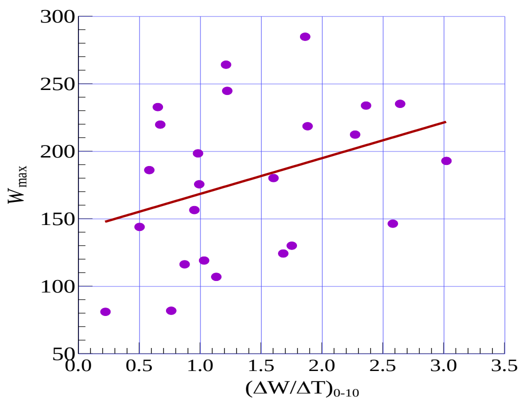

Figure 1: Empirical dependence between parameters W_{max} and $(\Delta W/\Delta T)_{0\text{-}10}$. It follows from this dependence that W_{max} (25) = 166.6 (see the text).

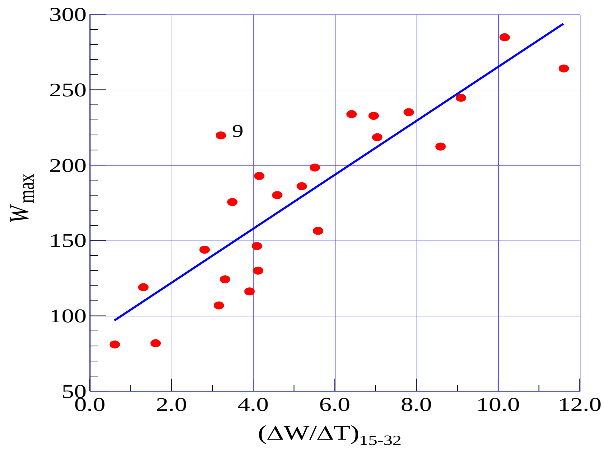

Figure 2: The same as on Fig. 1, but for averaging interval 15-32 months. From this Figure it follows that W_{max} (25) = 166.7 (see the text).

The following question is of interest: what minimum interval from the beginning of the cycle should be taken to reliably predict its maximum ? To find out this question, we considered test intervals of different lengths, starting from 10 months (Fig. 1). It can be seen from this Figure that the correlation dependence between the specified parameters is very scattered and can be approximated by a linear dependence

$$W_{max} = 26.44(\Delta W/\Delta T)_{0\text{-}10} + 141.91, \quad (1)$$

According to published data for 25th cycle, $(\Delta W/\Delta T)_{0\text{-}10}$ = 1.01, that correspnds to W_{max} (25) = 166.6. As it follows from Fig. 1, this is some middle value in range 100-250 units. Therefore, wider test intervals should be used to average out the random fluctuations of the parameters.

Fig. 2 represents the result at the averaging interval 15-32 months.

From Fig. 2 shows that the statistical relationship between the specified parameters is now closer and can be described by a linear relationship

$$W_{max} = 17.9(\Delta W/\Delta T)_{15\text{-}32} + 86.17, \quad (2)$$

According to observations for 25th cycle, $(\Delta W/\Delta T)_{15\text{-}32}$ = 4.5, which according to (2) gives the following value W_{max} = 166.7. As we can see, this value turned out to be very close to the previously obtained according to approximation (1). However, such a coincidence is obviously coincidental, given the large spread of points in Fig. 1.

Since the predicted cycle No. 25 is odd, it is interesting to consider similar correlation dependences only for odd cycles (Fig. 3). The corresponding approximating linear dependence is represented by the formula

$$W_{max} = 16.63(\Delta W/\Delta T)_{15\text{-}32} + 104.81, \quad (3)$$

Substituting the observed value for the 25th cycle $(\Delta W/\Delta T)_{15\text{-}32}$ = 4.5 into this formula, we have $W_{max}(25)$ = 179.6. Thus, switching to considering only odd cycles increases the predicted value by 13 units.

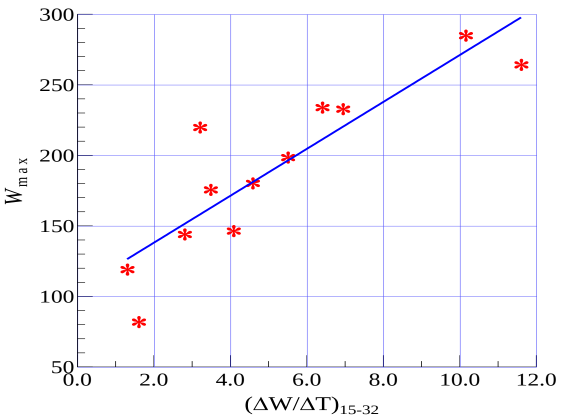

Figure 3: The same as in Fig. 2, but only for odd cycles. From the regression dependence (3), presented in this figure by a straight line, it follows that the predicted value of $W_{max}(25) = 179.6$.

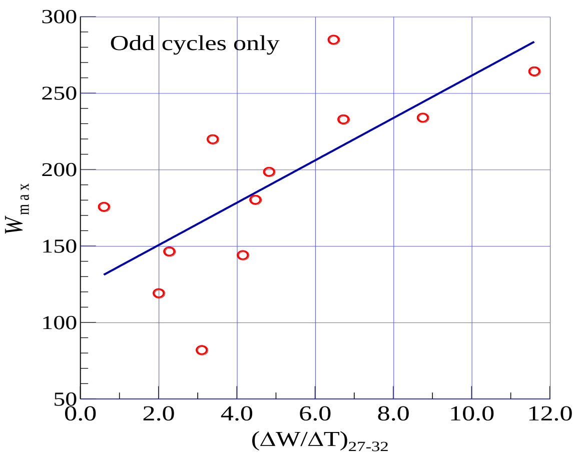

Figure 4: The same as in Fig. 3, but when averaging the $\Delta W/\Delta T$ parameter in the interval of 27-32 months. From these data it follows that $W_{max}(25) = 204.2$.

However, it turns out that the predicted value of $W_{max}(25)$ increases even more if we consider a narrower interval of 27-32 months of the cycle (Fig. 4). In this case, the regression equation has the form

$$W_{max} = 13.85(\Delta W/\Delta T)_{27\text{-}32} + 122.88, \qquad (4)$$

Substituting the observed value $(\Delta W/\Delta T)_{27\text{-}32} = 5.87$ into formula (4), we have W_{max} (25) = 204.2.

Thus, compared to approximations (1) and (2), the predicted value increases by almost 40 units. This growth means that in the interval of months 27-32 we have signs of "acceleration" (acceleration of growth) of the current cycle No. 25, that is, a situation opposite to the previous cycle No. 24.

It is worth recalling that in the first 20 months of the development of the 24th cycle, the activity did not exceed 20 units (in the old system), which promised a rather weak cycle. However, starting from the 24th month of the cycle, the general picture of the development of activity changed noticeably: the number of spots began to increase rapidly and this growth of activity continued until the 32nd month.

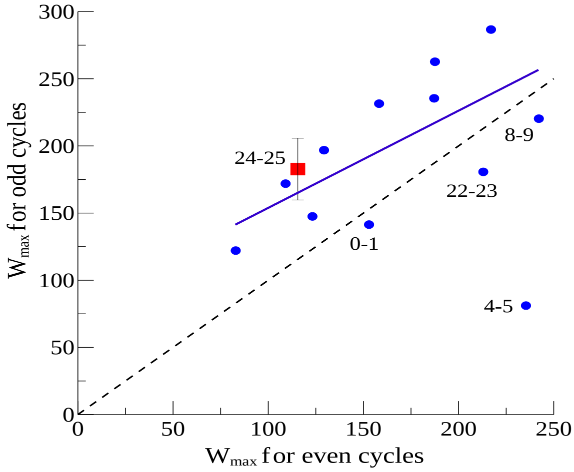

Figure 5: The ratio between the amplitudes of even and odd cycles (see the text).

After that, the activity grew more slowly and reached a maximum of about 67 units in the 38th month of the cycle (in March 2012). After that, the number of spots decreased slightly and remained almost unchanged during the 43-52 months of the cycle, being within 58-60 units. The actual amplitude of the 24th cycle turned out to be equal to W_{max} (24) = 82. Thus, the early forecast of Lozitsky & Efimenko (2012) based on the initial (monotonic) section of the growth phase was overestimated by ≈ 30%.

As for the above data for the 25th cycle, they correspond, in general, to the following most likely forecast W_{max} (25) = 185 ± 18. If, after all, the current 25th cycle will continue to develop according to the scenario of the 24th cycle (which had a non-monotonic curve of the growth phase and an abnormally bifurcated peak – see Lozitsky & Efimenko, 2014), then one can expect W_{max} (25) ≈ 130.

The above forecast W_{max} (25) = 185 ± 18 corresponds well to the Gnevyshev-Ohl rule (Gnevyshev, 1977), according to which the amplitude of the odd cycle is, on average, 10-50% greater than the amplitude of the previous even cycle (Fig. 5). In this Figure, blue dots represent the actual data for 24 previous cycles, and a red square with vertical intervals represents the most probable forecast of the authors of the presented work. The solid straight line shows the linear approximation of the Gnievyshev-Ohl rule, performed on all cycles except for cycles 4 and 5. The dashed line shows the line of equal values of the amplitudes of even and odd cycles.

From Fig. 5, it can be seen that the Hnievyshev-Ohl rule was violated not only in a pair of cycles 4-5, but also in cycles 0-1, 8-9, and 22-23 (though, to a lesser extent). If this rule will be also violated in cycles 24-25, then it would be a double (that is, twice in a row) violation of this rule, which has not been observed until now. This is another argument in favor of the prediction of W_{max} (25) = 185 ± 18 being more likely.

If this prediction is true, a possible Maunder or Dalton-type deep minimum of the age cycle could begin later, for example, from the 26th cycle of solar activity. More specifically, the nature of such changes can be traced to the relatively recent Dalton minimum (≈1800-1820).

Then, in the 4th cycle of solar activity, the amplitude of the smoothed number of sunspots reached $W_{max}(4)$ = 235.3, and in the next cycle it sharply dropped to $W_{max}(5)$ = 82.0 and remained practically the same in the next cycle: $W_{max}(6)$ = 81.2. Thus, the number of sunspots sharply decreased by a factor of 3, but in the next odd cycle No. 7 it increased to $W_{max}(7)$ = 119.2, i.e. almost by a factor of 1.5. Such sharp changes in established patterns of solar activity are called phase catastrophes by Tsirulnik et al (1997), i.e., this is a period when the amplitudes, periods and phases of oscillations that describe the observed changes in solar activity change dramatically. Periodic repetitions of phase catastrophes in the observed changes in solar activity indicate that the "memory" of solar activity can be relatively short - on the order of the duration of an 11-year cycle. In this regard, it can be expected that the method of internal predictors gives better forecasting results than the method of external predictors. The method proposed in the presented work is essentially a method of internal precursors, which uses a statistical relationship between current changes in solar activity (an increase in the number of sunspots in a certain area of the curve of the growth phase) and the amplitude of the cycle after a relatively short time (1-2 years) after the indicated changes in the number of spots.

Thus, the results presented in this study do not exclude the occurrence of a deep age minimum in solar activity in the next few cycles, for example, in only two cycles #26-27, as it was in the Dalton minimum. Given that solar activity has a complex deterministic-stochastic character, it is hardly possible to reliably predict this minimum by methods based on the patterns of many cycles of solar activity.

3. Conclusions

The main conclusion of this work is that the amplitude of the smoothed number of sunspots in the current 25th cycle will most likely be as follows: W_{max} (25) = 185 ± 18. It turned out that the forecasting result depends on which section of the growth curve is taken as the basis for forecasting, as well as whether all 24 cycles are taken into account, or only the odd ones. The prediction result is also affected by the initial assumption about monotonicity or non-monotonicity of the growth phase. A comparison of the rates of sunspot growth in different parts of the growth phase of different cycles shows that the current cycle #25 does not show early signs of non-monotonic growth similar to those observed in the 24th cycle. However, if cycle #25 will still have a non-monotonic curve of the growth phase, similar to such a curve in the previous cycle #24, then W_{max} (25) ≈ 130. Our forecast corresponds to the average power of the solar cycle, with the implementation of the Hnievyshev-Ohl rule. With such parameters of this cycle, there are no signs of approaching the deep minimum of the age cycle in the middle 21st century This does not exclude the fact that this deep age minimum can occur suddenly and sharply immediately after the 25th cycle, as was the case, for example, in the Dalton’s minimum.

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References

Attia A.F., Ismail H.A., Basurah H.M.: 2013, *Astrophys. and Space Science*, **344**, 5.
Clette F., Svalgaard L., Vaquero J.M., Cliver E.W.: 2014, *Space Sci. Rev.*, **186**, Iss. 1-4, 35.
Gnevyshev M.N.: 1977, *Solar Phys*., **51**, 175.
Li K.J., Feng W., Li F.Y.: 2015, *Journ. of Atmospheric and Solar-Terrestrial Physics*, **135**, 72.
Lozitsky V., Efimenko V.: 2012, *Visnyk Kyiv. Univ., Astronomija*, **49**, 47.
Lozitsky V.G., Efimenko V.M.: 2014, *Odessa Astron. Publ*., **27**, No.2, 90.
Petrovay K.: 2020, *Living Review Sol. Phys.*, **17**, art. No.2.
Pishkalo M.I.: 2014, *Solar Phys*., **289**, Iss. 5, 1815.
Rigozo N.R., Souza Echer M.P., Evangelista H., Nordemann D.J.R., Echer E.: 2011, *Journ. of Atmosph. and Solar-Terrestrial Physics*, **73(11–12)**, 1294.
Tsirulnik L.B., Kuznetsova T.V., Oraevsky V.N.: 1997, *Advances in Space Research*, **20**, 2369.
Zharkova V.V., Shepherd S.J.: 2022, *Monthly Not. of the Royal Astron. Soc*., **512**, Iss. 4, 5085.