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Global warming and solar anomaly

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During 2002-2008, there was no increase in global temperature, though green house gas concentrations had increased. Sun is the ultimate source of energy. It has been, therefore, examined if there was any anomaly in the solar characteristics during this period. The sunspot number data has been used for this purpose. This parameter has an 11-year solar activity cycle and the same is found in the global temperature. But the trend in sun's output, after removing solar activity effect, does not match with the long term trend of global temperature. Peculiarities in the duration and in the peak value of solar cycle 23 were identified which might have portended the increase of global temperature during 2002-2008. The possibility of the pause of increase in temperature could also be that the heat generated due to the increase in the greenhouse gas concentration was absorbed in deep ocean layer.

Keywords: Global temperature, Deep ocean heat content, Sunspot number, Total solar irradiance, Total ozone

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1 Introduction

Global temperature has increased by 0.7°C during the 20th century and is likely to further increase by 1 - 4°C during the 21st century[1]. This change is attributed to the increase in the concentration of greenhouse gases in the atmosphere by manmade activities. But during 2002-2008, there has been almost no increase in global surface temperature, though greenhouse gas concentration has increased during this period[2]. This urges one to look for the reasons responsible for this feature. Sun is the source of energy for earth's climate. This energy is absorbed by the land, atmosphere and ocean to generate global temperature. Hence, a small variation in this energy can cause variation in earth's climate[1,3]. Several studies have been done on the effect of solar change on global temperature whose results do not agree with each other (e.g. Duffy *et al.*[4] and references therein). Scafetta & West[5] report that most of the observed global warming trend since 1950 is due to the variations in total solar irradiance (TSI). This was refuted by Duffy *et al.*[4] who showed that solar variability does not explain the late 20th century warming. In this paper, anomaly in the solar characteristics during 2002-2008, if any, has been examined.

2 Data

Several parameters which shed light on the characteristics of sun are being monitored for a long period of time. One among them is sunspot number. This parameter has been chosen to study the effect of solar change on global warming. Data are available from ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/.

3 Results and Discussion

The Climatic Research Unit of University of East Anglia, UK has been doing a lot of work on global and hemispheric temperature anomaly. Figure 1 shows global temperature anomaly curve (GTAC) of the past half a century prepared by this unit[4]. In this figure, two features are discernable: (i) a short term feature and (ii) a long term feature. In the short term feature, an 11-year variation is seen and in the long term feature: a slow increase of temperature up to ~1963, a slow decrease after this year up to ~1968, no change during 1968-1976, a rapid rise after this year up to ~2002 and then no change during 2002-2008.

Figure 2 shows the plot of yearly averaged values of sunspot number from 1950 to 2012. Cyclic variation is clearly seen in this figure: peaks in the

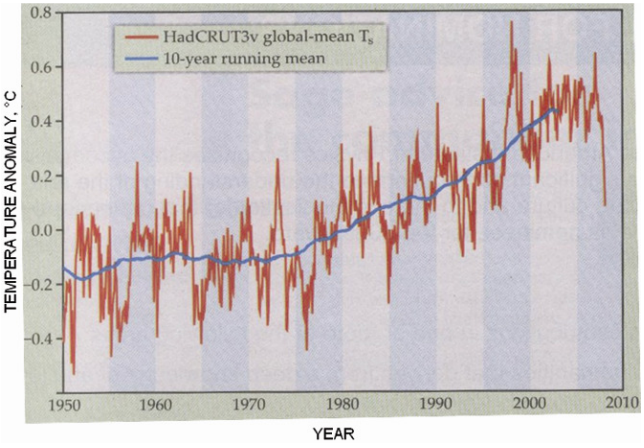

Fig. 1 — Observed monthly global temperature anomalies since 1950 [red curve is the HadCRUT3v data set of global-mean near-surface air temperature, Ts; blue curve is a 10-year running mean (Data from Climatic Research Unit, University of East Anglia, UK) (*Source*: Duffy *et al.*[4])]

years 1957, 1968, 1979, 1989 and 2000 and dips in the years 1953, 1964, 1976, 1986, 1996 and 2008. On an average, the time between two peaks or between two dips is ~11 years. Thus the short-term feature of global temperature anomaly (GTA) curve matches with the 11-year cycle of sunspot number. However, Fig. 2 shows that the long term trend of sunspot number does not match with the long term trend of GTA. In contrast, a decreasing long term trend is seen in this parameter. The slope of the trend line is -0.552. This sharp decrease may appear due to the peak value during 1957-58. However, if this value is smoothened by taking the average value of 1956-57 and 1958-59, the slope of the trend line changes marginally (-0.467). To further examine the long term trend of sunspot number, the 11-year running average has been calculated. The values, thus, obtained have been shown in Fig. 3. Here also, a decreasing trend of sunspot number with an increase in year is seen.

To find out if there were any anomaly in the solar output during 2002-2008, the durations of maximum to minimum, minimum to maximum and peak values of all the solar cycles from 1950 to 20012 have been examined. These are given in Table 1.

The peak is yet to reach in the solar cycle 24. The period 2002-2008 falls in the descending phase of the solar cycle 23. It is seen from Table 1 that in solar cycle 23, the duration of the maximum to minimum is 8 years and minimum to maximum is 4 years. That means the sun has taken ~1 year longer time to reach from dip to peak level and also ~1 year longer time to come down from peak to dip value

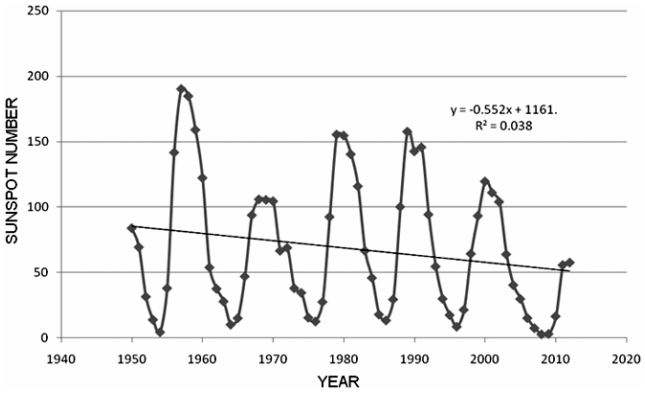

Fig. 2 — Yearly average of sunspot number from 1948 to 2008

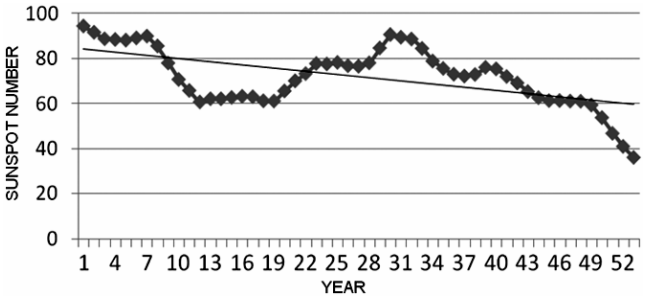

Fig. 3 — 11-year running average of sunspot number during 1948-2008 [x-axis year 1 corresponds to the average of values during 1948-1958]

(total duration ~12 years) in comparison to cycle 22, 21 and 19 (total duration ~10 years). The same is noticeable in cycle 20, and it is interesting to note that during this cycle also, there has been no increase in global temperature. Another interesting point to be noticed from this table is that the peak values during solar cycles 23 and 20 are almost one third less than their respective pervious solar cycles. That means during these two solar cycles, solar heating of the earth must have been one third less compared to the corresponding previous solar cycles.

One may argue how sunspot number is physically related to global temperature? Actually sunspot number is not physically related to earth's temperature; but its value is proportional to the solar irradiance which is responsible for earth's heating. In Fig. 4, the variation of sunspot number (SSN) and total solar irradiance (TSI) from November 1978 to March 2004 has been shown. Good correlation is seen. TSI is being measured since 1978 by different satellites[2]. It is the integral of the power over all the wavelengths emitted from the sun. TSI data are available at http://www.ngdc.noaa.gov/stp/SOLAR/IRRADIANCE/irrad.html. These data up to 2004

Table1 — Durations of maximum to minimum, minimum to maximum and peak ssn values in different solar cycles

Solar cycle no	Year of		Max to min duration, yrs	Year of		Min to max duration, yrs	Peak value
	Max	Min		Min	Max		
19	1957	1964	7	1954	1957	3	190.2
20	1968	1976	8	1964	1968	4	105.9
21	1979	1986	7	1976	1979	3	155.4
22	1989	1996	7	1986	1989	3	157.6
23	2000	2008	8	1996	2000	4	119.6
24				2008			

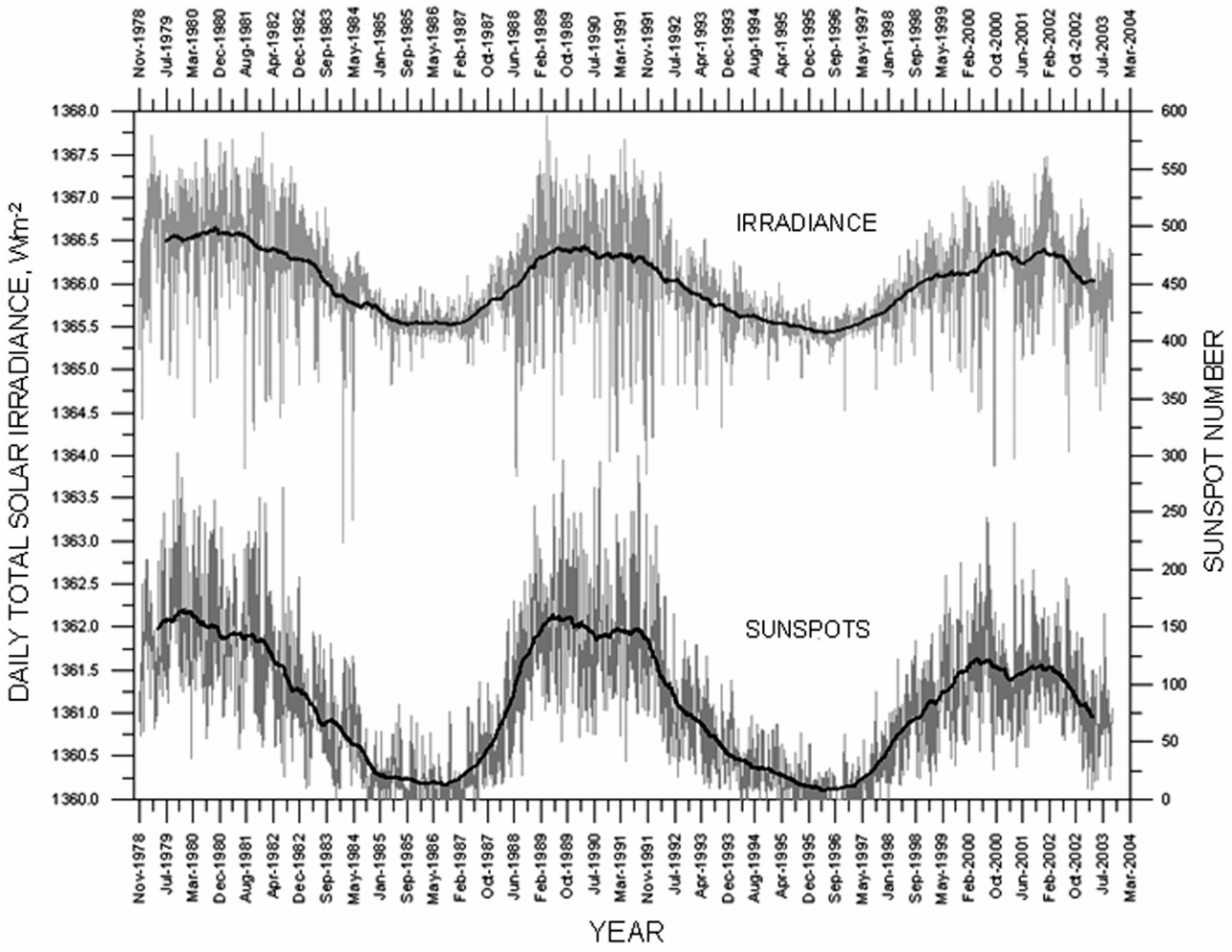

Fig. 4 — Variation of sunspot number (SSN) and total solar irradiance (TSI) from November 1978 to March 2004

have been compiled by NOAA and shown by Duffy *et al.*[4] Though the values of different satellites do not agree with each other, yet it is evident from Fig. 5 (Ref. 7) that TSI, like SSN, has 11-year variation matching with the short term trend of GTA and confirming the 11-year short term solar forcing on global warming. TSI variation from solar minimum to solar maximum is 0.07%, but radiation in all the wavelengths of the TSI do not vary by the same magnitude[6]. As for example, solar flux at 10.7 cm wavelength increases from solar minimum to solar maximum by a factor of ~3-4. The TSI values have been examined to search if there is any anomaly in this parameter. It is seen in Fig. 5 that TSI is monotonically decreasing after 2002 and is reaching a very low value in 2010 (Ref. 7).

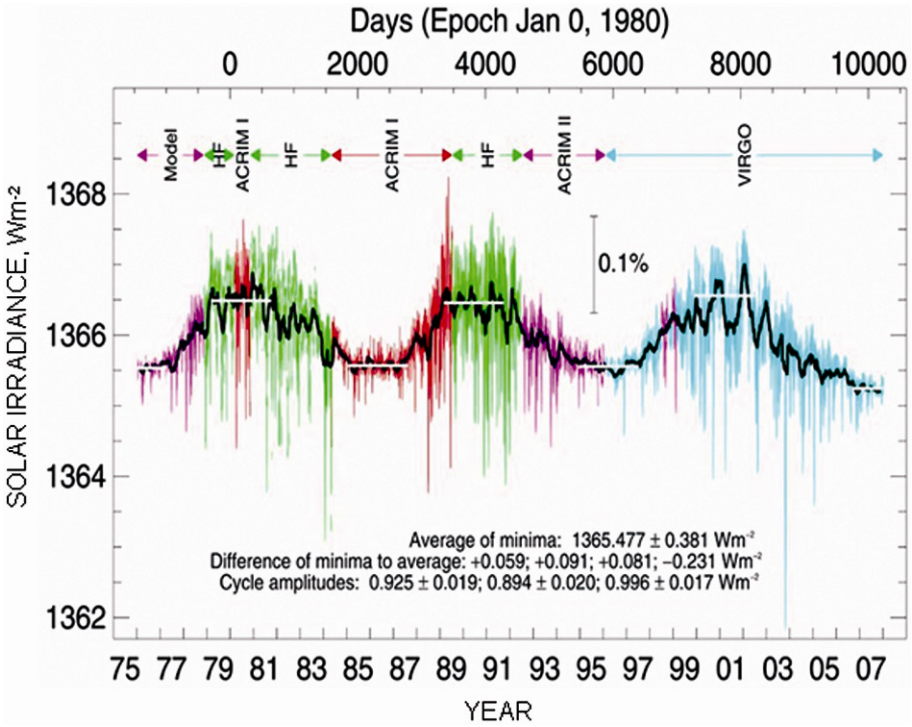

Fig. 5 — TSI values obtained by different satellites from 1978 to 2008 [*Source:* http://commons.wikimedia.org/wiki/File:Irradiance.jpg]

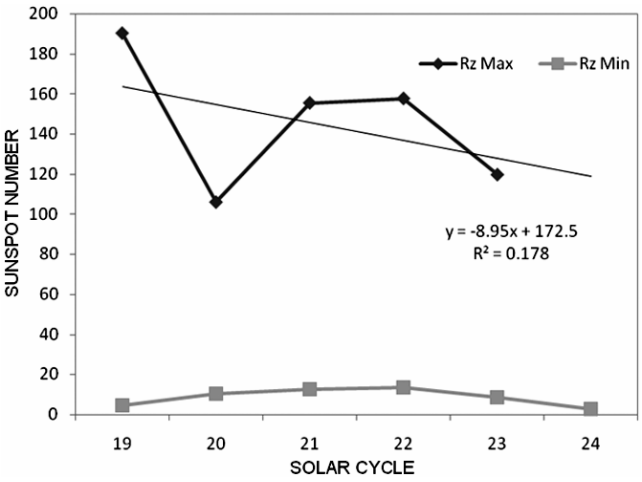

Fig. 6 — Peak values and dip values of all sunspot cycles from 1950 to 2012

Figure 2 shows that the variation of dip values and peak values from cycle to cycle is not uniform. In Fig. 6, the peak values and dip values have been plotted separately from the year 1950 to 2012 for different solar cycles. It is seen from this figure that the dip values do not change appreciably, but the peak values decrease considerably with years. And, therefore, it is the peak value which affects the global warming. Since SSN is directly proportional to TSI, the long term decrease of SSN should suggest a long term decrease of TSI and long term decrease in global temperature. But that has not been observed.

As mentioned above, the peak SSN in cycles 23 and 20 was low (119.6 and 105.9) and when SSN is low, sun emits less radiation. This less radiation should affect stratospheric ozone production and loss. Some reactions of ozone chemistry controlled by the solar radiation are:

$$O_2 + h\nu \rightarrow O^1D + O^1D \ (\lambda < 240 \text{ nm})$$
$$O^1D + M \rightarrow O^3P + M \ (M = O_2 \text{ or } N_2)$$
$$O^3P + O_2 + M \rightarrow O_3 + M$$
$$O_3 + h\nu \rightarrow O + O_2 \ (\lambda = 295\text{-}300 \text{ nm}, 450\text{-}800 \text{ nm})$$

In Fig. 7, total ozone measured at Delhi by Dobson spectrophotometer by India Meteorological Department for the period 1960-2010 has been shown (It may be mentioned here that Delhi Dobson instrument is internationally calibrated and is the standard Dobson instrument for the Asian region). It is noticed from this figure that during 1985 when sunspot number was low, ozone value was very high (292 DU) and during 2002-2008 (the declining phase of solar cycle 23) and 1968-1976 (the declining phase of solar cycle 20), ozone values have remained almost constant (274-284 DU and 271-278 DU, respectively); to be exact there is a decreasing tendency.

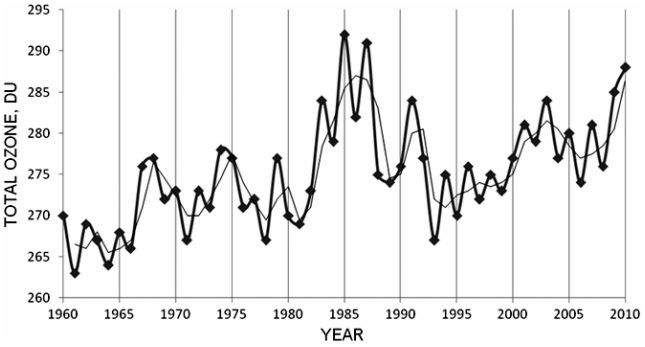

Fig. 7 — Total ozone values at Delhi from 1960 to 2008 [thin line is the best fit trend]

Very recently, Ahluwalia & Jackiewicz[8] have pointed out that there was a significant change in the solar behaviour during cycles 22 and 23. Interplanetary magnetic field intensity at Earth's orbit reached the highest value (9.1 nT) in 1991 (cycle 22) and in 2009, it declined to ~2/3 of its value in 1963, the lowest value ever measured[8]. Solar geomagnetic activity effect on Earth's climate has recently been examined by Mufty & Shah[9]. They have analyzed annual mean sea surface temperature (SST) (as representative or Earth's climate parameter) in conjunction with annual mean SSN and geomagnetic indices a_a (as representative of solar geomagnetic activity parameter) for the period 1850-2007. They found a close link between these two parameters.

Another possibility for no change of global temperature during 2002-2008 is ocean. The role of oceans in variability of the Earth's climate system was identified by the Intergovernmental Panel on Climate Change (IPCC), the World Climate Research Program (WCRP) and the US National Research Council (NRC) long ago. This is expected because of high density and specific heat of sea water. Oceans also have large thermal inertia and heat capacity. Heat content (temperature) of the ocean determines global temperature and wind pattern. Several studies have been done and are available on global ocean heat content (Ref. 10 and references therein). They are limited to the upper layer of the ocean. They show that temporal and spatial oscillations occur in the oceans; as for example, quasi-bidecadal changes in the upper ocean level heat content of Pacific ocean, a decadal scale oscillation in North Pacific sea surface temperature (Pacific Decadal Oscillation or PDO), North Atlantic Oscillation (NAO), the Atlantic Multi-decadal Oscillation, etc. Linked to surface temperature, these oscillations switch from positive index (warm phase) to negative index (cool phase) with some regularity on a multi-decadal time scale. During 1999-2001, PDO was in negative (cool) phase which shifted to positive (warm) phase in 2002, again shifted to negative phase and peaked in 2007. Before the mid-1970s, Atlantic and Indian oceans were in relatively cool phase, whereas after mid-1970s these oceans were in warm phase. Sea surface temperature (SST), like global temperature, also has 11-year variation and anomalies. It has been reported that SST anomalies rose from early 1910s to the early 1940s, dropped from the early 1940s to the mid 1970s, then again rose from mid 1970s to present. Another factor, at least partially responsible for no global warming during 2002-2008, is a series of small volcanic eruptions when aerosols shade the sun. As a result, oceans are heated less than the normal.

As the concentration of greenhouse gases is increasing, Earth system is warming. Over 90% of that increase in heat goes into warming the ocean. The absorption of heat by ocean takes place mainly in the upper layer. This heat gradually penetrates to the deeper layers by complex ocean circulation like meridional overturning circulation (MOC). Most studies on ocean warming have been limited up to 700 m (Ref. 11 and references therein). Study on warming of deep ocean layer is sparse because observations of deep ocean temperature started only around 10 years ago. Projects like AGRO ARRAY and experiments like lowering accurate thermometers by cable from research ships up to the ocean floor have given deep ocean data up to ~6 km. Recent study by Guemas *et al.*[12] show that global slower warming can be explained by changes in heat storage of the oceans. Balmaseda *et al.*[13] report that heat is getting absorbed in deep ocean and it is warming at an unprecedented rate. They also stated that El Nino events are associated with strong loss of heat from the deep ocean. During this event, ocean surface is warm because it takes heat from deep ocean layer. Very recently, Abraham *et al.*[14] have reviewed relation between deep ocean heat content and global warming. They showed that heat content of both upper and deep layers of the ocean has been increasing over time, but during the period 2002-2012, upper layer heat content has been almost flat but deep layer (depth >2000 m) heat content has been increasing. They stated that there is no pause in global warming due to increase in greenhouse gas concentration, but slow or no global warming is due to heat absorbed in the deep ocean.

Levitus *et al.*[10] have reported heat content of ocean up to 700 m, which shows that during 2004-2008 (solar cycle 23), there was no increase in ocean heating and during 1976-78 also (solar cycle 20), there was no heating, rather there was cooling.

4 Conclusions

Signature of short-term (11-year) solar variation is clearly seen on global temperature but the influence of long term solar variation (to decrease global temperature) is not seen. During 2002-2008, there was no increase in global temperature though greenhouse gas concentration had increased during this period. This period falls in the solar cycle 23. Behaviour of solar output during this cycle was found to be anomalous, TSI value was low, geomagnetic activity was high and ascending and descending periods were long in comparison to other solar cycles.

Low value of TSI means less amount of heat absorption in the stratosphere which affects the ozone amount. During 2002-2008, ozone amount did not change. Low value of TSI also means less amount of heat absorption by ocean whose heat capacity is large and can, therefore, integrate long term small variations in heat input.

No increase in global temperature during 2002-2008 is attributable to anomalies in solar output as well as absorption of heat in deep ocean layer. Therefore, more research is needed to understand the relationships among SSN, TSI, SST, deep ocean temperature, geomagnetic indices (a_a) and global temperature. Also, model studies need to be carried out to understand whether prolonged ascend and descend periods of a solar cycle has any effect on global temperature.

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