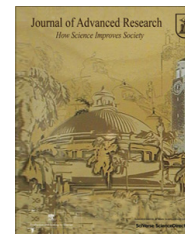Cairo University

Journal of Advanced Research

REVIEW

Deep solar minimum and global climate changes

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Abstract   This paper examines the deep minimum of solar cycle 23 and its potential impact on climate change. In addition, a source region of the solar winds at solar activity minimum, especially in the solar cycle 23, the deepest during the last 500 years, has been studied. Solar activities have had notable effect on palaeoclimatic changes. Contemporary solar activity are so weak and hence expected to cause global cooling. Prevalent global warming, caused by building-up of green-house gases in the troposphere, seems to exceed this solar effect. This paper discusses this issue.

Introduction

Climate change has become a prominent item on the agenda of world concerns. It is a growing crisis with economic, health and safety, food production security, and other dimensions. There is alarming evidence that important tipping points, leading to irreversible change in major earth systems and ecosystems, may already have been reached or passed. From 1860 to 1990, the global mean annual surface temperature increased 0.55 °C [1], at the same time, the continuation of industrial produced CO_2 gas in earth's atmosphere increased from 280 to 353 ppmv, leading to the hypothesis that the warmer temperatures signify the climate system's response to CO_2 gas increasing. However, statistical analysis of climate records reveals significant inter-annual and inter-decadal variability, suggesting that the cause of the warming is more complex than the influence of increasing greenhouse gases alone.

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The change of climate is pushing many earth systems towards critical thresholds that will alter regional and global environmental balances and threaten the world at multiple scales. Questions are being asked, hypotheses are being proposed, trying to identify the real forces that drive the global climate change. Is it a geological issue or cosmological issue or an issue of social behavior? In this paper we try to discuss the solar activity and its effects on the climate changes. Direct solar monitoring extends only the past 40 years. The solar activity change affects the climate through several physical processes: for one thing, the total radiation, particularly that in the ultraviolet range, varies with solar activity. When many sunspots are visible, the Sun is somewhat brighter than in "quiet" times and radiates considerably more in the ultraviolet. On the other hand, the cosmic ray intensity entering the Earth's atmosphere varies opposite to the solar activity, since the cosmic ray particles are deflected by the Sun's magnetic field to a greater or lesser degree. With increased solar activity (and stronger magnetic fields), the cosmic ray intensity decreases, and with it the amount of cloud coverage, resulting in a rise of temperatures on Earth. Conversely, a reduction in solar activity produces lower temperatures [2].

The present paper examines the deep minimum of solar cycle 23 and its potential impact on climate change. In addition,

a source region of the solar winds at solar activity minimum, especially in the solar cycle 23, the deepest during the last 100 years, has been studied. Is this episode comparable to the Maunder minimum or is it like the Dalton minimum? Furthermore, the near future solar cycle 24 and prediction of its conditions are presented.

Deep solar minimum of cycle 23

Solar activity affects the climate but seems to plays only a minor role in the current global warming. For example the Earth's temperature has risen perceptibly in the last 40 years while the solar brightness has not appreciably increased in this time [2,3]. The average solar activity has declined rapidly since 1985 and cosmogenic isotopes suggest a possible return to Maunder Minimum conditions within the next 50 coming years [4].

The solar cycle 23 started in April 1996 and had its peak in early 2000, 2001. The decline phase of this period extended from 2002 until December 2009, which is the longest decline phase in the last 23 solar cycles. We may observe the length of solar cycle 23 that extended for 13.5 years starting from April 1996, and it is a weak cycle. This solar cycle minimum seems to have unusual properties that appear to be related to weak solar polar magnetic fields [5]. Solar cycle 24 started in 2009. It was a late starter, about three and a half years later than the average of the strong cycles in the late 20th century and almost 3 year later than the weak cycles of the late 19th century. There are small polar coronal holes, and a relatively complex coronal morphology. This magnetic configuration at the Sun is remarkably different from the one observed during the previous two solar minima. The monthly and monthly smoothed sunspot numbers are plotted for the present cycle

Fig. 1   The monthly means (blue) and monthly smoothed (red) sunspot numbers for the latest three cycles and ascending phase, the data given from, http://sidc.oma.be/sunspot-data.

and the four latest cycles were displayed in Fig. 1. Magnetic activity during the years 2006–2009 has been very weak with sunspot numbers reaching the lowest values in about 100 years. This long and extended minimum is characterized by weak polar magnetic fields. The characters of solar cycle 23 and its activities were deeply studied; see for example [6–10].

Monthly and yearly means of sunspots during the solar cycle 23 and its decline phase until December 2009 are given in Table 1. The data used to prepare Tables 1, 2 and 3 have been obtained from Kandilli Observatory, Bogazici University, Turkey and from URL: http://sidc.oma.be, http://www.spaceweather.com.

Table 1   Monthly and yearly means of sunspot numbers of solar cycle 23, 24.

Year 2001:	Yearly means: 110.58												
Monthly mean:	95.6	80.6	113.5	107.7	96.6	134.0	81.8	106.4	150.7	125.5	106.5	132.2	
Year 2003:	Yearly means: 63.57												
Monthly mean:	79.7	46.0	61.1	60.0	54.6	77.4	83.3	72.7	48.7	65.5	67.3	46.5	
Year 2006:	Yearly means: 15.16												
Monthly mean:	15.3	4.9	10.6	30.2	22.3	13.9	12.2	12.9	14.4	10.4	21.5	13.6	
Year 2007 :	Yearly means: 7.5												
Monthly mean:	16.8	10.7	4.5	3.4	11.7	12.1	9.7	6.0	2.4	0.9	1.7	10.1	
Spotless days 149 of 365 days (41% spotless days)													
Year 2008:	Yearly means: 2.85												
Monthly mean:	3.3	2.1	9.3	2.9	3.2	3.4	0.8	0.5	1.1	2.9	4.1	0.8	
Spotless days 266 of 366 days (73% spotless days)													
Year 2009: yearly means: 3.1, start of solar cycle 24, January 2009)													
Monthly mean:	1.5	1.4	0.7	0.8	2.9	2.9	3.2	0.0	4.3	4.6	4.2	10.6	
Spotless days 260 of 365 days (71% spotless days)													
Year 2010: Yearly means: 16.6													
Monthly mean:	13.1	18.6	15.4	7.9	8.8	13.5	16.1	19.6	25.2	23.5	21.6	14.4 (December)	
Spotless days 51 of 365 days (14% spotless days)													
Year 2011													
Monthly mean:	18.8	29.6	55.8	54.4	41.6	37.0	43.9	50.6	78.0	88.0	96.7	73.0	73.0 (December)
2011 Spotless days 2 days													
Total spotless days since 2004: 821 days (typical solar min: 486 days)													
Year 2012, monthly mean 58.3 (January) 33.1 (February) 64.2 (March) 55.2 (April) 55.20 (May)													

Table 2 Monthly and yearly mean flare index of solar full disk of cycle 23.

Year 2001 is the maximum solar activates of cycle 23
Yearly mean = 6.80

| Monthly Means: | 2.76 | 1.25 | 7.65 | 10.20 | 2.89 | 4.86 | 1.84 | 6.38 | 11.77 | 9.50 | 10.95 | 11.39 |

Year 2003 is the year of starting decline phase of cycle 23
Yearly mean = 3.46

| Monthly means: | 2.69 | 1.55 | 3.33 | 2.62 | 4.35 | 4.54 | 2.55 | 1.59 | 0.77 | 12.11 | 4.53 | 0.68 |

Year 2006 is the year of staring solar minimum of cycle 23
Yearly mean = 0.54

| Monthly means: | 0.03 | 0.00 | 0.11 | 0.53 | 0.03 | 0.01 | 0.28 | 0.14 | 0.19 | 0.05 | 0. | 4.89 |

Year 2007, continuous of minimum of cycle 23
Yearly mean = 0.47

| Monthly Mean: | 0.49 | 0.01 | 0.01 | 0.02 | 0.24 | 1.53 | 1. 16 | 0.21 | 0.00 | 0.00 | 0.01 | 1.88 |

Year 2008, continuation of minimum of cycle 23
Yearly mean = 0.03

| Monthly means: | 0.05 | 0.00 | 0.20 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 |

Year 2009, continuation of minimum of cycle 23
Yearly mean = 0.027

| Monthly means: | 0.04 | 0.00 | 0.03 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.20 |

Table 3 Minimum and maximum of sunspot in the series of solar cycles.

Sunspot cycle number	Year of min	Smallest smoothed monthly mean	Year of max	Largest smoothed monthly mean	Rise to max (years)	Fall to min (years)	Cycle (years)
1	1755.2	8.4	1761.5	86.5	6.3	5.0	11.3
2	1766.5	11.2	1769.7	115.8	3.2	5.8	9.0
3	1775.5	7.2	1778.4	158.5	2.9	6.3	9.2
4	1784.7	9.5	1788.1	141.2	3.4	10.2	13.6
5	1798.3	3.2	1805.2	49.2	6.9	5.4	12.3
6	1810.6	0.0	1816.4	48.7	5.8	6.9	12.7
7	1823.3	0.1	1829.9	71.7	6.6	4.0	10.6
8	1833.9	7.3	1837.2	146.9	3.3	6.3	9.6
9	1843.5	10.5	1848.1	131.6	4. 6	7.9	12.5
10	1856.0	3.2	1860.1	97.9	4.1	7.1	11.2
11	1867.2	5.2	1870.6	140.5	3.4	8.3	11.7
12	1878.9	2.2	1883.9	74.6	5.0	5.7	10.7
13	1889.6	5.0	1894.1	87.9	4.5	7.6	12.1
14	1901.7	2.6	1907.0	64.2	5.3	6.6	11.9
15	1913.6	1.5	1917.6	105.4	4.0	6.0	10.0
16	1923.6	5.6	1928.4	78.1	4.8	5.4	10.2
17	1933.8	3.4	1937.4	119.2	3.6	6.8	10.4
18	1944.2	7.7	1947.5	151.8	3.3	6.8	10.1
19	1954.3	3.4	1957.9	201.3	3.6	7.0	10.6
20	1964.9	9.6	1968.9	110.6	4.0	7.6	11.6
21	1976.5	12.2	1979.9	164.5	3.4	6.9	10.3
22	1986.8	12.3	1989.6	158.5	2.8	6.9	9.7
23	1996.4	8.0	2000.3	120.8	4.0	9.5	13.5
Author's estimation of cycle 24							
24	2009.4	9.0	2013.2	105.0	4.3	7.8	12.1
Mean cycle values: 6.1				113.2	4.7	6.3	11.0

From Table 1 we note that the spotless days during years 2007. There were no sunspots observed over 147 days of the years 365 days (41%). During 2008, the spotless days were 266 of 366 days (73% spotless days). During 2009 the spotless days were 260 of 365 days (71% spotless days). The total spotless days during solar cycle 23 decline phase are 821 days, while the typical solar minimums were 486 days.

Monthly and yearly means for the flare index during the maximum activity of the solar cycle 23, and its decline phase until December 2009 are given in Table 2. This data show that the yearly means of flare index are less than 0.5 starting from the year 2006 that means the reduced solar activity appears starting from year 2006.
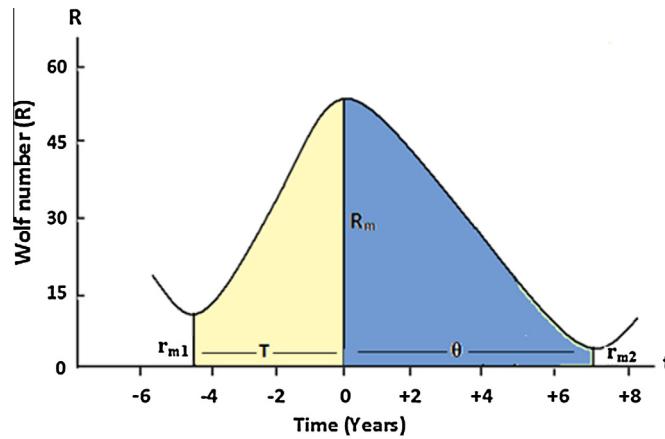
Fig. 2   Schematic diagram of sunspot curve of the 11-year cycle according Waldmeier Laws [14].

Predictions of solar cycle 24

Many techniques are used to predict the amplitude of a cycle during the time near and before sunspot minimum. They depend on the level of activity at sunspot minimum, and the size of the previous cycles, etc.

We used three methods for solar cycles predictions:

1. The first one depend on the Waldmeier Laws [11] which state that in the Mathematical Form, if calculated from cycle 1 to cycle 21, and considered as follows:

$$\log R_{\max} = (2.50 \pm 0.10) - (0.11 \pm 0.02)T,$$

and

$$\theta = 0.023 R_{\max} + 3.0,$$

where $R_{\max}$, T and θ are shown in Fig. 2.

2. The second method depends on the value of the geomagnetic aa index at its minimum which is related to the sunspot number during the ensuing maximum [12]. Feynman separates the geomagnetic aa index into two components: one in phase with and proportional to the sunspot number, the other is then the remaining signal.

3. The third method is due to Thompson [13]. He found a relationship between the number of days during a sunspot cycle in which the geomagnetic field was "disturbed" as well as the amplitude of the next sunspot maximum. His method has the advantage of giving a prediction for the size of the next sunspot maximum before sunspot minimum. Table 4 shows the solar cycle 24 predictions according this method statistics.

The statistical results of solar cycle 24 as a comparison with previous solar cycles 1–23 are given in Table 3. From Table 3, the lengths of last 23 solar cycles vary between 9.0 and 13.6 years, with average 11.078 years. The time of rise to the maximum $R_{\max}$ vary between 2.8 and 6.9 years with average $T = 4.296$ years, the fall time to the minimum of cycle varies between 4.0 years and 10.2 years with average $\theta = 6.782$ years, the length of the cycle $(T + \theta) = 4.296 + 6.782 = 11.078$. The largest smoothed sunspot monthly means (highest cycles) which more than 150 are cycle number 3, 18, 19, 21 and 22. T and θ are shown in Fig. 2.

From Table 3 and Fig. 3, we can conclude that the solar activity are rapidly inclined downward from about 30 years ago and will continue for the next 50 years. Solar activities have had notable effect on palaeoclimatic changes. The surface warming and the solar cycle in times of high solar activity are on average 0.2 °C warmer than times of low solar activity. Prevalent global warming, caused by building-up of green-house gases in the troposphere, seems to exceed this cooling solar effect [14].

The effect of solar activity on the climate change in history

The comparison between the changes during last 150 year for solar cycle variations, earth surface temperature, and CO_2 variability are dramatically changed during last 50 years and strongly increased [15]. We notice that agreement for the parameters variation occurring until the year 1960, especially between the temperature changes and solar cycle variations. There is no agreement between solar cycle variations and Earth surface temperature after the CO_2 dramatic increasing from the year 1960. The scientific consensus is that solar variety variations do not seem to play a major role in determining present-day observed climate change, but have played a major role in palaeoclimatic changes. For example, the climate cooling during the Maunder minimum "from year1645 until 1710", and Dalton minimum "from year 1797 until 1825" might be due to the solar activities collapse. We note that in the last 40 year there are no good correlations between temperature change and solar variability due to CO_2 increasing. The palaeoclimatic changes then effected by the solar variability, until about 50 years ago, when the CO_2 exceeded dramatically [16].

Activity and timing of the current minimum, as well as the timing of the Solar Cycle 24 maximum in 2013 compared with the start of the Dalton minimum [17].

Is repeating the Dalton minimum possible? This question was asked after the deep solar minimum of cycle 23 and ending up at 13.5 years long. The Solar Cycle 24 was a late starter, about three and a half years later than the average of the strong cycles in the late 20th century and almost three year later than the weak cycles of the late 19th century. Fig. 3 shows the similarity of the solar cycles behavior during Dalton minimum years and the last two solar cycles 22 and 23. The prediction of solar cycles 24, 25, 26 agree with this supposition [18].

Table 4 Solar cycle number 24 prediction.

Solar cycle number	24
Starting date of solar cycle (Year)	2009.4
Starting date of solar cycle (month)	May
Starting solar cycle maximum date (year)	2013.2
Starting solar cycle maximum date (month)	February
Maximum sunspot number	105
Solar cycle length (years)	12.1
Ascending phase length (years)	4.3
Decline phase length (years)	7.8

The solar cycle 3 and cycle 22 are the same in length and power. The solar cycle 4 nearly the same as cycle 23 for length and power except for the decline phase of solar cycle 23 and development of new peak during its decline phase. From the productions of solar cycle 24, 25, 26 [4], we can agree with the appearing of new Dalton minimum from now until the next 30 year.

For more data about the time period of Maunder minimum and Dalton minimum we can see the variations in solar activity during the last several centuries based on observations of sunspots and beryllium isotopes. The period of extraordinarily few sunspots in the late 17th century was the Maunder minimum [19].

The temperature variations over history were shown in Fig. 4, from the date of carbon 14 analysis and the tree ring data analysis, which were both affected by solar activities variations. The first part of figure shows the change of global temperature variations only within 0.6° in the last 120 year. The second part shows the change of temperature around 1.5° during 1400 year. The third part shows the dramatic change of temperature in 30 year only BC of 6° which means that the climate changes during this period with sudden change. These changes continued for 150 year BC by the same rate for about 6° of global temperature. Fig. 4 has been published in separate parts in few references and collected by the author [14,19–22].

From Fig. 4 we notice that the global temperature changes were dramatic in the period of 150 BC, and notable change during the period of Maunder minimum, and Dalton Mini-
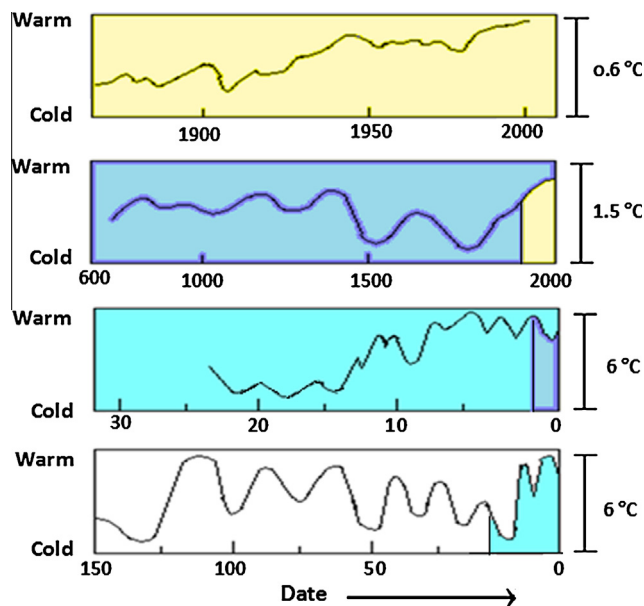
Fig. 4 Global temperature changes over history.

mum. Later there is a new parameter which effect on the nowadays climatic changes, like green-house gases, with the solar activity changes effect.

Conclusions

There is a new deep minimum of solar cycle 23 may extend through the next 30 year during the coming solar cycles 24, 25, and 26, similar to what occurred during Dalton minimum era (see Fig. 3). Although the solar activity during the last two solar cycle has a deep minimum there is a global warming, the variations in solar activity do not seem to play a major role in determining present-day observed climatic change. Prevalent global warming, caused by building-up of green-house gases in the atmosphere, seems to escalate and hence mask this solar effect. It played a major role in palaeoclimatic changes. The
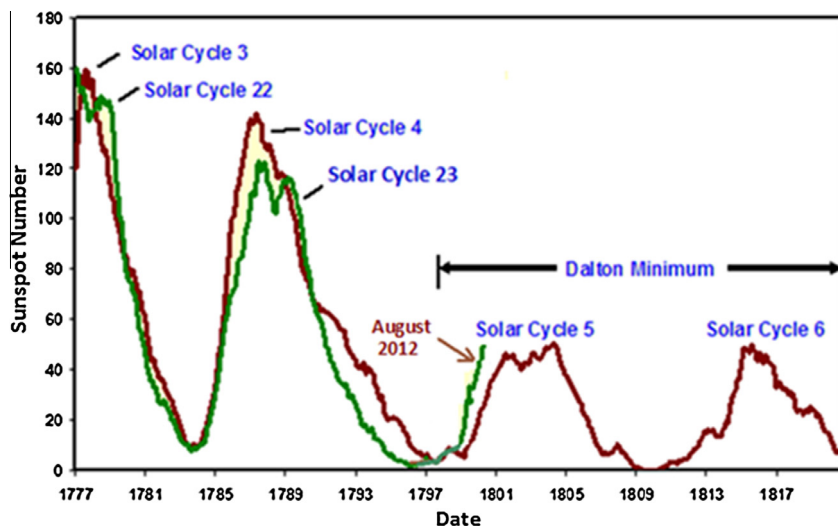
Fig. 3 The Dalton minimum era and the solar cycle 22, 23 and ascending phase of solar cycle 24 are overlaid on solar cycle 3, 4 and 5 above to show similarity.

climate cooling during the Maunder minimum and Dalton minimum might be due to the solar activities collapse [20].

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