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SPECTRAL ANALYSIS AND FORECASTING OF THE 25TH SOLAR CYCLES

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Abstract. In the present work, we propose an extrapolation method, developed on the basis of spectral analysis, digital filtering, and the principle of demodulation of a complex signal, for predicting the beginning of cycle 25 of solar activity. The Wolf number and other measured characteristics of solar activity have a very complex spectral composition. The Sun, by the nature of its radiation, contributes a significant stochastic component to the observational data. The experimental data are known only up to the present, and the prediction is about bridging the gap in our data set. Mathematically, the prediction problem boils down to extrapolation of discontinuous functions, which leads to a Gibbs phenomenon that occurs at the point of discontinuity and makes prediction into the future impossible. To overcome this discontinuity, additional physical models describing a continuous process are most often used. This paper uses only the Wolf series of numbers from 1818 to 2020. The authors developed an original forecasting technique using Fourier series, digital filtering and representation of the complex process as modulated and subsequent demodulation. As a result of decomposing the complex signal by Fourier series into separate components, the spectral ranges characteristic of the Wolf number were singled out. Taylor's series was used for construction of prediction or extrapolation algorithms. The extraction of spectral ranges, characteristic for the investigated process, is carried out by means of sequential digital filtering methods and information compression in accordance with the cut-off frequency of the digital filter. For example, when selecting eleven-year cycles of solar activity, we have to compress the information by a factor of 160. With such a processing scheme, the forecasting starts with the ultralow-frequency component with a period of more than 11 years, successively moving to the ranges of higher frequencies. The use of spectral analysis and Chebyshev filtering showed the possibility to predict the low-frequency component for the full cycle period. The eleven-year component forecast obtained by the authors is in good agreement with the data of the Brussels Royal Center.

Keywords: solar activity, forecasting, Fourier series, spectral analysis, Gibbs phenomenon, Chebyshev filtration, Wolf number.

Based on spectral analysis and Chebyshev filters, a prediction of Wolf numbers for the years 2021-2022 is obtained. The results are consistent with those of the Brussels Royal Centre.

The prediction of solar activity is of natural interest to near-Earth space explorers. According to [1] the sun is moving into a new mode of minimum activity, which was observed more than 100 years ago. The reduced regime of solar activity is supposed to last several solar cycles.

According to [2] the next solar cycle is characterized by minimum, duration and form. There are 1-3 year variations of minima and maxima, which complicate the forecast of the form and main maximum. The tentative prediction of cycle 25 according to the characteristics of the large-scale interplanetary magnetic field 2-3 years before the cycle start and the emission intensity F10.7 cm suggest that the average number of sunspots does not exceed 50, F10.7 is expected to be about 87. At the maximum of cycle 25, F10.7 = 115. The cycle itself is expected to be extremely low. It is predicted in [7] that cycle 25 is 40% of cycle 24 and 26 is 60% of cycle 24. Long-term sunspot forecasts are very difficult due to stochasticity. Figure 1 shows the well-known solar cycles.

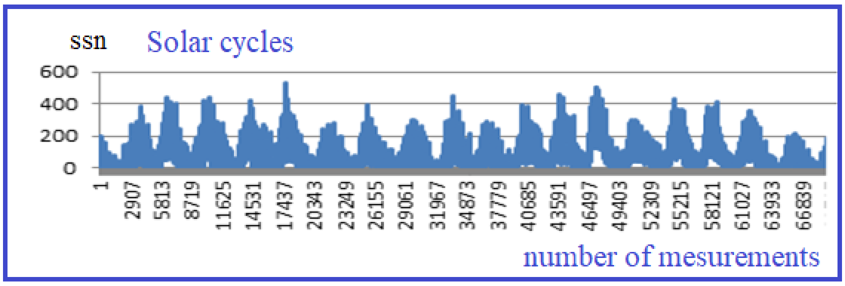

Figure 1. Measured values of Wolf number variations for 1818-2020.

It is not difficult to see what complex processes are reflected in these cycles of solar activity. It is known that periodic processes are better predicted. Use of spectral analysis [3-5] makes it possible to distinguish them from such complex processes. Using spectral analysis and Chebyshev filtering [3-5], we isolated individual components of the solar cycle and obtained smoothed variations of cycles from data up to the end of November 2020 (Fig. 2).

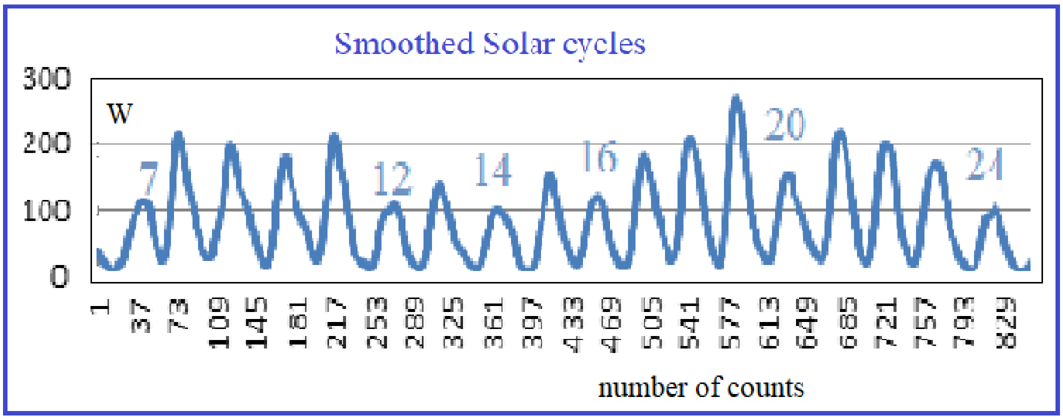

Figure 2. Smoothed solar cycles. The numbers denote the numbers of solar cycles.

Fig. 2 shows smoothed solar cycles with no daily variations. Here we can trace the height of the maximum and the duration of individual solar cycles. Further separation of the spectral components yielded the sum of the sinusoidal components. In Fig. 3 . we can clearly see the rapidly changing sinusoidal component, characteristic of individual cycles, and the slowly changing one, reflecting long variations in solar activity.

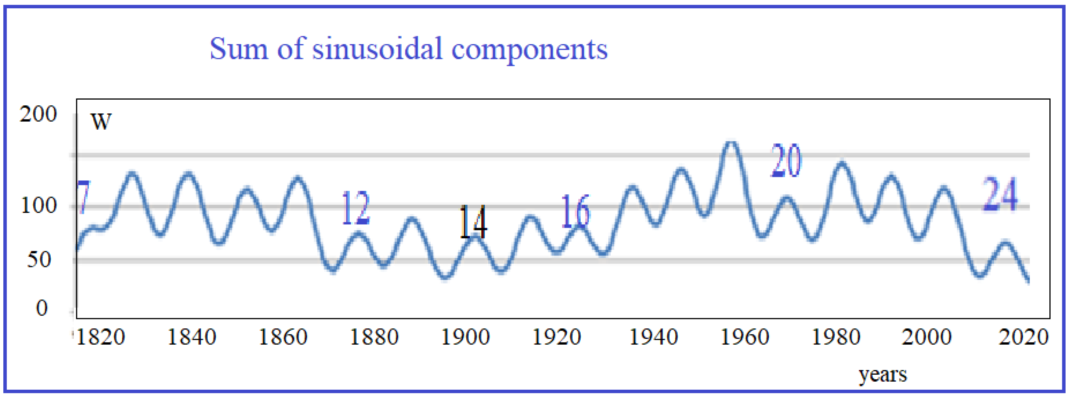

Figure 3. Sum of sinusoidal components in solar cycles.

Further separation of the solar spectra has yielded the secular variation of solar activity. The Sun's solar constant, or solar constant, where the 11-year component is no longer present.

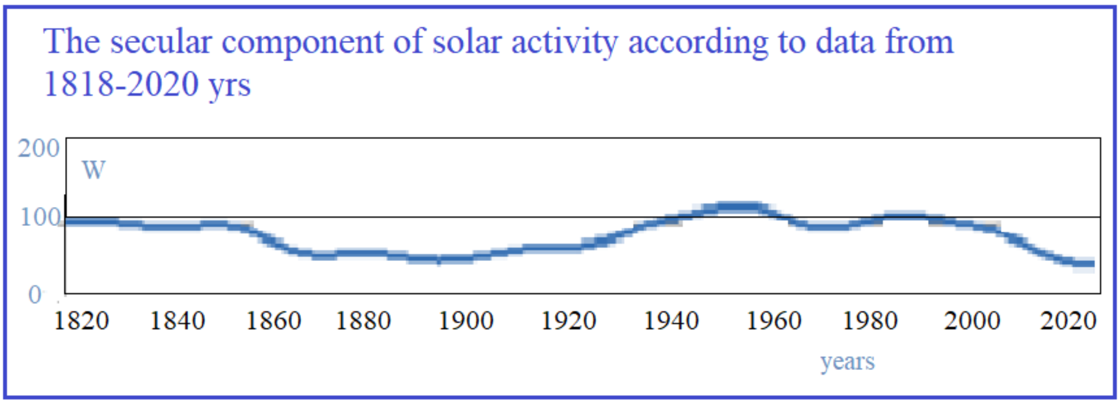

Figure 4. The secular component of solar activity over 200 years.

The prediction of such a complex signal as solar activity can only be made for the individual components. The prediction itself is currently an unsolved problem of approximating the discontinuous functions that are the series of measured data. At the ends of such a series fluctuations arise due to the discontinuity [5]. These fluctuations lead to errors which make the prediction meaningless. Researchers make various adjustments based on some a priori information about the process under study and on methods of mathematical statistics [2,6,7].

The following results are based on spectrum bounded forecasting. Prediction is most adequate when the process is represented as a sum of harmonic components and random noise. Thus, we should predict individual spectrum-limited components of the process for which spectral analysis is applicable [3-5]. Fig. 5 shows the forecast of the secular component of the solar activity for 25 cycles or for 13 years. In Fig. 5 on the abscissa axis the scale of readings with a division value of 160 days is plotted.

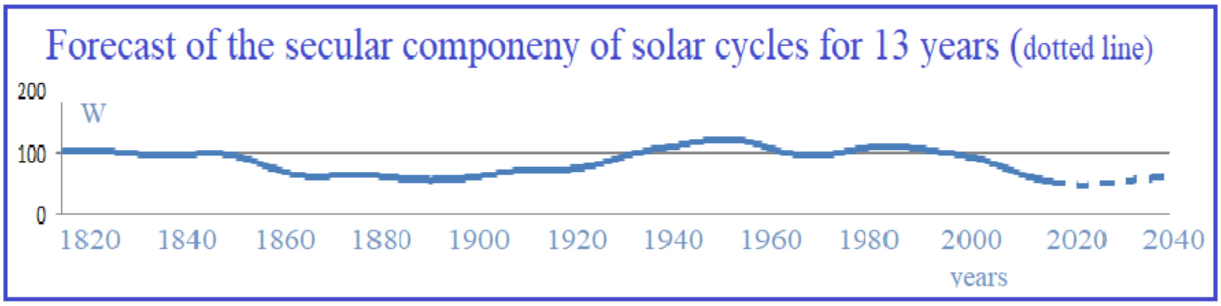

Figure 5. Forecast of the secular component of solar cycles for 13 years.

The current forecast of the low-frequency component obtained in this paper for the next 2 years and the current 13-month forecasts of solar activity provided by WDC-SILSO [6] based on the moving average methods and using the Kalman filter for extrapolation, are shown in Fig. 6.

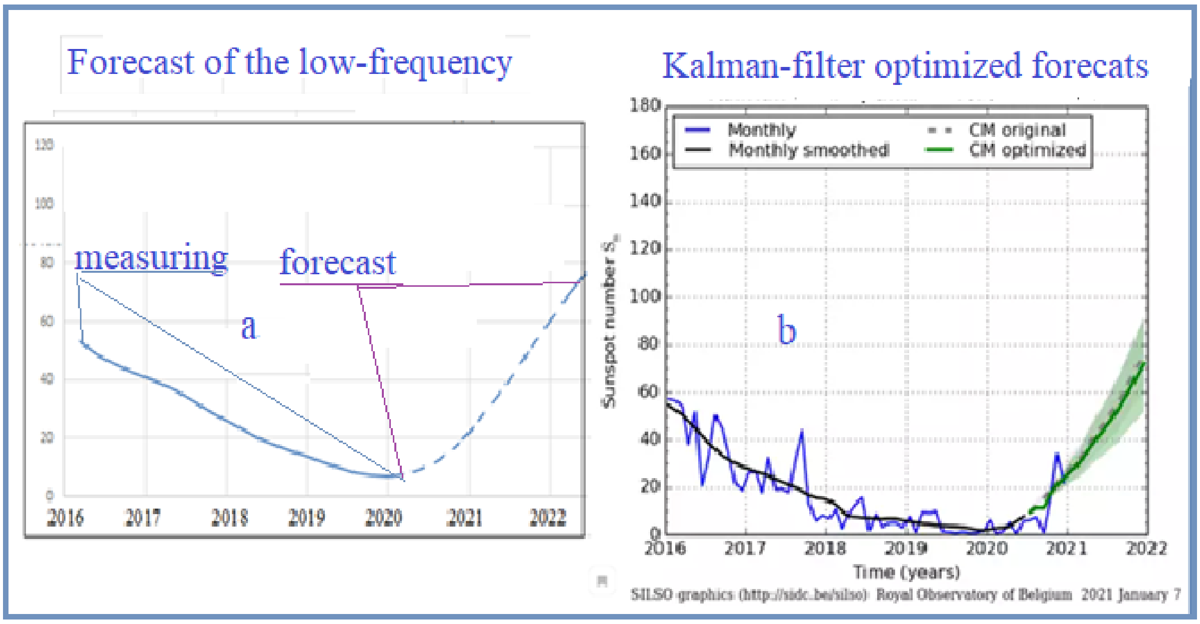

Figure 6. The assumed forecast in the time domain of the low-frequency component for the next 2 years (a) and the current 13-month forecast of solar activity according to the WDC-SILSO data [6].

The comparison shows that the projected curves coincide in terms of steepness and assumed maximum. However, the descending branch of cycle 24 obtained using weighted averaging methods (Fig. 6b) and Chebyshev filtering (Fig. 6a) differ in terms of the mean values and the 2020 minimum.

The Gaussian approximation of 25 solar cycles given in [2] shows that the increasing phase will last 5.3 years. The probability of F-scattering is expected to be maximizing, according to [8], since F-scattering is associated with ionospheric irregularities at different spatial scales.

Radio transmissions for frequencies above 10 MHz are expected to be difficult because the maximum critical frequency will not exceed 10 MHz, but the lifetime of orbiting satellites may be longer due to reduced atmospheric density and drag. Low electron concentrations will reduce the energy loss of radio waves as they pass through. All this information was obtained long before Cycle 25 began. The use of spectral analysis and Chebyshev filtering allows us to predict the low-frequency component for 1-2 years and the secular component for several cycles. The data we obtained are in agreement with long-term studies and can be used for operational forecasting of solar activity. This forecast is also useful for solving problems of the ionosphere state [4,5].

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