ISSN: 2347-3487

Regression Analysis of Sunspot Numbers for the Solar Cycle 24 in Comparison to Previous Three Cycles

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ABSTRACT

Sunspots are temporary phenomena on the photosphere of the Sun which appear visibly as dark spots compared to surrounding regions. Sunspot populations usually rise fast but fall more slowly when observed for any particular solar cycle. The sunspot numbers for the current cycle 24 and the previous three cycles have been plotted for duration of first four years for each of them. It appears that the value of peak sunspot number for solar cycle 24 is smaller than the three preceding cycles. When regression analysis is made it exhibits a trend of slow rising phase of the cycle 24 compared to previous three cycles. Our analysis further shows that cycle 24 is approaching to a longer-period but with smaller occurrences of sunspot number.

KEYWORDS

Regression analysis, Sunspot numbers, Solar cycles

Academic Discipline and Sub-Disciplines

Physics

Subject Classification

Astronomy

Type (Method/Approach)

Regression analysis corresponding to Solar Terrestrial Physics

Council for Innovative Research

Peer Review Research Publishing System

Journal: Journal of Advances in Physics

Vol 4, No. 2

editor@cirjap.com, japeditor@gmail.com

www.cirjap.com

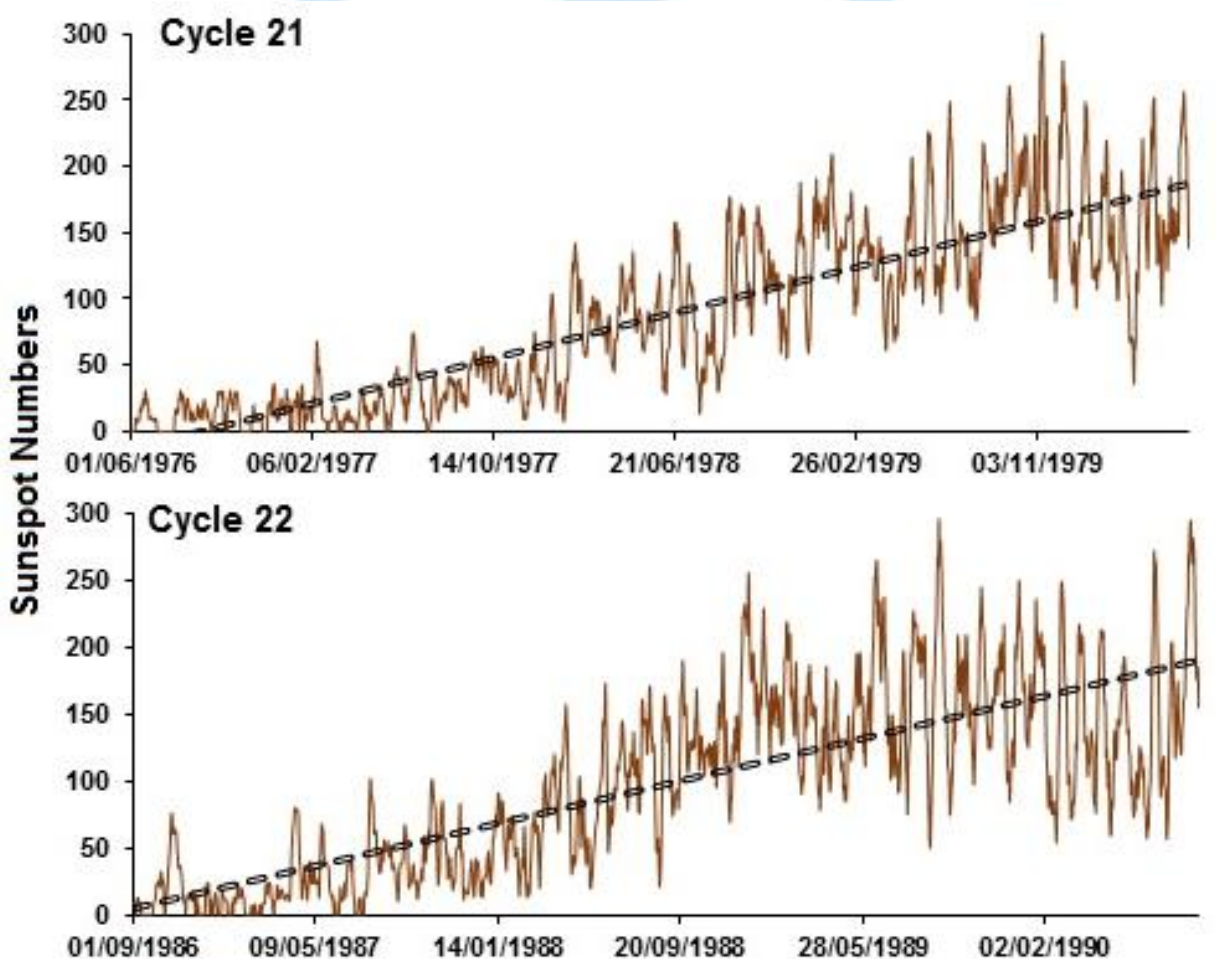
ISSN: 2347-3487

INTRODUCTION

Solar activity rises and falls with an 11-year cycle that affects us in many ways. Increased solar activity includes increase in extreme ultraviolet and x-ray emissions from the Sun, which produce dramatic effects in the Earth's upper atmosphere. Increase in the number of solar flares and coronal mass ejections (CMEs) raise the likelihood that sensitive instruments in space will be damaged by energetic particles accelerated in these events. The Sun's magnetic field constructs its atmosphere and outer layers through the corona and into the solar wind. Its spatial and temporal variations lead to phenomena known as solar activity. Every part of the solar activity is strongly modulated by the solar magnetic cycle, since the latter serves as the energy source and dynamic engine for the former[1]. The current solar cycle 24, began on December 2008, but showing minimal activity through early 2009. Sunspots did not begin to appear immediately after the last minimum in 2008. Although they started to reappear in late 2009, they are at significantly lower than predicted. The Solar cycle 24 has been in low rising phase for the last four and half years [2]. We have taken the first four years of the four solar cycles 21 to 24 to examine sunspot numbers in the rising phase of the cycles.

SUNSPOT NUMBER ANALYSIS

In Figure 1, the sunspots numbers for the solar cycles 21, 22, 23 and current cycle 24 have been plotted with the first four years duration of each cycle. This figure shows that while for the solar cycles 21 and 22 the peak sunspot number reaching almost 300, for cycle 23 the number is around 200 and for current cycle 24, peak sunspot number is below 150. Therefore the decrease in peak sunspot numbers from cycle 21 to 24 evidently leads us to a low solar activity days.



ISSN: 2347-3487

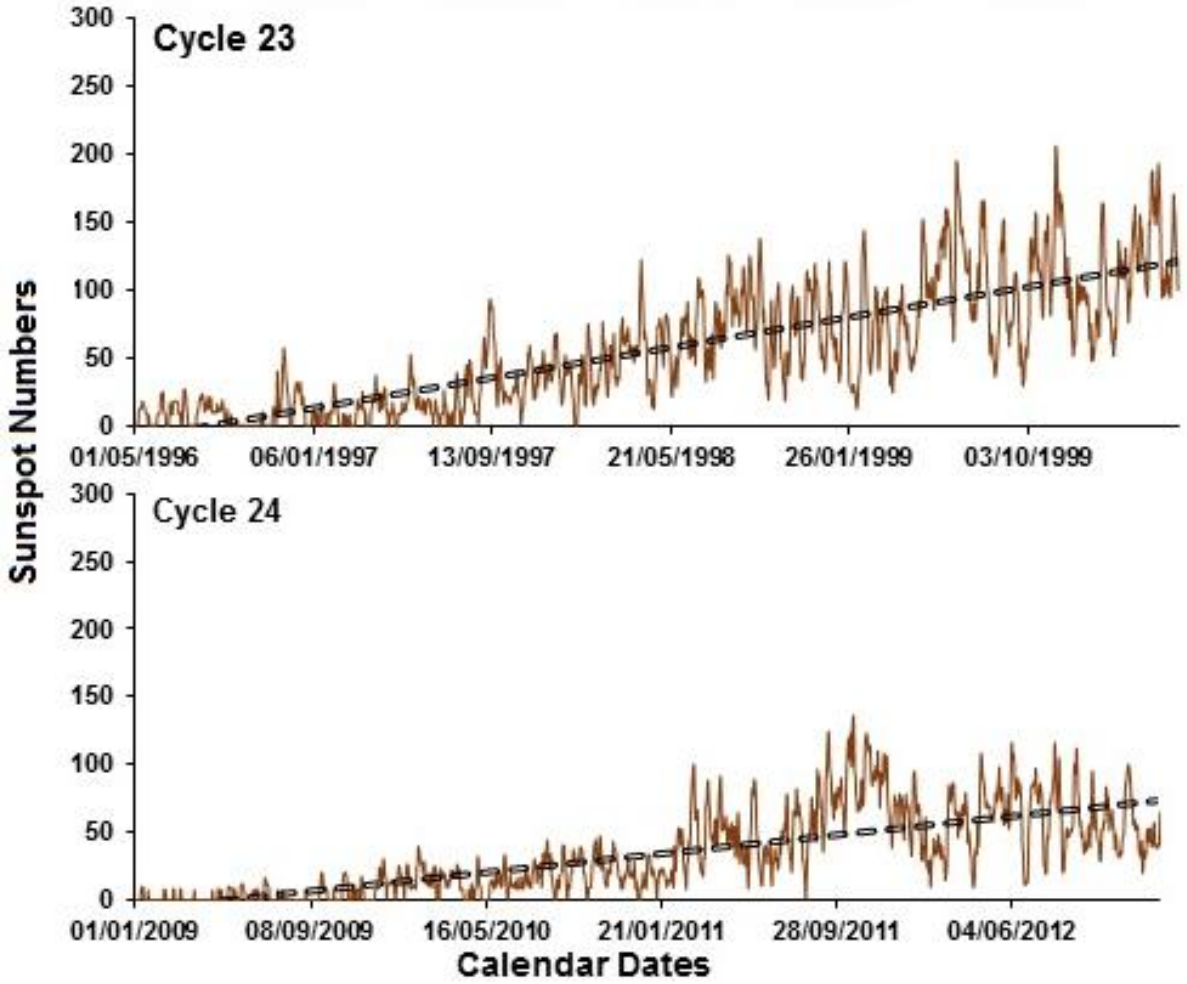


Figure 1: Plots of Sunspot numbers for the first four years of the solar cycles 21 to 24

The trend line equations for the four plots presented in Table 1 showing values of slopes, intercepts and R-squared values for the four cycles. The table reveals that all the slopes, intercepts and R-squared values for solar cycle 24 are smaller than the previous cycles and thus indicating the trend line for cycle 24 is flatter than previous cycles.

Table 1 – Comparison of slopes, intercepts and R-squared values of SSN plots for all the four solar cycles

Cycle No.	Trend line equation	Slope (m)	Intercept (c)	Correlation factor (R^2)
21	*y = 0.1375x - 3851.9*	*0.1375*	*- 3851.9*	*0.7433*
22	*y = 0.1282x - 4054.8*	*0.1282*	*- 4054.8*	*0.6209*
23	*y = 0.0897x - 3164.9*	*0.0897*	*- 3164.9*	*0.675*
24	*y = 0.0555x - 2217.7*	*0.0555*	*- 2217.7*	*0.5749*

REGRESSION ANALYSIS OF SUNSPOT NUMBERS

Regression analysis is a statistical tool for the investigation of relationships between variables. Here the response variable or the dependent variable is sunspot numbers and the explanatory variable or the independent variable is the calendar dates. A residual is the difference between the actual value of a dependent variable and the value of variable that was predicted by a statistical model. In the context of a regression analysis, a residual is how far a predicted value is deviated from the actual value of the dependent variable. This is also called an "error term".

Figure 2 demonstrates the plots of residuals of the regression analysis of the SSN values for the four cycles we have chosen. It shows that the variations of residuals are lesser than previous three solar cycles. While the variations for solar cycles 21, 22 and 23 are between -150 to +150, it is only between _75 to +75 in case of current cycle 24. This may be an interesting finding to support the prediction that the solar activity in the first four years of 24th cycle is very much weaker than the preceding three cycles.

ISSN: 2347-3487

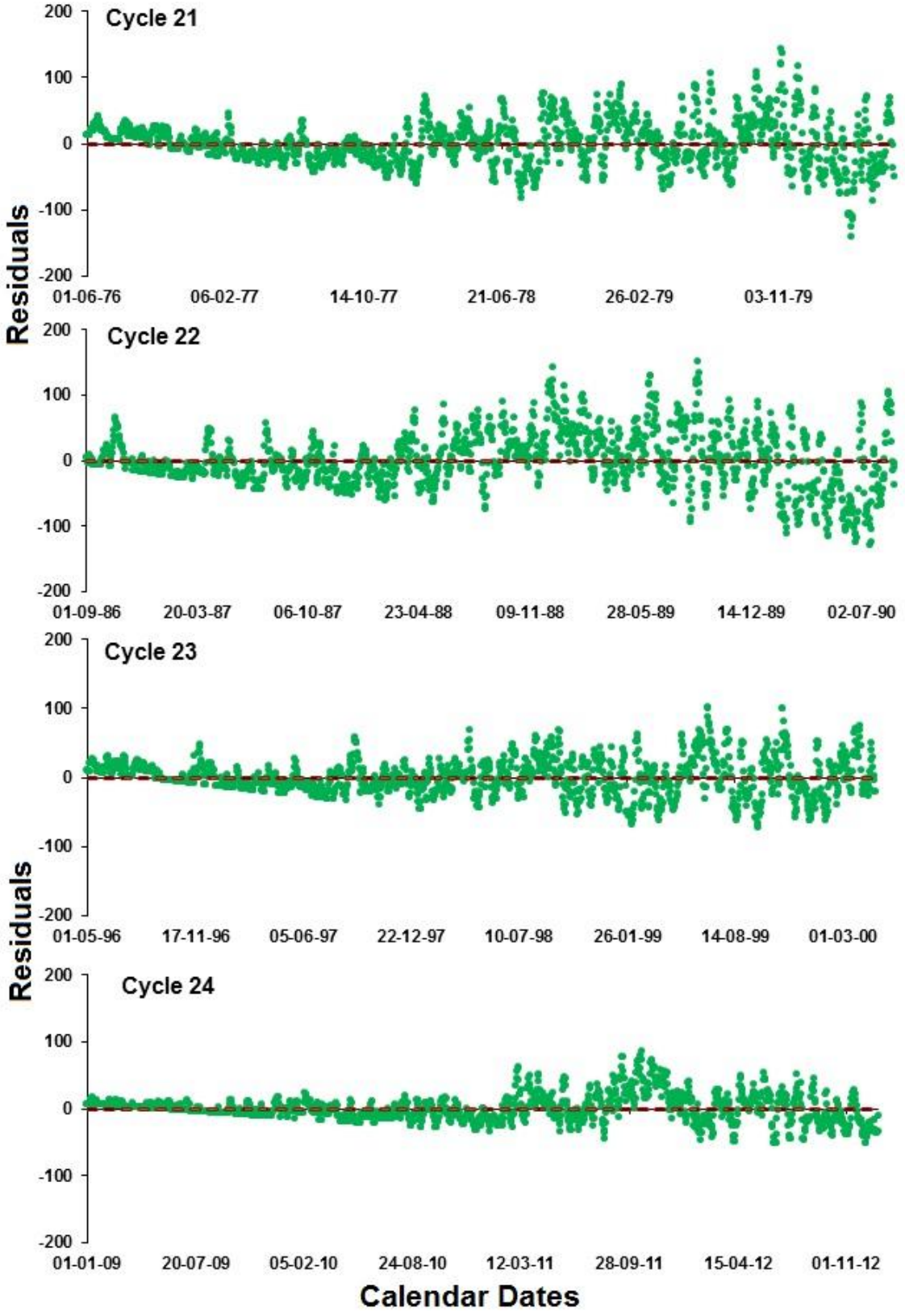


Figure 2:Plots of residuals for the regression analysis of sunspot numbers

Figure 3 shows the four line fit plots of regression analysis for the four solar cycles. Here we have plotted the sunspot numbers and its best fit graph with the predicted values of them which perfectly synchronizes with each other. This is also an interesting feature to be noticed.

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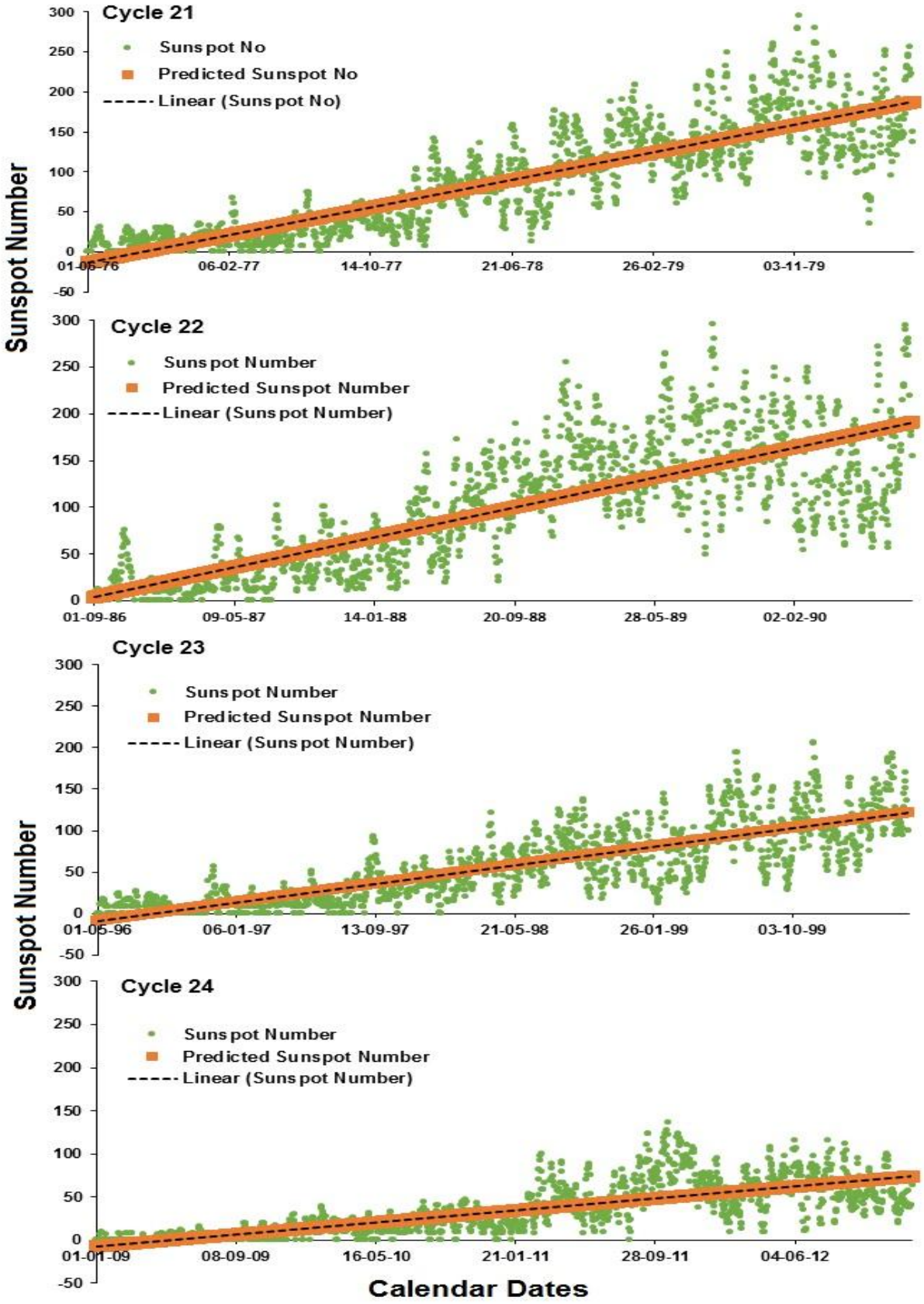

Figure 3: Line fit plots of regression analysis for the sunspots numbers

SOLAR CYCLE DURATION

Figure 4 depicts the plot of solar cycle numbers with their respective durations. The figure clearly shows that as the solar cycle number increases, the cycle's duration decreases in most of the cases. Only one solar cycle actually falls in the so-

called duration of the solar cycles i.e. 11 years. Solar cycles 4 and 23 are the longest duration cycles with 13.7 and 12.6 years of duration respectively whereas cycle 2, 3 and 22 have durations less than 10 years. Physically it may be interpreted as the activity of the sun is being low gradually solar cycle's duration decreases with a rapid rising and long tailing [3, 4]. This long tailing of the cycles causes most of the low solar activity days.

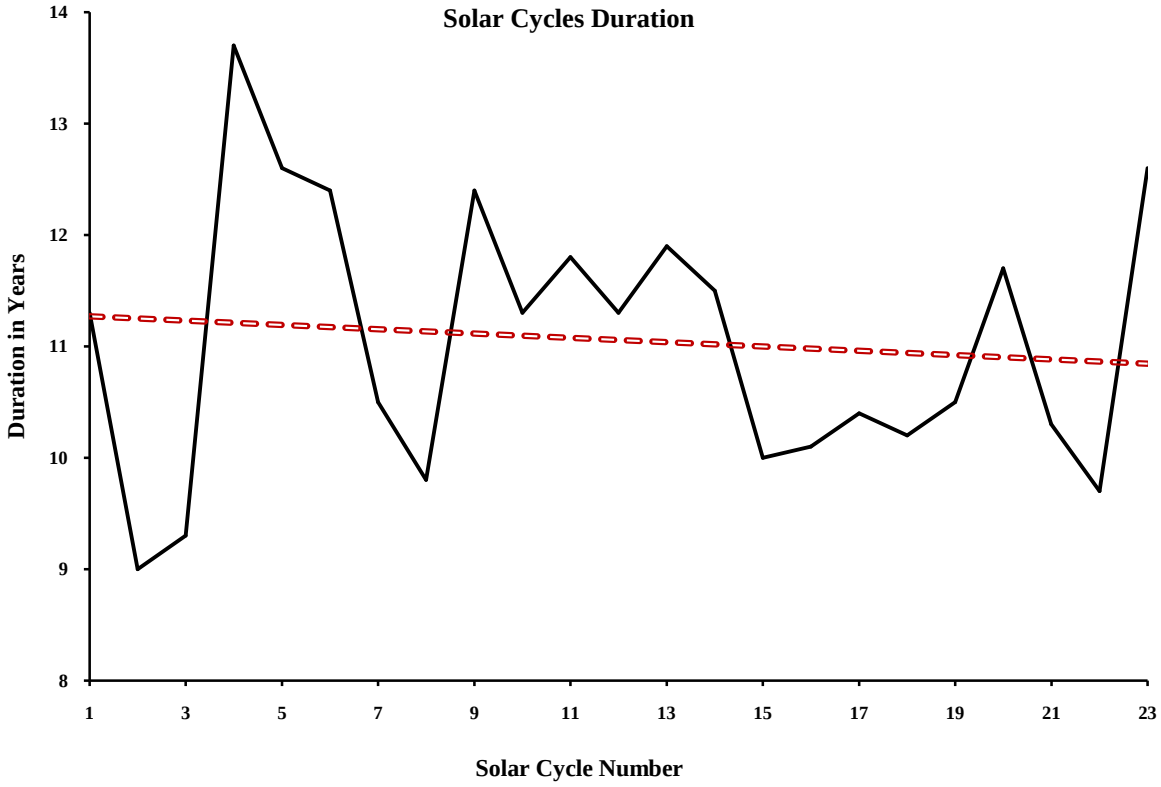

Figure 4: Plots of Solar cycle number with the corresponding duration of the cycles.

CONCLUSION

A table comprising the X-class solar flares occurred during running the solar cycle 24 is given below. Here the sunspot regions from where the solar flares ejected, classes of the solar flares and if coronal mass ejection (CMEs) and geomagnetic storms(GM) happened on those stipulated dates or not are shown. It may be noticed from Table I that there is no X-class flare in 2009 and 2010, which means minimal solar activity in those two years.

Table 2 – X- class flares occurred in solar cycle 24 (first four years) [data source]

Years	Dates (MMM DD)	Sunspot regions	Flare Classes	CME	Type of GM Storm
2011	Mar 9	1166	X1.5	Yes	G2
	Aug 9	1263	X6.9	Yes	-
	Feb 15	1158	X2.2	Yes	G1
	Sep 6	1283	X2.1	Yes	G3
	Sep 7	1283	X1.8	Yes	G1
	Sep 22	1302	X1.4	Yes	-
	Sep 24	1302	X1.9	Yes	G4
	Nov 3	1339	X1.9	Yes	-
2012	Jan 27	1402	X1.7	Yes	-
	Mar 5	1429	X1.1	Yes	G2
	Mar 7	1429	X5.4	Yes	G3
	Mar 7	1430	X1.3	No	-
	Jul 6	1515	X1.1	Yes	G1

	Jul 12	1520	X1.4	Yes	-
	Oct 23	1598	X1.8	Yes	G3

In Table 3, some of the top X-class flares occurred during the taken periods of the three previous cycles are shown.

Table 3 – Some top X class flares occurred in solar cycle 21, 22, 23 (first four years) [data source]

Cycle No.	Dates (DD/MM/YYYY)	Flare Classes
21	11/07/1978	X15.0
22	06/03/1989	X15.0
	16/08/1989	X20.0
	29/09/1989	X 9.8
	19/10/1989	X13.0
23	06/11/1997	X 9.4

A conclusion may be drawn from tables 1 and 2 that the current solar cycle 24 in its rising phase compared to the three previous solar cycles 21, 22 and 23 is going to be a very low-activity cycle as there is no X class flare bigger than X5.0 till 2012.

ACKNOWLEDGEMENT

Author is thankful to the CSIR for awarding him a Net fellowship.

DATA SOURCES

The data sources used in this paper are,

1. *http://www.noaa.gov*
2. *http://wdc.kugi.kyoto-u.ac.jp*
3. *http://www.ngdc.noaa.gov*

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