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PREDICTION VERIFICATION OF SOLAR CYCLE 25 BASED ON THE PRECURSOR METHODS

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Abstract

Prediction of the level of solar activity is vital for all space programs, planning of space missions, weather variability, and climatic changes. Various approaches are used to predict the forthcoming solar cycle. In this paper, spotless days (SLDs) around the preceding minimum and the geomagnetic index aamin are used as precursors to re-predict the maximum of the 25th cycle from observed data sets. This method shows results that are quite acceptable, which gives the maximum amplitude of solar cycle 25 using SLDs to be equal to R_{25SLD} *= 108.58 and the time of rise* T_{25SLD} *= 4.2 years. Using aamin, R25aamin = 111.6 and T25aamin = 3.98 ~ 4 years. Finally, the predicted maximum for the upcoming cycle* 26^{th} *is found to be* R_{26SLD} *= 96.6.*

Introduction

The periodic variations of solar activity cycles are considered a puzzle in solar physics, since we are far from understanding all processes of the solar dynamo. Deliberating on solar activity is a very important part of solar physics because of its significant impact on Earth's technological systems, which induces both violent short-term space weather and gradual long-term climatic changes. This emphasis is motivated by the present surge of interest in precisely this area, prompted by an unusually long and deep solar minimum and by sharply conflicting forecasts for the maximum of the incipient cycle. Solar cycle prediction is an extremely extensive topic of research, covering a wide variety of mathematical and physical forecasting schemes that are designed to improve the forecast [1, 2] and references therein. Many attempts have already been made in the past to predict the future strength of upcoming cycles, [3] traditionally based on forecasting physical models, e.g., Precursor, which include polar magnetic field, geomagnetic indices, and spotless days SLDs, and statistical forecasting, e.g., auto regression moving average [4, 5]. It should be noted that regression techniques, which provide short-term exploration, suffer from low performance during the transition from one cycle to another. An extrapolation model without considering the prediction starting point was utilised by [6]. Nevertheless, some extrapolation methods may still be worth future study. Model-based forecasts are quickly coming into their own, and despite not having long proven records, their predictions are accepted with increasing confidence by the community [7]. Geomagnetic variations during solar minima are caused by the solar polar field in connection with the solar open flux [8]. According to dynamo theory, the measurement of the Sun's axial dipole gives more accurate results than the polar field for the forecasting needed to carry out the prediction of the previous cycles [9]. The polar field precursor yielded predictions in the right range during the past few solar cycles [7]. The historical measurements of geomagnetic records are used for driving the interplanetary field [10, 11]. This makes aa-index such a good predictor for the amplitude of the following cycle. Kane [12], Brown [13], Wilson [14], and Leighton [15] have used this aspect for decades. Precursor indices give an estimate of the amplitude of the next cycle one or two years before the previous cycle has ended [16]. However, the geomagnetic aa index at its minimum is a good predictor for the amplitude of the following cycle. The spotless days (SLDs) are noted along different phases of solar cycles, including the maximum phase. The highest number of SLDs has been used to define the minimum phase and the count of the events around the preceding minimum for forecasting the strength of the forthcoming solar cycle [17–19]. So, precursor method forecasting is the leading indicator of solar activity through solar minimum and is the most common category of prediction. It is already superior to extrapolation methods.

In this paper, we discuss verification of our early prediction of cycle 25th using the observed geomagnetic indices aamin and SLDs around the preceding minimum (deep minimum) of the 25th solar cycle as a precursor to re-predict the maximum level of the present cycle 25. Also, using the spotless events (SLD_S) around the preceding minimum to predict the upcoming cycle on the 26^{th}.

Source of data sets

Here we consider two precursors – solar variables, which are: the observed spotless days (SLDs) over two years around the preceding minimum (deep minimum) between two consecutive cycles. The source of data comes from the website: www.side.be/silso/datafiles

Secondly, the geomagnetic variable aa-index at minimum is taken from the website: www.geomg.bgs.ac.uk/data_service/data/magnetic_indices/aaindex [last accessed 19 July 2026].

Analysis and Results

In the present work, we are only concerned with the issue of re-predicting the amplitude of early forecasting of solar cycle 25^{th} [12] using two indices of sun activities: spotless days SLDs and aa index as precursors.

Prediction according to spotless days SLDs:

We first used the least squares method to find the empirical equation for the ratio RM/Rm against S_{om}/S_{omn}:

(1) $$Ln\left(\frac{R_M}{R_m}\right) = a + b\left(\frac{S_{om}}{S_{omn}}\right)$$

The correlation coefficient of the above relation is cc = 0.65

Where cc is the correlation coefficient, R_M and R_m are the maximum and minimum Wolf numbers of solar cycles, S_{om} is the count of SLDs at about two years around the preceding minimum, and S_{omn} is the count around the upcoming solar cycle under test.

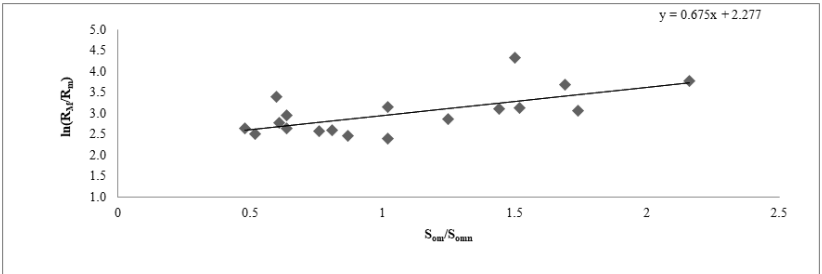

Fig. 1 Represent the logarithmic formula

Fig. 1. Depicts visually Eq. (1) for solar cycles 7–24

Evaluation of the peak of the 25th cycle, depending on the observed SLDs, can be given by Eq. (2)

(2) $$R_{25\ Somnt} = 182.7 - 0.174S_{omn} = 108.6$$

Where S_{omnt} is the total predicted spotless days near the minimum, and the correlation coefficient cc=0.68

The corresponding time of rise Tr

(3) $$T_{25Somnt} = 2.729 + 0.003S_{omn} = 4.3 \text{ years}$$

Fig. 2 and Fig. 3 are the linear regression relationships on implicit information.

For an odd cycle 7–23

Prediction of the strength of odd cycles between cycles 7–23 gives:
R_{25odd} = 114.99 and T_{25odd} = 4.27 years

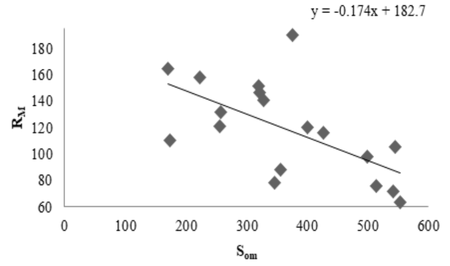

Fig. 2 Variation of R_{max} with S_{om} (total)

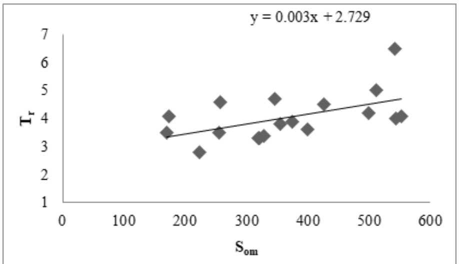

Fig. 3 Variation of time of rise Tr with S_{om}

Predictions according to aa_{min} index

The observed aa-index data is available from cycle 12 onward. Our forecasts were dedicated to the estimation of the strength and timing for both total and odd cycles, written as:

For total cycles 12–24:

(4) $R_{25aat} = 19.12 + 8.115 \times 11.4 = 111.6$ where cc = 0.86

(5) $T_{25aat} = 4.838 - 0.075 \times 11.4 = 4.25$ years

Fig. 4 exhibits linear fit variations of maximum Wolf number as a function of aa_{min}.

Fig. 5 is the relation between the total time of rise T_{25} and aa_{min}

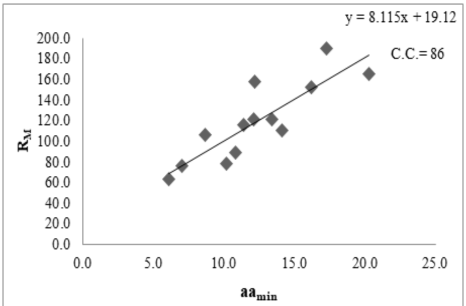

Fig. 4 Variations of maximum Wolf number with aamin (total)

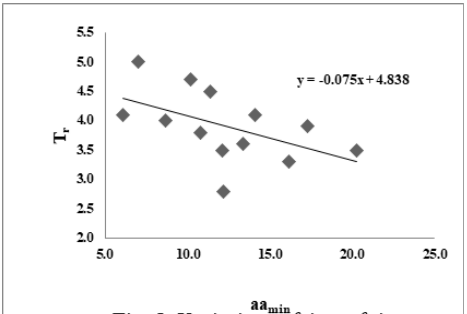

Fig. 5 Variations of timr of rise against aamin (total)

For odd cycles 13-23

Also, the results between aa_{minodd} and both $R_{max25odd}$ and $T_{25aaodd}$ are given by:

$R_{25aaodd} = 99.5$ $T_{25aaodd} = 4.1$ Years

The results show that cycle 25 will reach its maximum in late 2024.

An early prediction of the upcoming 26th solar cycle

We employ the modern era of sunspot cycles starting from cycle 10 onward to forecast cycle 26 using the empirical formula of Eq. (1) as follows:

$$(6) \qquad Ln\left(\frac{R_M}{R_m}\right) = 2.380 + 0.611\left(\frac{S_{omn}}{S_{omn+1}}\right) \qquad \text{where cc} = 0.63$$

Fig. 6 exhibits this relation.
However, we get:

$$(7) \qquad R_{26t} = 177.60 - 0.160 \times 457 = 96.6 \qquad \text{where cc} = 0.60$$

We notice that cycle 26 will attain less strength than the previous cycles.
Our results are comparable with NOAA and NASA (recent level) of 115 in 2025.
Fig. 7 shows the variation of the maximum Wolf number (RM) as a function of spotless events around the following minimum. The linear fit is represented by the corresponding equations.

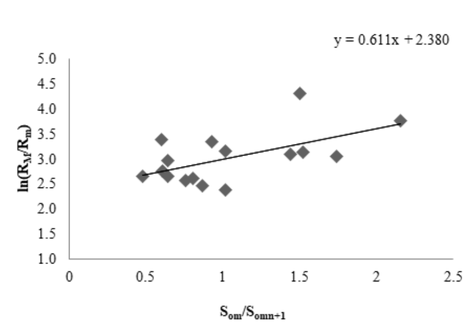

Fig. 6 Represent the logarithmic formula

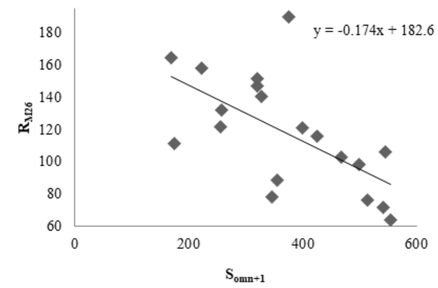

Fig. 7 The relationship between R_M with (S_{omn+1}).

Comparison with the results of other authors

A number of forecasts, applying various techniques, have been published recently for the peak of the 25th solar cycle. Table 1 represents the results for cycle 25; our results are in the lower tier of the table. It is clear that our results concur with most other investigators in the sense that cycle 25 has lower amplitude than cycle 24. On the other hand, there are a few authors who claim that cycle 25 may be of similar or higher amplitude than 24.

Table 1. Predictions of Solar cycle 25

Author & year	Method	Maximum amplitude
Javaraiah (2017)	Cosine function + linear fit	30–40
Covas et al. (2019)	Neural networks Spatiotemporal	57 ± 17
Kakad et al. (2017)	Shannon entropy model	63 ± 11.3
Labonville et al. (2019)	Solar dynamo models	89 (+/- 29/14)
Attia et al. (2013)	Neural networks Neuro-fuzzy	90.7 ± 8
Gopalswamy et al. (2018)	Microwave imaging observations	89 and 59
Recent work	precursor technique of spotless total	108.6
	odd	114.99
	aa_{min} total	111.6
	aa_{min} odd	99.5
	precursor technique of SLDs (26^{th})	96.6
NOAA and NASA	Recent	115
Recent work	precursor technique of SLDs (26^{th})	96.6

Conclusion

In the present study, we have used two major solar indices - spotless events and aa_{min}. That has a better understanding of the variation of solar activity. The data sets of both parameters are used to estimate and forecast the level of activity for solar cycles 25^{th} and the upcoming cycle 26^{th}. Our work illustrates that cycle 25 will achieve a low amplitude in comparison to cycle 24.

Precursor techniques are major contributors to the consensus prediction of the solar maximum phase, and they are the most successful ones dealing with such a problem.

Large-scale discrepancy in the results is attributed to the large-scale variety of methods of analysis and data sets.

It seems that the distribution of SLDs across the successive solar cycles is responsible for the variety of their strength.

The more frequently and longer the record of SLDs, the smaller the values of the maximum Wolf number.

The simultaneous results show the effectiveness of our proposed method of analysis, which confirms our early prediction.

We can conclude with a sufficient degree of confidence that solar activity 22–26 will systematically decrease because of the increasing phase shift between SLDs and the strength of the solar cycle, possibly leading to a noticeable reverse relationship between SLDs and the maximum level.

Our results fall within the uncertainty of NOAA/NASA consensus predictions (December, 2019).

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ПРОВЕРКА НА ПРОГНОЗАТА НА 25-ия СЛЪНЧЕВ ЦИКЪЛ ВЪЗ ОСНОВА НА МЕТОДИ НА ПРЕДВЕСТНИЦИТЕ

Р. Хелал, М. Семейда, А. Абулуфа

Резюме

Прогнозирането на нивото на слънчева активност е жизненоважно за всички космически програми, планирането на космически мисии, промени във времето и климатични изменения. Използват се различни подходи за прогнозиране на предстоящия слънчев цикъл. В тази статия дните без слънчеви петна (**SLD**) около предходния минимум и геомагнитният индекс **aamin** се използват като предвестник за повторно прогнозиране на максимума на 25-ия слънчев цикъл от набор от наблюдателни данни. Този метод показва доста приемлив резултат, който дава максималната амплитуда на 25-ия слънчев цикъл, използвайки SLD, равна на $R_{25SLD} = 108.58$, а времето на покачване $T_{25SLD} = 4.2$ години. Използвайки aamin, $R_{25aamin} = 111.6$ и $T_{25aamin} = 3.98 \sim 4$ години, накрая се установява, че прогнозираният максимум за предстоящия 26-ти цикъл е $R_{26SLD} = 96.6$.