LONG-TERM FORECAST OF SOLAR ACTIVITY USING THE 150-YEAR HARMONIC AND CHARACTERISTICS OF CYCLES OF THE RELIABLE PART OF WOLF'S NUMBERS

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Abstract: *In work the Zurich number of average monthly numbers of Wolf (a number of relatives of solar spots – WSN) consisting of the average monthly values restored by Wolf on sketchy observations (the restored row from 1749 to 1849), and a number of the regular observations from 1849 to our days (a reliable row) is considered. Comparison of characteristics of spectral components and the analysis of their smoothness for the reliable and restored parts showed essential differences in their behavior. Selection of long-period components of a reliable row and extrapolation them on an external time interval gives the chance for reconstruction or prediction of temporary dynamics of a row. This work confirms existence of a 150-year harmonica for a reliable part of a row from 1849 to 2015 that, taking into account characteristics of reliable cycles, allows to predict solar activity.*

ДОЛГОСРОЧНЫЙ ПРОГНОЗ СОЛНЕЧНОЙ АКТИВНОСТИ ПО 150-ЛЕТНЕЙ ГАРМОНИКЕ И ХАРАКТЕРИСТИКАМ ЦИКЛОВ ДОСТОВЕРНОЙ ЧАСТИ РЯДА ЧИСЕЛ ВОЛЬФА

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Резюме: *Эпохи максимума или минимума солнечной активности характеризуются огибающей максимумов циклов и тесно связаны с длиннопериодной («вековой») компонентой ряда чисел Вольфа. Её удачная интерполяция и продление на внешний временной интервал дают возможность прогнозировать общий ход солнечной активности на временных масштабах в несколько циклов. Трактуя длиннопериодную компоненту, как огибающую средних значений циклов, разбивая циклы по длительности и опираясь на взаимосвязь интервальных оценок нескольких циклов можно детализировать прогноз на масштабах цикла.*

Introduction

Eras of the increased or reduced solar phenomena (SP) are characterized by the periods of a maximum or minimum of the "envelope" of cycles maxima and closely related to a long-period ("-century") component of a Wolf number sequence. The Zurich sequence of average monthly Wolf numbers (W = Wrest U Wtool) includes a reestablished sequence Wrest (since 1749 till 1849) and a certain sequence of Wolf numbers Wtool (the regular instrumental observations since 1849 till present). The successful interpolation of a long-period component of a sequence W and its extension on an external time interval give a chance to predict the common course of solar phenomena at time scales in several cycles. This work follows the basic concepts explained in the publication [1], where the 150-year frequency component (by a certain part of the sequence), which can form a basis of the long-term forecast of SP, is emphasized.

Spectral characteristics of a sequence W and choosing the underlying array

Sequence W is rather non-uniform due to the history and methods of its formation. Differences in total characteristics of the sequences Wrest and Wtool cycles, i.e. the cycles I ÷ IX and X ÷ XXIII groups are analysed in work of [2] where it is noted that only the characteristics of cycles VIII and IX are most concordant to the characteristics of cycles of a sequence Wtool. The analysis of cleanliness of spectral components showed also essential differences in their behaviour. In the work of [1], proceeding from character of a spectrum, a sequence is divided into five spectral intervals with the following time periods, put in years **:** P1 [24 < T], P2 [6.8 < T < 24], P3 [4.26 < T < 6.8], P4 [1.66 < T < 4.26], P5 [T<1.66]. Sequences P2(t) and P3(t) describe the main and second frequency components and so we will pass to the analytical signals characterizing these sequences, applying to them the Hilbert transform [3]. It allows finding a time dependence of the envelope and "instantaneous" frequency of these spectral components. The behaviour of the "instantaneous" frequencies of the components P2(t) and P3(t) shows the Fig. 1., where the area corresponding to a sequence Wtool is marked by the lower legend. The distortions are shown clearly and their degree increases with removal to the past. Characteristics of the time domain adjoining 1849, i.e. area of the VIII ÷ IX cycles (the top legend) are least distorted. It is the given estimations that define the choice of the underlying array for prediction of SP – a sequence Wtool with possible inclusion of the cycles VIII ÷ IX.

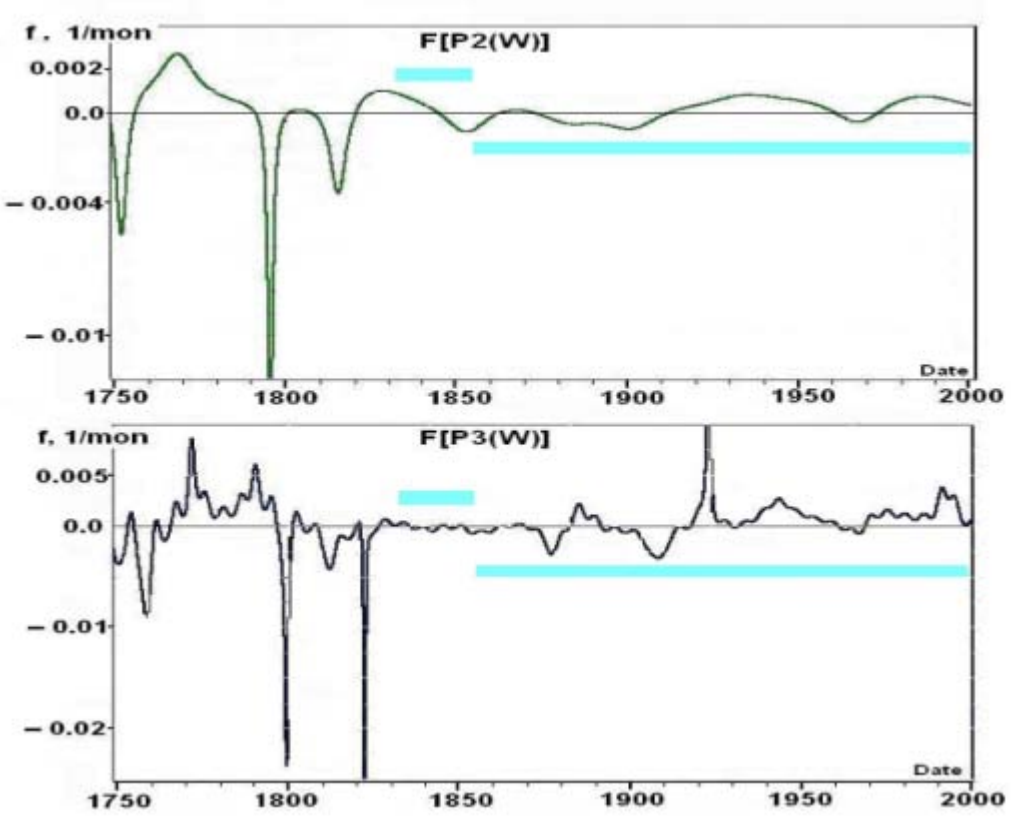

Fig. 1. Review of the "instantaneous" frequencies of spectral components of P2 (from above) and P3

We would like to remind the role of the components P1 ÷ P5 of the sequence W. The sum of a long-period component P1 and a basic frequency component P2 reflects the main time and amplitude characteristics of the cycles. The sequence P3 corrects branches of increasing and reduction. The component P4 transforms a clean relief of the cycles due to the quasitwo-year-olds - the local maxima are arisen, the displacement of the basic maximum is possible, i.e. the cycles assume more individual character. The high-pitched excess of the P5 includes annual and 155-d frequency components. The review of the sequences of the main spectral areas P1 ÷ P3 with relevant envelopes of the components P2 and P3 is presented on Fig. 2.

Representation of the underlying array for the issues of forecasting and reconstruction

Further a sequence Wtool (since 1849 till may 2015) is examined. Determination of the standard (table) parameters of cycles leans on the sequence W* which is deduced from a sequence of

monthly Wolf numbers W by the flexible averaging based on 13 months (W => W*). The average sequence, proceeding from simple rules, is divided into time spans (cycles), which are compared to duration Tc, the maximal value of Wolf number in the given span Wm and the time moment Tm – the duration of branch of increasing (Tm < Tc), corresponding to this maximum. At the same time, several local maxima and lack of monotony in behaviour of branches of increasing and reduction are peculiar for many cycles, which complicate the characteristics evaluation regarding to the issues of forecasting and reconstruction. Leaning on a sequence P13=P1+P2+P3 (a sequence Wtool without quasitwo-year-olds and a high-pitched part), after the relevant splitting into spans (cycles) we pass to one-vertex cycles with the monotonic branches of increasing and reduction, which are shown on a Fig. 3. All main characteristics of cycles remain however.

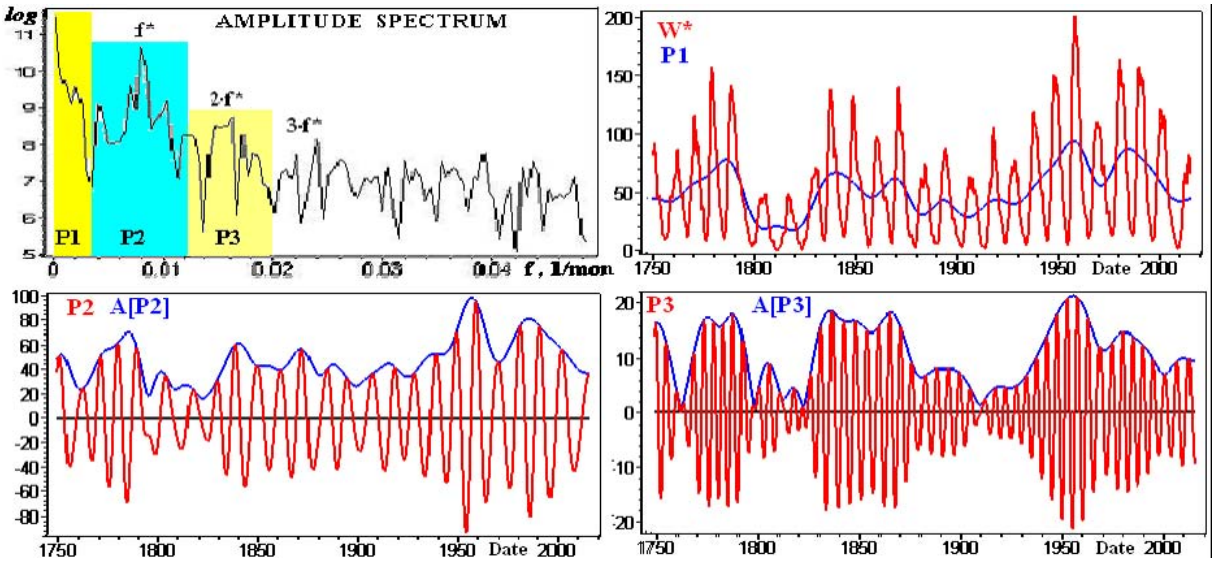

Fig. 2. Spectrum of a sequence of Wolf' numbers and review of spectral components of P1÷P3. A[P2], A[P3] – a time dependence of the envelope for spectral components P2 and P3

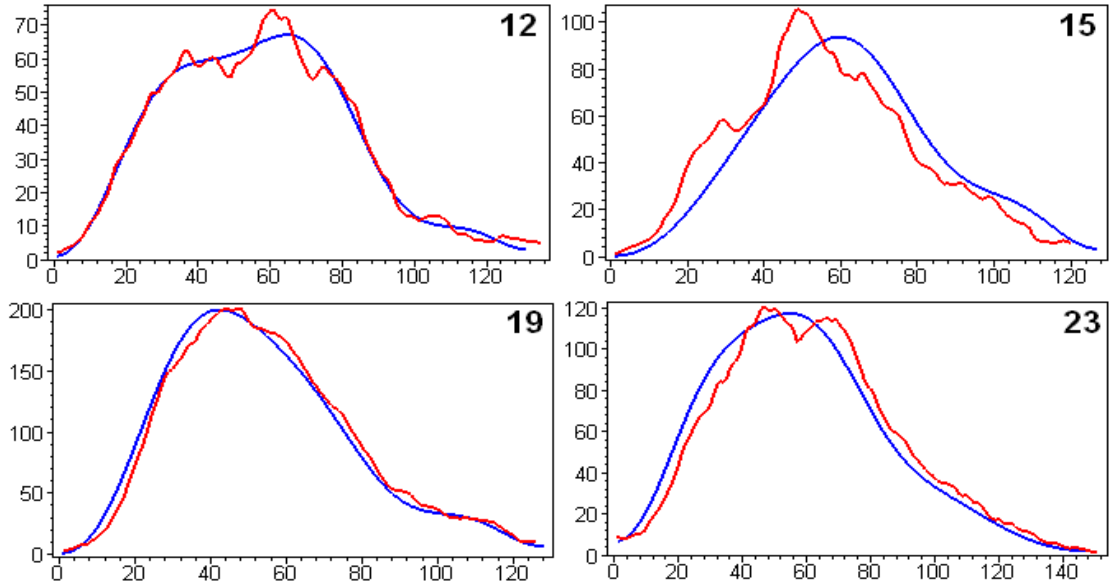

Fig. 3. Comparison of cycles in W* and P13 modifications

Leaning on slowly varying functions P1(t) and envelopes of the main and the second frequency components A[P2] and A[P3] it is possible to design the "envelope" maxima for cycles in representation of P13**:** A[P13]=P1+A[P2]+A[P3], which is imposed well on sequence P13(t) maxima. Extrapolation on an external span of slowly varying function A[P13] addresses actually the problem of

the long-time forecast of SP. Considering close connection of A[P13] with a long-period component it is enough to do that for P1(t) [2].

It is convenient to interpolate P1 by the sine P1_sin with the parameters, which are determined from the maximum of its correlation with P1 when scanning by reference to frequency and phase [1]. For the long-period component of the sequence Wtool (1849 ÷ 2015) the period of an approximating sinusoid equals to 150 years. Extrapolation of P1_sin on an external interval is presented on Fig. 4.

Conclusion

Eras of the The provided approach allows to predict the duration of an era of the reduced solar phenomena, the moment of beginning of its minimum and to estimate its level. We would like to note that the amplitudes of the cycles VIII and IX are reasonably described in this approach and it is possible to talk about compatibility of W and a 150-year frequency component on an interval more than 180 years. Dynamics of the current minimum of SP differs from the scenarios of Maunder Minimum and Dalton Minimum development.

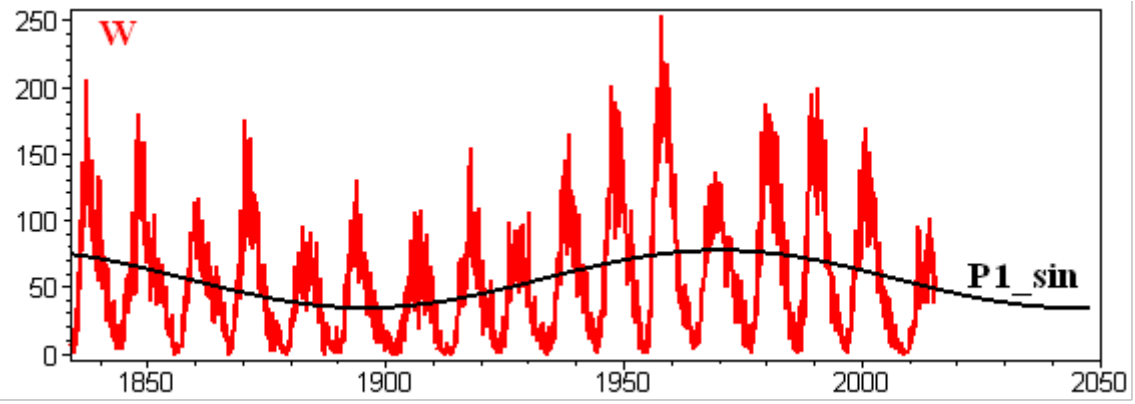

Fig. 4. Imposing of sin-approximation P1 on a certain sequence of Wolf numbers Wtool and its extrapolation

References:

1. Shibaev, I. G. Estimation of the Reconstructed Part of the Wolf Series and the Possibility of Its Correction, Solar System Research, V. 42, No. 1, 2008, p. 63 – 72. DOI: 10.1134/S0038094608010073.
2. Шибаев, И. Г. Реконструкция восстановленной части ряда чисел Вольфа по 150-летней гармонике и характеристикам циклов достоверной части ряда чисел Вольфа / Труды Всероссийской ежегодной конференции: Солнечная и солнечно-земная физика -- 2016, Пулково, Санкт –Петербург, 10 – 14 октября 2016 г., с. 349-352.
3. Bendant, J., A. Pirsol. Random data. Analysis and Measurement Procedures, John Wiley & Sons, Inc., NY; 1986.