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PREDICTION OF CHARACTERISTIC FEATURES OF THE 25TH SOLAR ACTIVITY CYCLE

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Abstract
Forecasting by extrapolation of Wolf numbers (W) in the 25th solar activity (SA) cycle from a series of measurements up to and including 2023 was carried out. The forecasting technique is based on the method of approximate transformation of the finite-time forecasted process into an infinite function, or a finite function on the spectrum. Such an operation was performed by ordering the spectrum of the finite-time function using digital Chebyshev filters in the time domain and filters based on frequency discretisation using Chebyshev window functions. Approximating the initial conditions to the desired prediction region yields a more accurate prediction and shape of the 25th cycle curve. The calculations show that if we use the numerical series starting from 2009, the maximum of about 100 is expected in 2025, and the cycle itself turns out to be rather short, ending in 2027. Forecasting a numerical series starting in 2015 or 2017 results in a more gentle start to the cycle, i.e., a longer minimum, which was observed at the beginning of cycle 25, an increase in cycle length to 2030, and a double-humped maximum similar to cycle 24. Extrapolation of the eleven-year component showed an average maximum value of 150 for Wolf numbers in cycle 25. The use of data on Wolf numbers for 2020-23 allowed us to refine the forecast. A comparison of the obtained forecast with data from the Royal Observatory of Belgium and Boulder is presented.

Keywords: solar activity cycle, forecasting method- extrapolation, Fourier series, spectral analysis, Chebyshev filtration, Wolf numbers.

Introduction
Due to the stochastic nature of processes taking place on the Sun, each solar cycle is unique and has its own characteristics. Forecasting solar cycles is a difficult task, and scientists have been studying the Sun for more than 200 years. The paper [1] describes the characteristics of solar cycles, including the variety of forms, duration, slope of the ascending and descending branches, and maximum and minimum values. The first reliable forecasts for the 25th solar cycle were made in 2016 [2-5] with a three-year lead, but the start of the cycle was unexpectedly delayed by another year. The generally accepted start date for the 25th cycle is defined as the beginning of 2020. In 2019, we obtained a forecast for the start of the 25th solar cycle using the spectral analysis method [6, 7]. The forecast was in good agreement with that of the Royal Society of Belgium [8]. The forecast was preceded by a study of long-term sunspot data, from 1818 to the present day. We extracted individual components from these data using digital filtering, and identified the longest-period, or secular, component. This was the most interesting for predicting future solar activity, as it showed that the minimum level was ending and a slow increase was imminent at the end of the cycle. However, we also identified other harmonic components, including an 11-year cycle. The long-term trend showed that the average maximum number of Wolf number was not expected to exceed 100 for the 24th and 25th cycles SA.

The peculiarities of the 25th solar cycle
Refinement of the forecast based on Wolf number data for the last two years suggests a relatively quiet development of the 25th solar cycle, with an average maximum up to 120 in a period of 10.5 years. The maximum is expected to occur in 2025, and the cycle is expected to end in 2030. Figure 1 shows 11-year solar cycles, starting with cycle 19 and ending with cycle 25. Cycle 25 was obtained by extending filtered Wolf number data up to 2019. The red line also shows a narrower 11-year spectral range projected over a longer time horizon. Note that non-zero minimum values were observed in cycles 19, 20, 21 and 22; zero minimum values were observed in 23, 24 and 25. It has already been noted that during cycle 24 a zero value was observed for one year, typical of the current cycle.

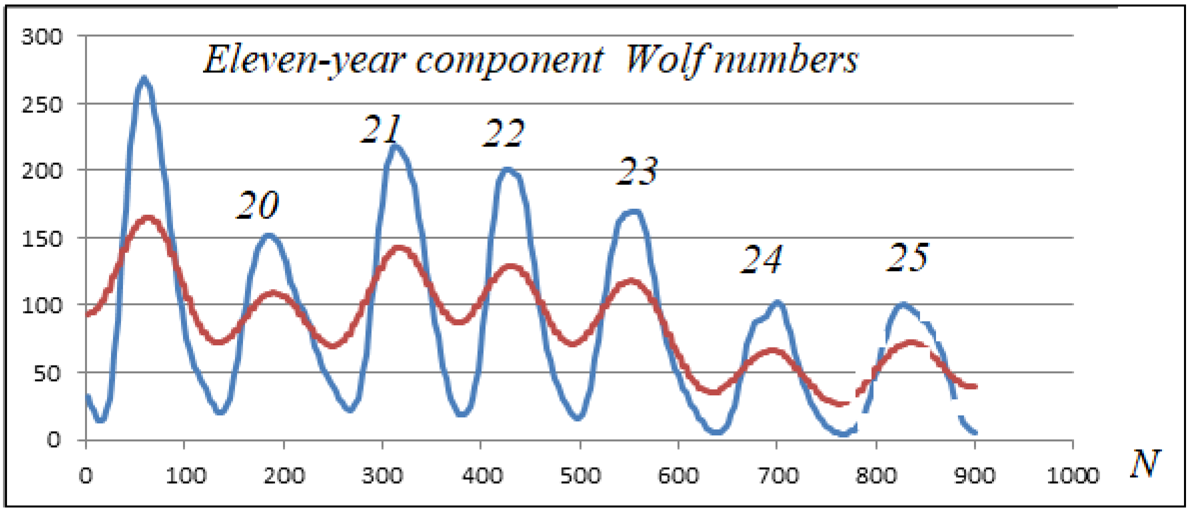


Figure 1. Eleven-year cycles for solar cycles 19-25 with various filter parameters [6,7].

Figure 2 shows a comparison between our forecast using data up to and including 2023 and the Cycle 25 forecast provided by the Royal Observatory of Belgium. The green, orange, and red color's represent extrapolation results for curves with different filtering parameters, which are similar to the blue and red curves in Figure 1.

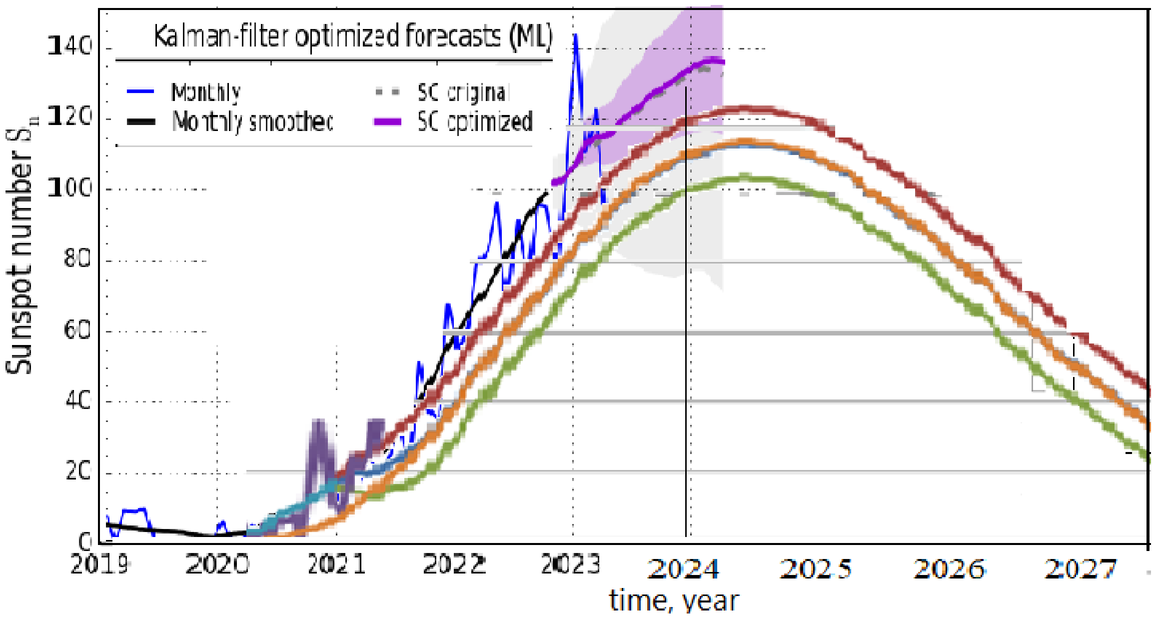


Figure 2. Comparison forecasts of cycle 25 for the 11-year component by extrapolation (red, orange and green curves) obtained by authors, and the improved 12-month ahead forecast of Royal Observatory of Belgium, obtained by method (ML).

Figure 2 shows the forecast for the beginning of 2024 obtained by the McNish and Lincoln method from WDC-SILCO [9], improved by applying the adaptive Kalman filter. The solid coloured areas marked in Fig. 2 characterize the magnitude of possible uncertainties of this forecast. The results obtained by the authors are in satisfactory agreement with the forecasts of the Royal Observatory of Belgium. Note that the authors' forecasts presented in Fig. 2 refer only to the 11-year spectral component of the solar cycle.

In Figure 3, the purple curve shows the smoothed curve of eleven-year cycles from the end of cycle 23 and the forecast for cycle 25, refined by Wolf numbers, including February 2024.

A smoothly varying broad cycle is obtained, which is shown in Fig.4. It compares the authors' refined forecast based on data from 2023 with the Belgian Observatory forecast for data as of March 1, 2024.

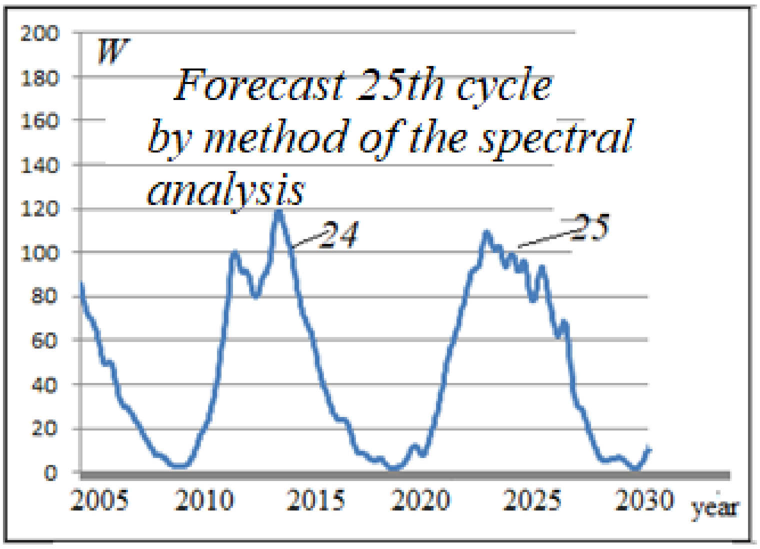
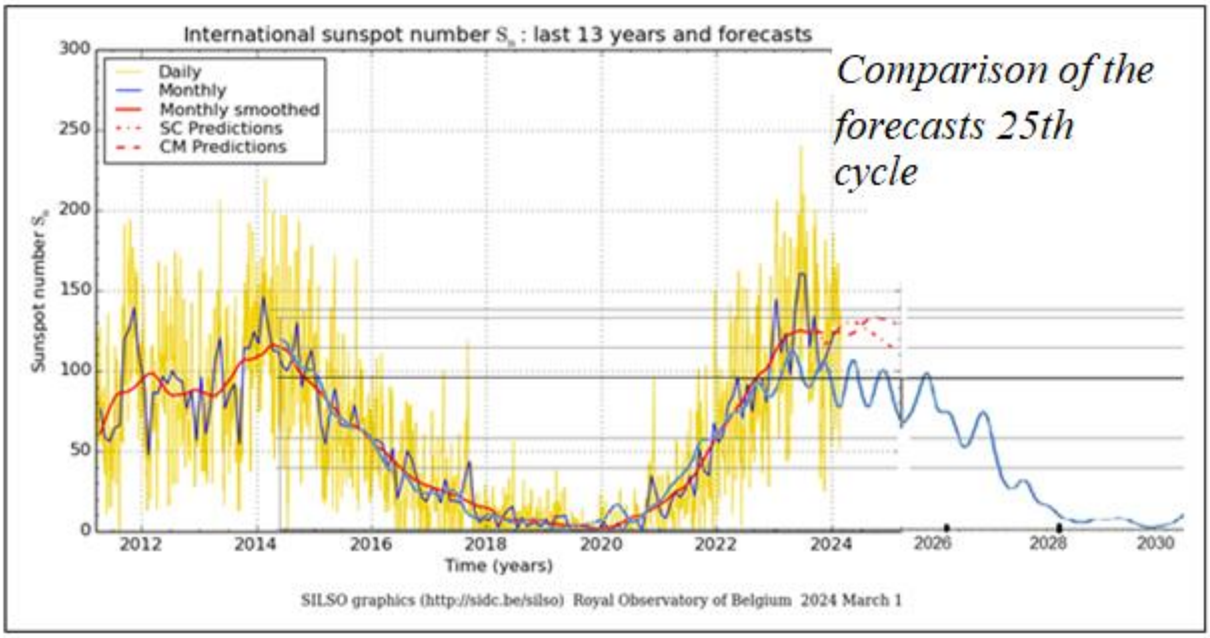


Figure 3. Refined Forecast of the 25th cycle of Solar activity.



"Source: WDC-SILSO, Royal Observatory of Belgium, Brussels".

Figure 4. Comparison of the forecast for the 25th solar cycle obtained by the authors (blue curve) with data from the Belgian observatory as of March 1, 2024.

Another comparison, the resulting forecast of cycle 25 is shown in Figure 5. Here is a comparison of forecasts with monthly average data from Boulder. There is satisfactory agreement of the data presented.

The satisfactory comparison of forecasts for the 25th solar cycle indicates the potential of spectral analysis and extrapolation methods in studying complex processes in natural environments. Using only experimental data, it is possible to identify and study individual components of complex processes and to obtain forecasts for both rapidly changing and long-term components responsible for slowly changing global variations. The slightly underestimated values for the Wolf numbers in our forecast compared to more recently measured values are due to the fact that an eleven-year component was forecast. In a full forecast, taking into account higher-frequency components, the values of Wolf numbers may increase by 20-40%, and the curve will be more indented.

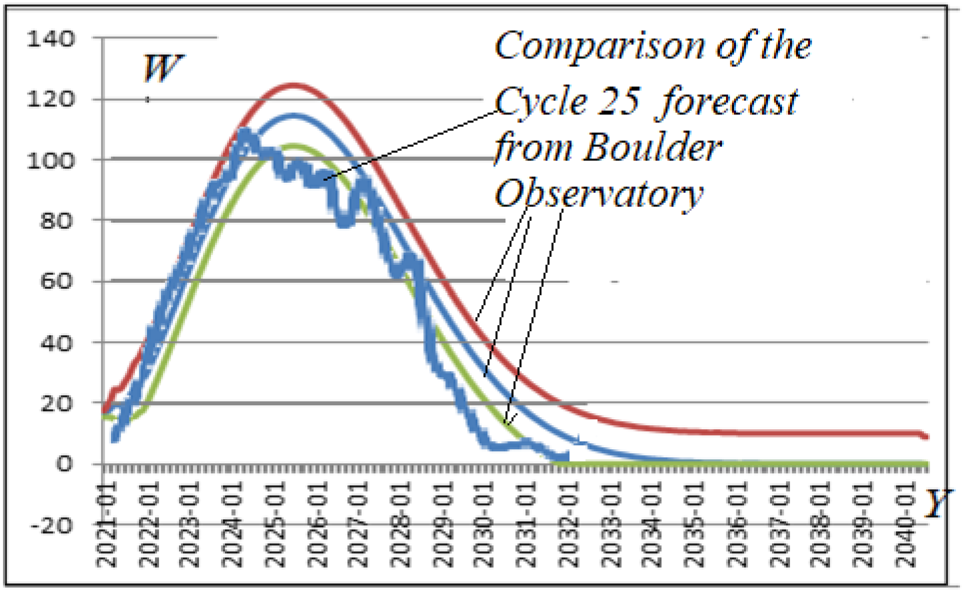


Figure 5. Comparison of the predictions of monthly average data Wolf numbers according to Boulder [10] and the author's predictions (bold curve).

Conclusion

The refinement of the forecast for the 25th solar cycle, based on spectral analyses of data from 2022 to early 2024, is mainly concerned with the mean value of the maximum. The originally proposed Wolf number value of around 100 was underestimated, and we can now confidently say that this value will exceed 150. As noted back in 2020, the peak of the 25th solar cycle is expected in 2025, and the cycle itself will last until 2030. A key characteristic of the observed cycle is the long period of zero values at the beginning of the cycle, but after 2023 there is a sharp rise in Wolf number values that will correct the late start, resulting in the average maximum of the 25th cycle exceeding that of the 24th cycle. Thus, the 24th solar cycle will remain the lowest in the last 100 years.

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