

Prediction of future fifteen solar cycles

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ABSTRACT

In the previous study (Hiremath 2006a), the solar cycle is modeled as a forced and damped harmonic oscillator and from all the 22 cycles (1755-1996), long-term amplitudes, frequencies, phases and decay factor are obtained. Using these physical parameters of the previous 22 solar cycles and by an *autoregressive model*, we predict the amplitude and period of the future fifteen solar cycles. Predicted amplitude of the present solar cycle (23) matches very well with the observations. The period of the present cycle is found to be 11.73 years. With these encouraging results, we also predict the profiles of future 15 solar cycles. Important predictions are : (i) the period and amplitude of the cycle 24 are 9.34 years and 110 (± 11), (ii) the period and amplitude of the cycle 25 are 12.49 years and 110 (± 11), (iii) during the cycles 26 (2030-2042 AD), 27 (2042-2054 AD), 34 (2118-2127 AD), 37 (2152-2163 AD) and 38 (2163-2176 AD), the sun might experience a very high sunspot activity, (iv) the sun might also experience a very low (around 60) sunspot activity during cycle 31 (2089-2100 AD) and, (v) length of the solar cycles vary from 8.65 yrs for the cycle 33 to maximum of 13.07 yrs for the cycle 35.

Subject headings: sunspots – solar cycle – prediction

1. Introduction

Owing to proximity, the sun influences the earth's climate and environment. Overwhelming evidence is building up that the solar cycle and related activity phenomena are correlated with the earth's global climate and temperature, the sea surface temperatures of the three (Atlantic, Pacific and Indian) main ocean basins, the earth's albedo, the galactic cosmic ray flux that in turn is correlated with the earth's cloud cover and, Indian monsoon rainfall (Hiremath and Mandi 2004 and references there in; Georgieva *et. al.* 2005; Hiremath 2006b). The transient parts of the solar activity such as the flares and the coronal

mass ejections that are directed towards the earth create havoc in the earth's atmosphere by disrupting the global communication, reducing life time of the earth bound satellites and, keep in dark places of the earth that are at higher latitudes by breaking the electric power grids. Owing to sun's immense influence of space weather effects on the earth's environment and climate, it is necessary to predict and know in advance different physical parameters such as amplitude and period of the future solar cycles.

There are many predictions in the literature (Ohl 1966; Feynman 1982; Feynman and Gu 1986; Kane 1999; Hathaway, Wilson and Reichmann 1999; Badalyan, Obrido and Sykora 2001; Duhau 2003 Sello 2003; Maris, Poepscu and Besliu 2003; Euler and Smith 2004; Maris, Poepscu and Besliu 2004; Kaftan 2004; Echer *et. al.* 2004; Gholipour *et. al.*, 2005; Schatten 2005; Li, Gao and Su 2005; Svaalgaard, Cliver and Kamide 2005; Chopra and Dabas 2006; Dikpati, Toma and Gilman 2006; Du 2006; Hathaway and Wilson 2006; Clilverd *et. al.*, 2006; Tritakis and Vasilis 2006; Lantos 2006; Lundstedt 2006; Wang and Sheeley 2006; Choudhuri, Chatterjee and Jiang 2007; Javaraiah 2007) on the previous and future 24th solar cycles and beyond. Most of these studies mainly concentrate on prediction of the amplitude (maximum sunspot number during a cycle). However, prediction of period (length) of a solar cycle is also very important parameter and the present study fills that gap.

Recently we modeled the solar activity cycle as a forced and damped harmonic oscillator that consists of both the sinusoidal and transient parts (eqn 1 of Hiremath 2006a). From the 22 cycles (1755-1996) sunspot data, the physical parameters (amplitudes, frequencies, phases and decay factors) of such a harmonic oscillator are determined. The constancy of the amplitudes and the frequencies of the sinusoidal part and a very small decay factor from the transient part suggests that the solar activity cycle mainly consists of persistent oscillatory part that might be compatible with long-period (~ 22 yrs) Alfvén oscillations. In the present study, with an *autoregressive* model and by using the physical parameters of 22 cycles, we predict the amplitudes and periods of future 16 solar cycles. Thus prediction from this study can be considered as a *physical and precursor* method.

A P th order *autoregressive* model relates a forecasted value x_t of the time series $X = [x_0, x_1, x_2, \dots, x_{t-1}]$, as a linear combination of P past values $x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \dots + \phi_p x_{t-p} + W_t$, where the coefficients $\phi_1, \phi_2, \dots, \phi_p$ are calculated such that they minimize the uncorrelated random error terms, W_t . The routine is available in IDL software. Important condition for using an *autoregressive model* is that the series must be *stationary* such that its mean and standard deviation do not vary much with time. Hence, one can not apply *autoregressive model* directly to the observed sunspot series as it consists of near sinusoidal trends whose amplitudes and the standard deviations entirely different for different solar cycles. On the other hand, the derived physical parameters of the forced and damped

harmonic oscillator (Hiremath 2006a) for all the 22 solar cycles are stationary and, hence in the following, we use an *autoregressive* model to predict the future 15 solar cycles.

The solution of the forced and damped harmonic oscillator (see the equation 1 of Hiremath 2006a) of the solar cycle consists of two parts : (i) the *sinusoidal* part that determines the amplitude and period of the solar cycle and, (ii) the *transient* part that dictates decay of the solar cycle from the maximum year and also determines bimodal structure of the sunspot cycle around the maximum years for some cycles. In the present study, we use physical parameters of the sinusoidal part only to predict amplitude and period of future cycles.

2. Results and conclusion

Using past 22 cycles' physical parameters, we construct the next (23rd) solar cycle and presented in Fig 1. Except decaying part of the solar cycle, one can notice that the predicted curve exactly matches with the observed curve. With this encouragement and from an *autoregressive* model, the physical parameters of future 16 solar cycles are computed and reconstructed solar cycles are presented in Fig 2. For the coming cycles 24-38, the results are summarized in Table 1. In Table 1, the first column represents the cycle number, the second column represents the year from minimum-minimum, the third column represents the period (length) of the solar cycle and, the last column represents the maximum sunspot number during a cycle. It is interesting to note that the amplitude of the cycle 24 is low compared to the amplitude of cycle 23 and is almost similar to average value computed from all of the predicted models (<http://members.chello.be/j.janssens/SC24.html>). Other interesting predictions are : (i) during the cycles 26, 27, 34, 37 and 38, the sun will experiences a very high solar activity, (ii) during cycle 31 (2087-2099 AD) the sun will experiences a very low sunspot activity and, (iii) length of the solar cycles vary from 8.65 yrs for the cycle 33 to maximum of 13.07 yrs for cycle 25.

To conclude, the solar cycle is modeled as a forced and damped harmonic oscillator. From the previous 22 cycles sunspot data, the physical parameters such as the amplitudes, the frequencies and phases of such a harmonic oscillator are determined. The sinusoidal part of the forced and damped harmonic oscillator of previous solar cycles is considered for the prediction of future 16 cycles. With an *autoregressive* model and using previous 22 cycles parameters, coming 16 solar cycles are reconstructed from the predicted parameters. Important results of this prediction are : the amplitude of coming solar cycle 24 will be smaller than the present cycle 23 and around 2087-2099 AD, the sun will experiences a very low sunspot activity.

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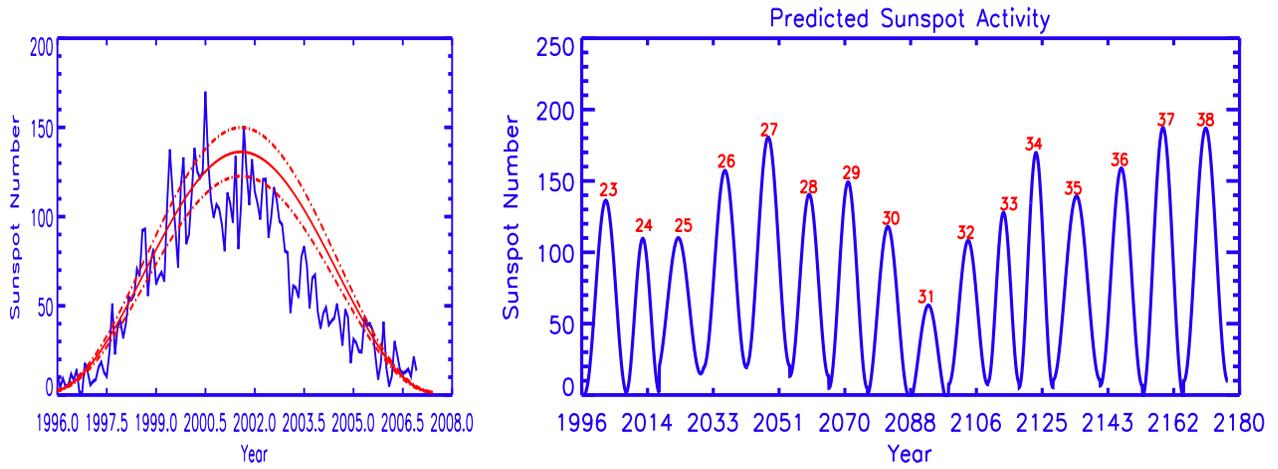


Fig. 1.— Prediction of the future solar cycles. (a) The left plot illustrates the predicted (red continuous) curve over plotted on the observed (blue curve) sunspot cycle 23. The dashed red curves represent uncertainty in the Prediction. (b) The right plot illustrates predicted future 15 solar cycles. The red numbers over different solar cycle maximum are the cycle numbers.

Table 1. Predicted sunspot cycles

Cycle Number	Year Min-Min	Period (Years)	Maximum Number
23	1996.00-2007.73	11.73	136±14
24	2007.73-2017.07	9.34	110±11
25	2017.07-2029.56	12.49	110±11
26	2029.56-2041.50	11.94	157±16
27	2041.50-2053.51	12.00	180±18
28	2053.51-2064.30	10.80	140±14
29	2064.30-2075.01	10.71	149±15
30	2075.01-2086.79	11.78	118±12
31	2086.79-2097.95	11.16	63±6
32	2097.95-2108.84	10.89	108±11
33	2108.84-2117.49	8.65	128±13
34	2117.49-2126.92	9.43	170±17
35	2126.92-2139.99	13.07	139±14
36	2139.99-2151.74	11.75	159±16
37	2151.74-2163.19	11.45	187±19
38	2163.19-2175.48	12.29	187±19