# Prediction of basic elements of the forthcoming solar cycles 24 and 25 (years 2005-2027)

Vasilis Tritakis*, Helen Mavromichalaki†, George Giouvanellis †

* *Research Center of Astronomy and Applied Mathematics, Academy of Athens,*

† *Nuclear and Particle Physics Section, Physics Department, University of Athens,*

*vas@academyofathens.gr, emavromi@cc.uoa.gr, giogiouvas@yahoo.gr*

**Abstract.** Fundamental parameters of a solar cycle could be predicted if we take in mind an existed interdependence between successive 11-year and 22-year cycles. Elements which could be predicted are, the time of rise, the total duration and the yearly values of the activity on the maximum and minimum epochs of the cycles as well as the time of maximum and the second minimum. Predicted values of these parameters for the cycles No. 24 (2005-2016) and 25 (2016-2027) are tabulated in this contribution. The small value of standard error (high coincidence between observed and calculated values) which has been succeeded during the application of the present method in the past solar cycles implies success of the proposed method of prediction for the forthcoming cycles.

**Keywords:** Sunspot number, prediction, solar cycle, odd-even cycles, space weather
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## INTRODUCTION

The impressive progress in the solar physics research during the last decades has not succeeded to describe the exact mechanism of the solar activity development, yet. This is a very serious difficulty to define a confident solar cycle prediction based on pure physics. However, the rapid evolution of new and dynamic branches of solar and space physics like, Space Weather, Solar Variability, Global Change have made the necessity of accurate short-term and medium – term solar activity predictions very urgent.

Since the prediction of the solar activity by physical methods is still impossible but the demand for predictions is very intense, it is reasonable to turn to the only way left which is the development and the improvement of empirical methods which can approach an approximated profile of a forthcoming solar cycle.

This is a very long and old way along which many methods of this category have been developed and a large number of papers have been published on this subject. The common point of these methods is the use of statistical characteristics of solar cycles or various optical, geomagnetic and interplanetary precursors. All these methods are separated in three major categories concerning to the range of the prediction they can possibly succeed. The short–range category comprises methods they attempt to predict solar activity for the next few days or weeks, the middle-range methods offer forecasting for the next 11-year solar cycle, while the long range methods risk

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predictions for several solar cycles. Methods of the last category are rather hopeless or they contain only philological interest because the relatively short duration of systematic observations of the Sun (120 years or 10-12 solar cycles) does not allow the formulation of a significant prediction way.

On the other hand, short-term methods are mainly based on the continuously recording of the solar disk and the near interplanetary medium seeking for some indication of solar activity change. The medium –range methods are based on empirico-statistical characteristics of the previous solar cycles which can be extrapolated to the forthcoming cycles. There are tenths of methods which can be classified in the last category the oldest of which were introduced by legends of the solar activity subject like [1], [2], [3], [4]. In the present study we attempt to forecast the main parameters of the next couple of 11-year solar cycles using some very close relations they exist between two successive solar cycles especially a couple of an even-odd cycles they form a 22-year magnetic cycle [5].

## DATA ANALYSIS

A substantial point of the following method is that uses alternative data from the typical Wolf's numbers. These data come from the relation,

$$I_\alpha = 1/2\,(\sqrt{A} + \sqrt{f}) \qquad (1)$$

where $I_\alpha$ is the area index, A and f the areas of sunspots and faculae, measured by the Greenwich Observatory, respectively [6], [7]. The reason we prefer to use this index instead to the well and wide accepted Wolf Numbers (W.N) is the presence of faculae which add physical meaning in the final formula. It is widely known that the faculae are good indicators of the small scale solar magnetic fields they surround active centers and make solar activity more effective. In addition, this index varies smoothly within a rather narrow range of values that makes it very predictable, in contrast to the Wolf's numbers they vary abruptly within a wide range of values. The variations of both the Wolf's numbers (upper panel) and the area index (bottom panel) for the time span 1884-2004 are depicted in Fig. 1. It is obvious that sunspot number values are ranged between 0 and 200 and Area index varies in the range from 7 and 55.

Fundamental data of both indexes can be easily found and downloaded by the sites:

http://www.ngdc.noaa.gov/stp/SOLAR/ftpwhitelightfaculae.html
and http://www.ngdc.noaa.gov/stp/SOLAR/ftpsunspotnumber.html.

A serious problem we faced during processing was the limited record of faculae which exceeded until the year 1969. After that year, the Greenwich Observatory which compiled this record abolished the areas and faculae observations patrol. Fortunately, the correlation between the $I_\alpha$ and the $\sqrt{R}$ is extremely high, almost 98% (Figure 2), so we were able to complete our faculae time series until nowadays, in a high confidence level 97% by extrapolating the relation,

$$I_\alpha = 3.98\sqrt{R} + 4.43 \qquad (2)$$

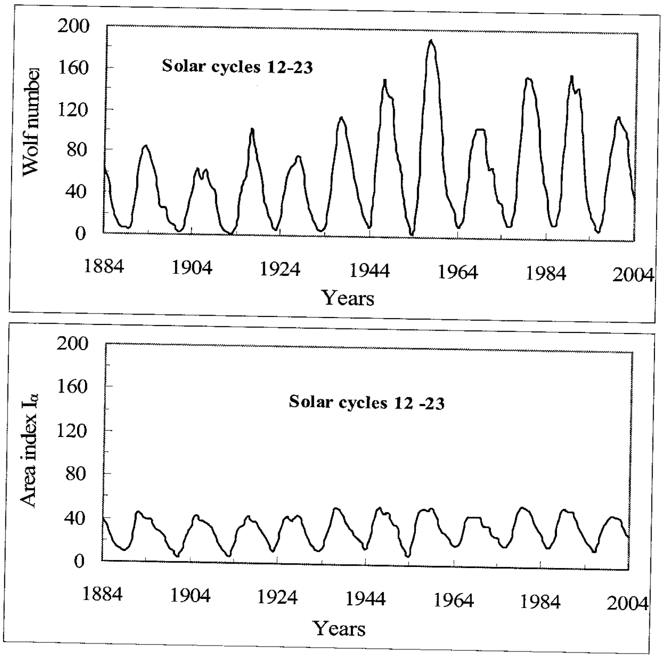


**FIGURE 1.** Time distribution of the Wolf's numbers (upper panel) and the area index (lower panel) for the solar cycles 12-23 (1884-2004).

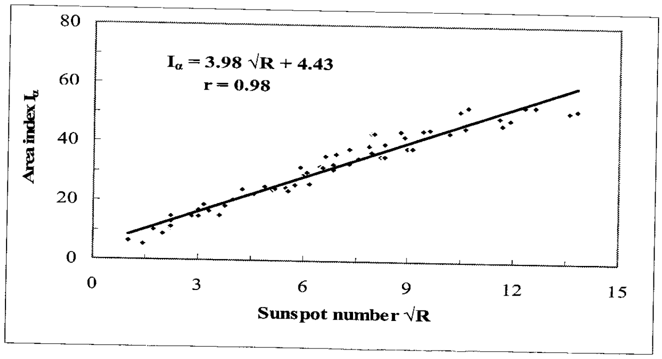


**FIGURE 2.** Correlation diagram between the area index $I_\alpha$ and the sunspot number $\sqrt{R}$.

## THE METHOD

According to our way of prediction, the most important point of a solar cycle is the quasi-triangle area which is limited by the ascending branch of a solar cycle and the vertical from the maximum to the time axis, called "ascending triangle" (Figure 3).

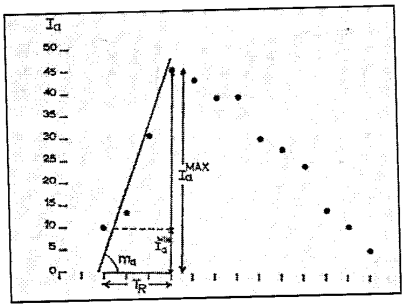


Figure 3: The ascending triangle of a typical solar cycle. Parameters $T_R$ , $m_\alpha$ , $I_\alpha^{max}$ and $I_\alpha^{min}$ are defined.

Two very important parameters of this triangle is the slope of the ascending branch $m_\alpha$ that could be calculated by the least square method and the time of rise $T_R$ that is, the time interval from the appearance of the preliminary indications of a new solar cycle to the maximum of it.

It is known that there are differences in solar activity from cycle to cycle. There are series of cycles with very high activity level (odd cycles) as well as series of cycles with quite low activity (even cycles). A different behavior between even and odd solar cycles is presented in solar activity, where even sunspot cycles are characterized by two well defined 'still stands' in the level of activity during the declining phases of such cycles. It is known that there are systematic differences in the overall shapes of successive 11-year modulation cycles and similarities in the shapes of alternative 11-year cycles that are related to the 22-year magnetic cycle and to the polarity reversals of the polar magnetic field of the Sun [8]. So, considering a couple of an even and an odd cycle according the Waldmeier's numbering system of solar cycles (the cycle that starts in the year 1610 is cycle No.1) we verify that there are strong correlations among basic parameters of the cycles they belong to the same couple. At first, there is a strong correlation between the time of rise and the slope of the ascending branch of the even cycle. In addition, the inverse slope of the ascending branch of the all studied here even cycles correlate very well with the rising time of the corresponding next odd cycles given a correlation coefficient 90%. The regression line of both even and odd cycles is given in Fig. 4, separately. From this figure it is clear that the rising time of the odd cycles is smaller than that of the even cycles, a result that was expected due to a previous work [9]. The regression in both panels of the figure 4 gives a very good formula for predicting the time of rise of a forthcoming cycle by the slope of

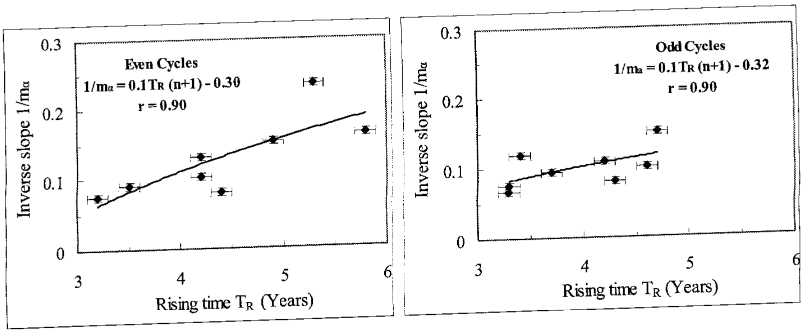


**FIGURE 4.** Correlation diagrams of the inverse slope of an even cycle to the time of rise of the next odd cycle (left panel) and of the same parameters of a couple odd -even cycle (right panel).

a cycle which has competed the ascending branch.

The relations which could help in the prediction of $T_R$ are defined ,

$$1/m_\alpha = 0.1T_{R(n+1)} - 0.30 \quad (\text{for even cycles})$$
$$1/m_\alpha = 0.1T_{R(n+1)} - 0.32 \quad (\text{for odd cycles}) \qquad (3)$$

where $m_\alpha$ is the slope of a certain cycle and $T_{R(n+1)}$ is the rising time of the next cycle.

The application of the above relations to past solar cycles gave accuracy, that is, a coincidence between real and predicted values of the slope, 91% which is a very high criterion of confidence.
The accuracy for odd cycles is about 91% and for even cycles is also high and about 92%. The choice of two relations and not only one had been guided by the differences of odd and even cycles, that are described by many researchers [10], [11], [8]. Generally, the odd cycles are characterized by one maximum, hard rising time, "saddle-like" shape and "mesa-type" maximum, whereas even cycles are characterized by two maxima, soft rising time, "peak-like" shape and "point-type" maximum [12].

When we succeed to predict the time of rise of a forthcoming cycle we can proceed to the next step which is to predict the total time of a forthcoming solar cycle that is, the time span between the first and the second minimum of the cycle. It could be done by dividing all the solar cycles in two groups. Group1 contains the cycles ({1, 2}, {5, 6}, {9, 10}, {13, 14}, {17,18}, {21, 22}, {25, 26}...) and Group 2 contains ({3,4}, {7, 8}, {11,12}, {15,16}, {19,20}, {23, 24}...). The way we divide solar cycles in the above two groups implies a quasi periodicity of 22 years which coincides to the solar magnetic field inversion [8]. In the figure 5, the correlation between the total time and the time of rise of each cycle for the groups 1 and 2 is depicted, while the equations (5) and (6) below express the relevant relations. If $T_R$, for each group are the predicted from the relations (3) and (4) values, we can predict the total time with accuracy 95% and 92% for the groups 1 and 2 respectively (Fig. 5)

$$T_{tot} = 0.85\ T_R + 7.63 \quad \text{(group 1)} \quad (5)$$
$$T_{tot} = 0.55\ T_R + 7.62 \quad \text{(group 2)} \quad (6)$$

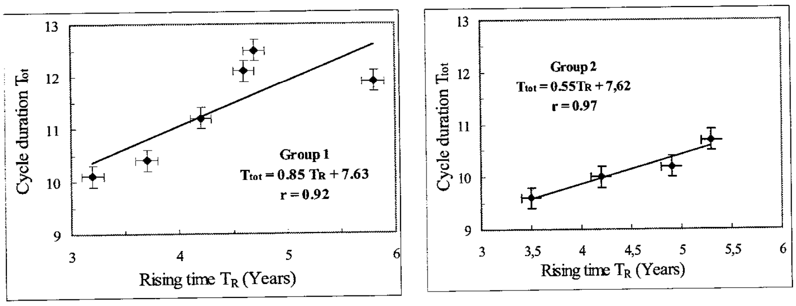


**FIGURE 5.** Correlation diagrams between the total time and the rising time for both group 1 and group 2 cycles.

The maximum area index during a certain cycle could be predicted by the following relations (7) and (8), where $T_R$ is the rising time predicted by the relations (3) with accuracy 96% for group 1 and 95% for group 2 presented in Fig. 6.

$$I_\alpha^{max} = -5.30\ T_R + 70.22 \quad \text{(group 1)} \quad (7)$$
$$I_\alpha^{max} = -6.20\ T_R + 72.16 \quad \text{(group 2)} \quad (8)$$

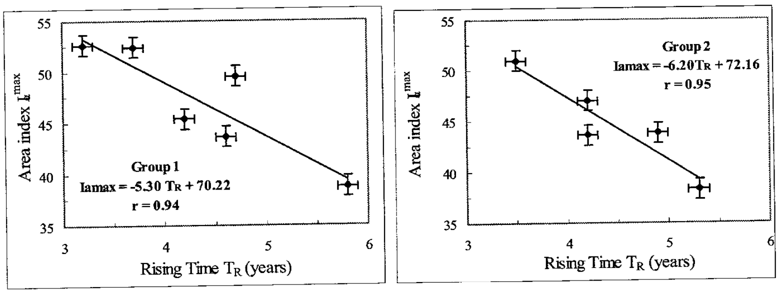


**FIGURE 6.** The regression lines between the area index and the rising time for both group 1 and group 2 cycles.

## RESULTS

**Application to Past Cycles:** As an example we present an application of the proposed method to the past cycles 21 and 22. The time evolution of these solar cycles (1975-1995) expressed by the area index $I_\alpha$ are depicted in Figure 7, while a comparison between observed and predicted by this method values of some important elements of the above cycles are tabulated in the Tables I(a) and I(b). It is obvious that the coincidence between observed and predicted values is very high, something which makes us very optimists concerning the prediction of the same elements for the forthcoming cycles No. 24-25 (2005-2027). It is important to be noticed that the predicted values of the basic elements of cycle 21 are very close to the observed ones. It is noteworthy that the epoch $I_\alpha^{max}$ deviates only four months from the observed value.

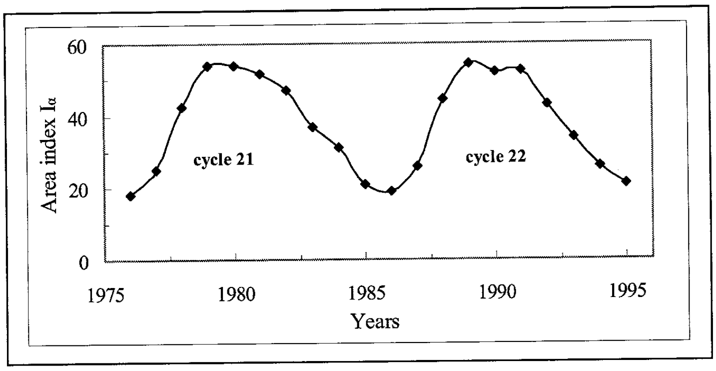


**FIGURE 7.** Time distribution of area index $I_\alpha$ for solar cycles 21 and 22

| Parameters | Used data cycle 19 | Predicted data cycle 21 | Observed data cycle 21 | Residuals Obs-Cal |
|---|---|---|---|---|
| $m_\alpha$ | 15.02 | - | - | - |
| $T_R$ | | 3.8 years | 4.3 years | **0.5** years |
| $T_{tot}$ | - | 11 years | 10.6 years | **0.4** years |
| $I_\alpha^{max}$ | - | 47.43 | 50.52 | **3.09** units |
| $I_\alpha^{max}$ epoch | - | Jun 1979 | Oct 1979 | **4** months |

**TABLE I(a).** Results of the application of the proposed model to the cycle 21

| [illegible]meters | Used data cycle 20 | Predicted data cycle 22 | Observed data cycle 22 | Residuals Obs-Cal |
|---|---|---|---|---|
| [illegible] | 7.63 | - | - | - |
| [illegible] | | 4.4 years | 4 years | **0.4** years |
| [illegible] | - | 10.7 years | 11.2 years | **0.5** years |
| [illegible] | - | 47.6 | 46.9 | **0.7** units |
| [illegible] epoch | - | Jul 1989 | Mar 1989 | **4** months |

**TABLE I(b).** Results of the application of the proposed model to the cycle 22

**Application to Forthcoming Cycles:** In the Table II purely predicted values of basic elements of the forthcoming solar cycles No. 24 and 25 (2005-2027) are tabulated. In the last column the accuracies between observed and predicted values of these elements for the past solar cycles No. 12-23 are bolded. The high values of coincidence between observed and calculated elements imply optimistic results for our prediction.

| Parameters | Used data cycle 22 | Predicted data cycle 24 | Accuracy |
|---|---|---|---|
| $m_\alpha$ | 12.51 | - | - |
| $T_R$ | | 3.7 years | 91% |
| $T_{tot}$ | - | 10.7 years | 92% |
| $I_\alpha^{max}$ | - | 50.26 | 92% |
| Rmax | - | 132.59 | 92% |
| $I_\alpha^{max}$ epoch | - | Jun 2009?!! | 90% |

| Parameters | Used data cycle23 | Predicted data cycle 25 | Accuracy |
|---|---|---|---|
| $m_\alpha$ | 8,46 | - | - |
| $T_R$ | | 4.4 years | 90% |
| $T_{tot}$ | - | 11.3 years | 95% |
| $I_\alpha^{max}$ | - | 46.9 | 95% |
| Rmax | - | 113.86 | 92% |
| $I_\alpha^{max}$ epoch | - | Dec 2020?!! | 90% |

**TABLE II.** Predicted values of the basic elements of the forthcoming cycles No. 24 and 25.

## CONCLUSIONS

The application of the above prediction method to all the confident past solar cycles supports the aspect that there is a great interdependence between two successive 11-year cycles they form a couple of even-odd cycle, according to the Waldmeier's numbering system. It is obvious that the evolution of an odd cycle depends very much on the evolutionary behaviour of the preceding even cycle. A reasonable exploitation of this interdependence can lead to a high accuracy prediction of the same basic parameters of a forthcoming 11-year cycle. The important point of this method is that the use of the area index values instead of the widely known Wolf's numbers or relative sunspot numbers as solar activity indicator. The reason for this change is the high predictability of the area index in contrast to the Wolf's numbers. The predicted values tabulated above in the Table I(a) give high grade of coincidence between observed and predicted values which in all cases exceed 90%. Concerning to the special characteristics of the predicted cycles we could underline that the prediction for the forthcoming solar cycle No. 24 gives a high solar activity cycle with maximum on June 2009 (fast rising and high maximum). On the other hand, the prediction for solar cycle 25 forms the profile of a moderate solar activity cycle with maximum on December 2020 (slow rising and medium maximum).


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