A NEW METHOD TO PREDICT THE SOLAR CYCLE

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Abstract. We present here a new method to forecast the sunspot cycle. This method is based on the superimposed epochs analysis, where the peak years are considered to be the zero epochs. We predict yearly relative sunspot numbers for the cycles. 24 and 25. The next solar maximum will be in 2012, with the amplitude of almost 149, and in 2023, with the amplitude of almost 120.

Key words: solar cycle – solar activity – forecast.

1. INTRODUCTION

Solar activity variations represent a key of our understanding about the evolution of our star. The most common variability is that of almost eleven-years cycle. Many methods of prognosis have been elaborated to estimate the solar cycles amplitude, during times. Petrovay (2010) published a comprehensive analysis of the forecast methods of the solar cycle. He classified these methods in mainly three classes: precursor methods, extrapolation methods and model-based predictions. Precursor methods rely on the values of some measures of solar activity or magnetism, at a specified time, to predict the amplitude of the following solar maximum. Extrapolation methods consider that the physical process giving rise to the sunspot number record is statistically homogeneous and form a time series that can be analyzed. The last class of forecasting methods relies on physical models.

The cycle parameters have been used as precursors in some methods. A simple approach of sunspot cycle prediction is correlating the amplitudes of consecutive cycles. A significantly better correlation exists between the minimum activity level and the amplitude of the next maximum. Cameron and Schussler (2007) have shown that the activity level three years before the minimum is a better predictor of the next maximum. The polar magnetic field measurements can be also used to estimate the next solar maximum. This method is still at the beginning since data of the polar magnetic field are available only from 1976 (Wilcox Observatory).

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Relations between the sunspot cycle and geomagnetic indices variations were noted long ago. The component of the geomagnetic variations actually follows sunspot activity with a variable time delay. Thus a geomagnetic precursor based on features of the cycle dominated by this component gives relatively significant errors. Du (2011) argues that the *aa* geomagnetic index used as precursor of the sunspot maximum forecast may probably fail for the cycle 24 prognosis.

Flux transport dynamo models rely on the strong polar fields ruling around sunspot minimum and formed by the advection of following polarity flux from active regions by the poleward meridional flow. Amplitude and speed fluctuations of the meridional flows may influence the polar fields and thereby may serve as precursors of the upcoming solar cycle. Using data from SOHO, Hathaway and Rightmire (2010) found an excess of speed of the poleward flow of the magnetic features during the decreasing phase of cycle 23 relative to previous cycle. They suggested that this slowing might explain the belated start of cycle 24.

Various authors have made different predictions for solar cycle 24, estimating that the relative number of sunspots will reach the maximum values of 90 if the peak will occur after 2013, and of 140 if the maximum will produce in 2012. If the maximum of sunspot activity will occur in 2012 is possibility to have a secondary maximum in 2014. There are authors who predict higher values for the relative number of spots. Pesnell (2008) summarized all these predictions in a comprehensive article.

We present here an original method of forecasting the sunspot number, method based on the statistical analysis of the superimposed epochs. The zero epoch has been chosen the year of the maximum sunspot activity and the time series considered contains the yearly value of the relative sunspot numbers from 1700 to 2009.

2. METHOD

Our method of prediction is based on the superimposed epochs analysis. This is a statistical method referred to a zero moment or epoch and it is usually applied in astronomy, meteorology, geophysics, etc. Ambroz (1979) provided a detailed description of this method applied in solar physics.

We have considered the relative sunspot numbers registered from 1700 to present, i.e., 28 solar cycles, and establishing as zero epochs the year of maximum. As each solar cycle length varies from one to another, we assigned the values $w_{i,j} = -1$ to the years missing in each solar cycle, and considered a standard cycle's length of 16 years. This length was dictated by the cycle 4 and cycle 7 with the most prolonged descendent phase and ascendant phase respectively. Consequently, all data can be written as a matrix w_{ij}, where the index $i = \overline{0, n-1}$ refers to the number of cycles and the index $j = \overline{-7,0,7}$

refers to the years inside a cycle, where $j = 0$ represents the year of maximum sunspot activity (the zero epoch). Since the soft deals only with positive values of the index, we considered a shifted index, $j = \overline{0,15}$: there are 16 points and the maximum year (zero epoch) corresponds to $j = 7$.

The cycle 24 corresponds to $i = n = 28$ in our time series. The superposition of all solar cycles registered from 1700 to present is plotted in Fig. 1. The basic idea of our method of forecast relies on the correlation of two consecutive solar cycles. If $w^{<i>}$ denotes the cycle *i*, then the correlation coefficients are $r_i = corr(w^{<i>}, w^{<i-1>})$. Fig. 2 plots these coefficients vs. the number of the solar cycles that means time, with $i = \overline{1, n-1}$. We notice the allure of this curve that modulates as the secular solar cycles.

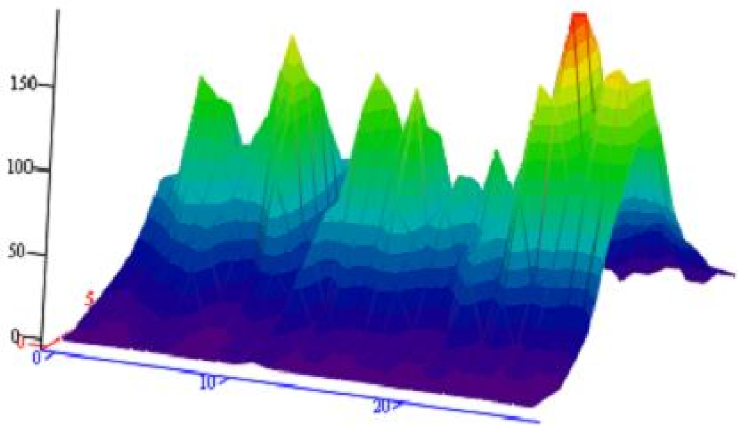

Fig. 1 – Superposition of all solar cycles registered from 1700 to present: the year of sunspot maximum is considered as zero epochs.

We estimated the annual relative sunspot number value, denoted with $p^{<i>}$, knowing the observed value for the previous year ($w^{<i-1>}$) and using the algorithm described below.

$$p^{<i>} = w^{<i-1>} \cdot slope(w^{<i-1>}, w^{<i-2>}) + intercept(w^{<i-1>}, w^{<i-2>}) \tag{1}$$

where $i = \overline{2, n-1}$. The *slope* and *intercept* have the usual meaning from mathematics.

For results, see Fig. 3.

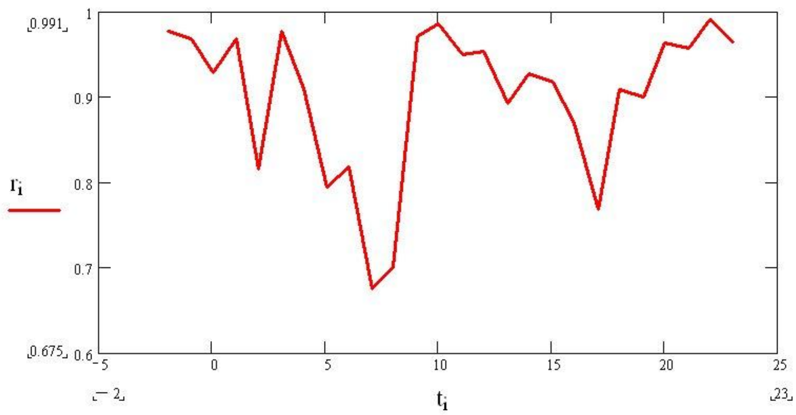

Fig. 2 – The correlation coefficients for each two consecutive solar cycles vs. time expressed in cycle number.

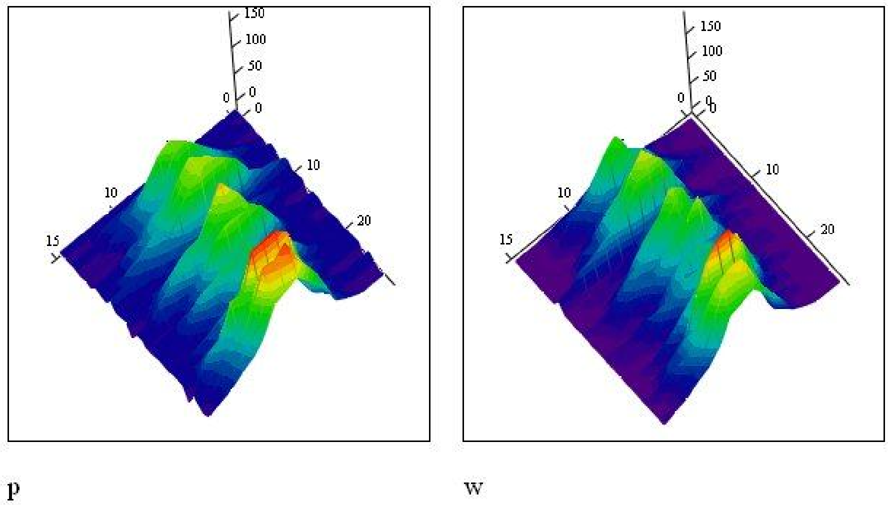

Fig. 3 – The computed relative sunspot numbers (*p*) versus the observed ones (*w*).

Table 1 summarizes the relative sunspot number values obtained by this method for the cycles 24 and 25. The years before the maximum (zero epoch) are denoted with negative numbers and those belonging to the descendant phase of each cycle are denoted by positive numbers. We reiterate that a standard cycle of the model has 16 years $(j=\overline{0,15})$ in our algorithm. This procedure gives negative values of sunspot number when physically the year before or after the epoch zero does not exist, i.e., the respective cycle is shorter. The results from Table 1 indicate a forecasted duration of twelve years for both cycles: four years on the ascendant phase of the cycle, the maximum year (zero epoch) and a descendant phase counting only seven years.

Table 1.

The numerical results of the forecast algorithm for the cycles 24 and 25

Years before maximum	(j=0)	6 (j=1)	5 (j=2)	4 (j=3)	3 (j=4)	2 (j=5)	1 (j=6)	0 (j=7)
Cycle 24	–7.2	–7.2	–7.2	5.2	21.9	77.3	114.9	148.9
Cycle 25	–1	–1	–1	8.6	21.5	64.3	93.3	119.6
Years after maximum	1 (j=8)	2 (j=9)	3 (j=10)	4 (j=11)	5 (j=12)	6 (j=13)	7 (j=14)	8 (j=15)
Cycle 24	137.8	128.7	76.5	46.3	32.6	13.7	3.7	–7.2
Cycle 25	111	104	63.7	40.4	29.8	15.2	7.5	–1

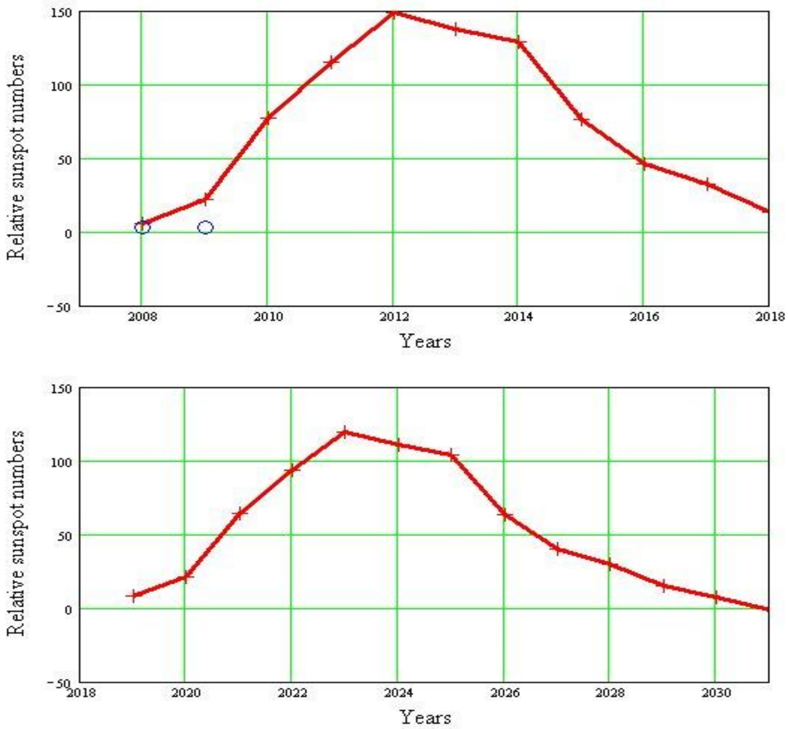

Fig. 4 – The cycles 24 and 25 activity level forecast: crosses represent the predicted values and circles represent the observed values for 2008 and 2009.

Fig. 4 plots the results of this forecast taking into account that cycle 24 started in 2008 and we had the definitive sunspot number registrations for the first two years. These values are marked with circles on the figure. We have obtained for the solar cycle 24 a maximum equal to $p24=148.9$ to be reached in 2012 and for the solar cycle 25 a value $p25=119.6$ to be reached in 2023. Our method predicts the next solar minimum to be in 2019.

3. CONCLUSIONS

Summarizing our results, we point out that we have introduced in this work a new method of forecast the solar cycle. This method is based on the superposed epochs analysis where the year of maximum of each solar cycle was considered as zero epoch. The standard solar cycle was dimensioned to sixteen years, but with negative values of sunspot number when a year lacked physically from the cycle, i.e., the cycle was shorter.

By correlating two consecutive solar cycles we are able to predict the next solar cycle level of activity. Our forecasts place the cycle 24 maximum to be reached in 2012 with almost 149, the next solar minimum in 2018, and the cycle 25 maximum in 2023 with almost 120 values of the sunspot number. We notice that these predicted values, especially for the cycle 25, could be improved as time goes by, and we obtain new observed value registrations of the relative sunspot number.

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REFERENCES

Ambroz, P: 1979, *Bull. Astron. Inst. Czechosl.*, **30**, 114.
Cameron, R., Schussler, M.: 2007, *Astrophys. J.*, **659**, 801.
Du, Z.: 2011, *Solar Phys.*, **270**, 407.
Hathaway, D. H., Rightmire, L.: 2010, *Science*, **327**, 1350.
Pesnell, W. D: 2008, *Solar Phys.*, **252**, 209.
Petrovay, K.: 2010, *Living Reviews in Solar Physics*, Vol. **7**, No. 6.

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