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On links between global temperature and solar activity

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Summary. — We show that variations of monthly values of global surface air temperature have been dominated by a specific oscillation (with a period equal to that of the 11 year sunspot cycle) together with it second harmonic from 1990 up to the present time. This specific oscillation (upon which its second harmonic is superimposed) phase-leads the 11 year sunspot cycle by about 65°, and has its last maximum in 1998. The second harmonic of this oscillation has maxima at 1998 and 2002, hence making 1998 and 2002 the warmest year and second warmest year on record worldwide, respectively. Some specific association is also given between El Niño events and the latter second harmonic as well as the annual/seasonal heat/temperature cycle. Furthermore, an explanation (associated with solar activity) is given for the global warm spell which occurred in July-August 2003.

PACS 92.60.Ry – Climatology.
PACS 96.40.Kk – Solar modulation and geophysical effects.

1. – Introduction

In a recent publication [1] we established relationships between solar activity and terrestrial climate-weather variations. After the latter publication, we were gratefully given a record of monthly values of global surface air temperature from 1990 up to the current year (*e.g.*, see also ref. [2]). An analysis of this record yielded results, which clearly display new and specific relationships between the 11 year sunspot cycle and global temperature variations. The aim of this short paper is simply to present and briefly discuss these results.

2. – Analysis

To start with, let us represent the discontinuous line in fig. 1 by $T(t)$, where t denotes time. We obtained $T(t + 2\text{ years})$ by systematically delaying $T(t)$ by 2 years, that is, by shifting $T(t)$ towards the right-hand side in fig. 1 by 2 years. Then we computed the correlation coefficient R between $T(t+2\text{ years})$ and the solid curve line in fig. 2 together with its backward extrapolation to 1990 using relevant data from NASA. The value

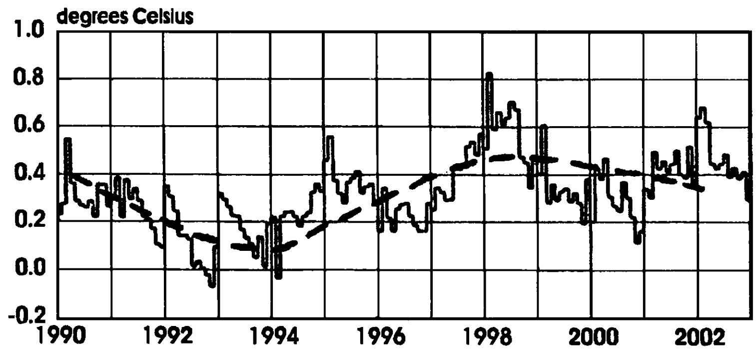

Fig. 1. – A plot of monthly values of global surface air temperature from 1990 up to 2003 (solid line) as reported in ref. [2]. By means of the curve-fitting methods given in ref. [3], we have fitted a discontinuous line through the solid-line variations in order to display variations at periods greater than 6 years.

of R so computed was $+0.97$ at 99.9% statistical significance level. This high positive correlation implies that the waveform of the 11 year solid curve line in fig. 2 (together with its backward extrapolation to 1990) is approximately similar (aside from amplitude considerations) to the waveform of the discontinuous line in fig. 1 from 1990 up to 2003 except that the two waveforms differ in phase by about 65°.

Figure 3 has been drawn specifically in order to show more focus at amplitude-modulating periodicities smaller than 11 years. A minimum (or a node) is clearly dis-

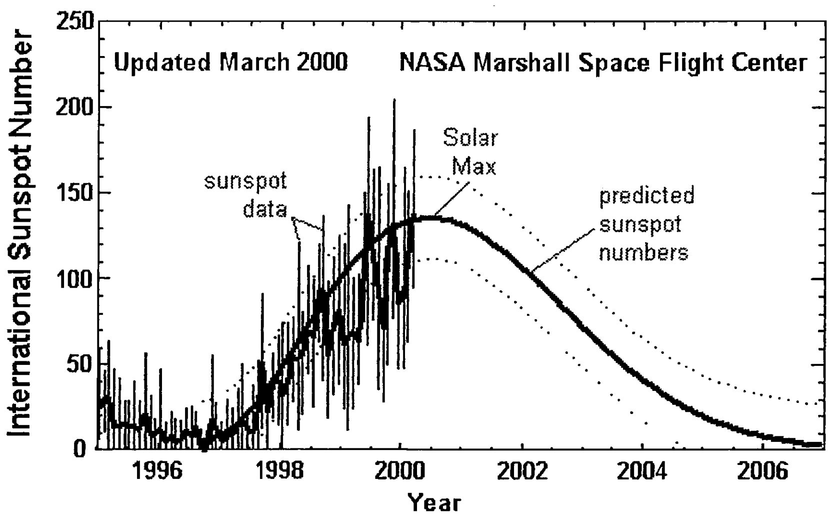

Fig. 2. – A graphical display of the 11 year sunspot cycle from 1995 as obtained from the NASA Marshall Space Flight Center of the USA. The dotted lines above and below the solid curve line indicate the prediction curve's range of error. The vertical bars indicate the full range of daily sunspot numbers that were averaged to obtain monthly data points.

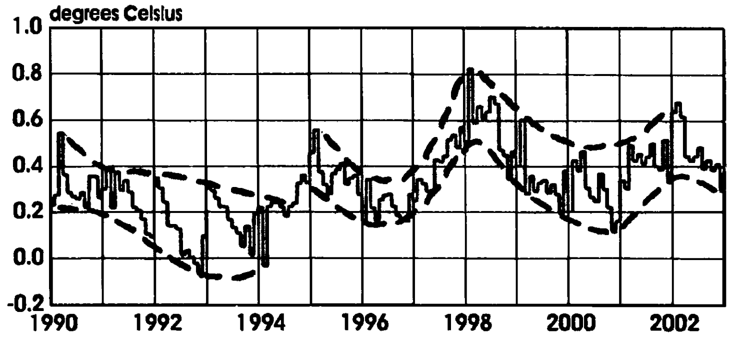

Fig. 3. – A plot of monthly values of global surface air temperature from 1990 up to 2003 (solid line) as reported in ref. [2]. Discontinuous lines have been fitted along the maximum points as well as along the minimum points of the solid-line variations using the curve-fitting methods given in ref. [3].

played in fig. 3 at early 1991, early 1996 and late 2000. This implies the presence of an amplitude-modulating oscillation $M(t)$ with a period of $4^1/_2$ to 5 years. According to standard amplitude-modulation theory, minima in $M(t)$ would coincide with minima (or nodes) in fig. 3. Also maxima in $M(t)$ would coincide with maxima (or antinodes) in fig. 3.

The following additional observation is interestingly noted with respect to fig. 3. Each minimum and maximum of the 11 year sunspot cycle (from 1990 to 2003) is less than 1 year away from a minimum (or node) of fig. 3. This observation together with the account given above show that the period of $M(t)$ is (approximately) similar to the period of the second harmonic of the 11 year sunspot cycle and hence also of $T(t)$. The cause of the rather rapid change in the shape or mode of amplitude-modulation envelope which took place in fig. 3 during late 1994 may be easily obtained from refs. [1,4]. In fact it is this late 1994 change in amplitude-modulation envelope which made the structure at 1995 (in fig. 3) appear as if it were a "normal" maximum (*i.e.* a maximum coinciding with a maximum of the relevant amplitude-modulating forces(s) or influences). If we disregard any "maximum" that is formed or forced merely by a change in the mode of the relevant amplitude-modulation envelope, we may make the following observation from fig. 3. The latter figure displays an antinode in mid-1993 as well as maxima in mid-1998 and in mid-2002, thus making 1998 and 2002 the warmest year and second warmest year on record world-wide, respectively [2]. This implies the presence of an amplitude-modulating oscillation with a period of 4 to 5 years as already established earlier using minima and nodes instead of maxima and antinodes.

Let us now look at how the annual/seasonal temperature cycle interacts with $M(t)$ in fig. 3. From 1990 to mid-1994, the annual temperature cycle interacts multiplicatively with $M(t)$, leading to the existence of an amplified annual temperature cycle in early 1990 and from late-1991 to 1994 (see fig. 3) as well as a reduced annual temperature cycle in early 1994 and in and around 1991. Note that the annual temperature cycle in this case is amplified at and near an antinode and de-amplified at and near a node in line with standard amplitude modulation theory. But from 1995 onwards, the annual temperature cycle interacts additively with $M(t)$ involving neither amplification nor de-amplification of the annual temperature cycle (see fig. 3). Now a comparison of fig. 3

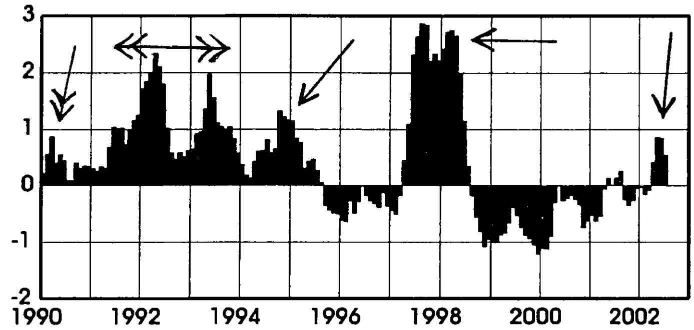

Fig. 4. – Bimonthly data for multivariate El Niño/Southern Oscillation (ENSO) index from 1990 up to June-July 2002 as reported in ref. [5]. We have drawn single-headed arrows in order to indicate positive protrusions which coincide with both El Niño events and maxima (or quasi-maxima) of $M(t)$ in fig. 3. Also the double-headed arrows show positive protrusions which coincide with both El Niño conditions and amplification of the annual temperature cycle made by $M(t)$ through multiplicative interaction.

and fig. 4 clearly leads to the following observation. El Niño events coincide with: i) Sufficient amplification of the annual temperature cycle by $M(t)$ through multiplicative interaction, and ii) maxima of $M(t)$ which occur when $M(t)$ and the annual temperature cycle interact additively. Indeed the observation just mentioned is consistent with the conclusion given earlier in ref. [6] that ENSO events are associated with sufficiently large heat/temperature oscillations at annual and sunspot-related periods as well as specific spatial wavelengths. As may be deduced from refs. [1,4,6], the annual temperature cycle undergoes large amplifications when it is in multiplicative interactions with sunspot-related temperature oscillations.

Finally we end this paper with a short account which may be useful in making future predictions of global temperature variations. We have seen in fig. 3 that from 1990 to mid-1994, the annual global temperature cycle interacts multiplicatively with $M(t)$ resulting into the formation of "node-antinode" temperature patterns (or in short form "NAT patterns"). Also from 1995 onwards the multiplicative interaction is replaced by an additive process, leading to the formation of "sinusoidal" temperature patterns (or in short form "ST patterns"). The pertinent question which we need to ask ourselves is: When will the ST patterns in fig. 3 (which started in 1995) change into NAT patterns through a change of the post-1995 additive process mentioned above into a multiplicative process?

For reasons detailed in Njau [9], global or regional or locational ST patterns mounted upon a longer-period oscillation often change into NAT patterns at or near a minimum of the latter oscillation. Also global or regional or locational NAT patterns mounted upon a longer-period oscillation often change into ST patterns at or near a minimum of the latter oscillation. The two inferences just mentioned are illustrated in the temperature records from the USA and Colombo (Sri Lanka) shown in figs. 5 and 6, respectively. In fig. 5 the NAT patterns change into ST patterns at about the minimum of the thick-line curve. The series of ST patterns in fig. 6, on the other hand, change into NAT patterns just before the minimum of the thick-line oscillation. Before proceeding further, it is worth taking note of the following two features about fig. 6. Firstly the solid-line oscillation in fig. 6 varies approximately in anti-phase mode with the thick-line oscillation in fig. 8. Note

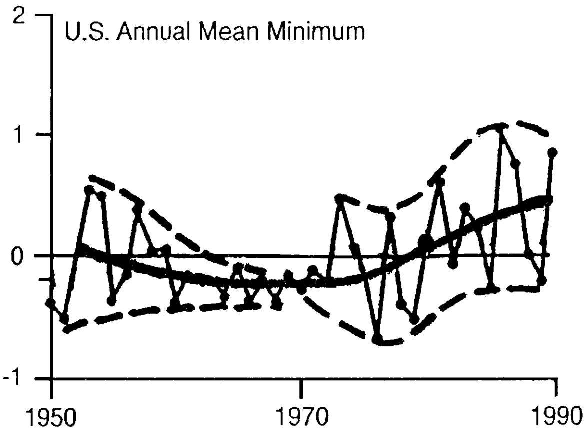

Fig. 5. – A plot of US annual mean minimum temperature from 1950 up to 1990 (thin solid line) as reported in ref. [7]. We have used discontinuous lines to sketch out the NAT and ST patterns on the basis of the curve-fitting methods given in ref. [3]. Besides, a thick-line curve has been fitted through the (long-term) mean of the thin solid-line variations using the methods in ref. [3].

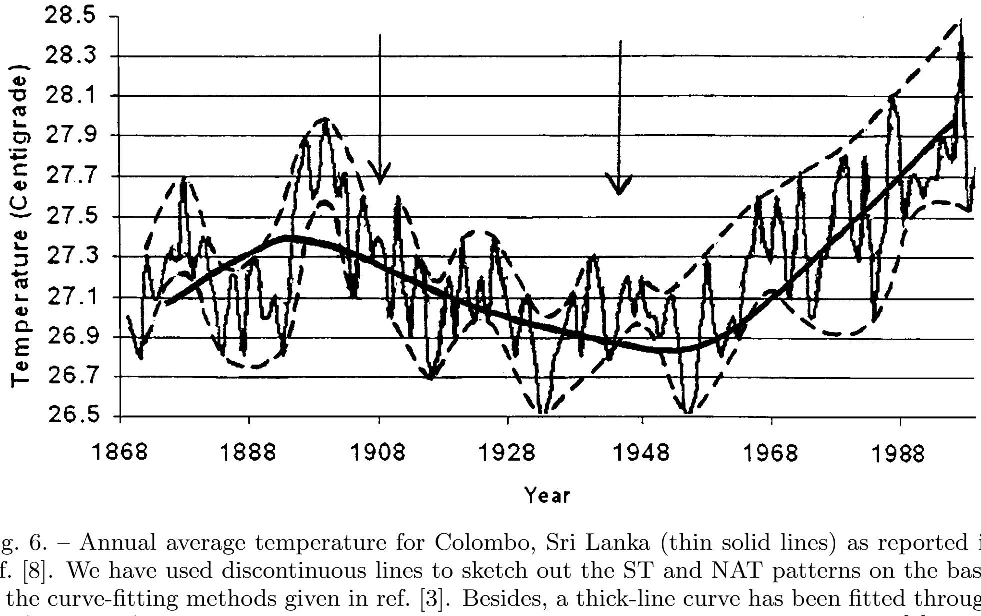

Fig. 6. – Annual average temperature for Colombo, Sri Lanka (thin solid lines) as reported in ref. [8]. We have used discontinuous lines to sketch out the ST and NAT patterns on the basis of the curve-fitting methods given in ref. [3]. Besides, a thick-line curve has been fitted through the (long-term) mean of the thin solid line variations by means of the methods in ref. [3]. Each arrowed line shows the timing of a rapid change in an ST pattern or a rapid change from an ST pattern to a NAT pattern.

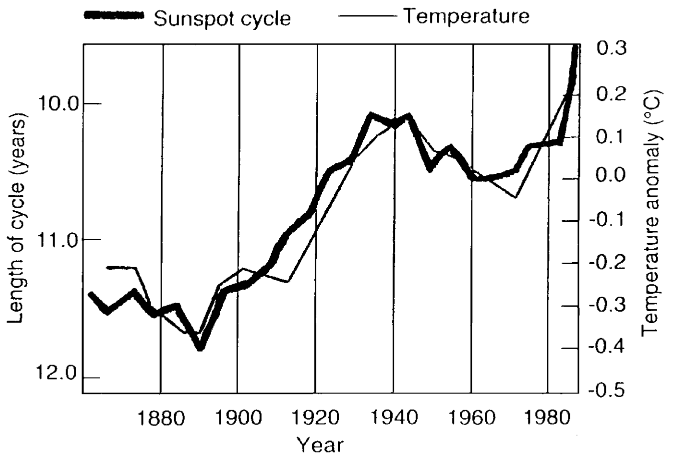

Fig. 7. – Variations in global mean temperature and period of the 11 year sunspot cycle as a function of time, as reported in ref. [10].

that while the former oscillation has a maximum at year 1895 and a minimum at year 1955, the latter oscillation has a minimum at year 1894 and a maximum at year 1958. Secondly the NAT and ST patterns in fig. 6 (sketched by discontinuous lines) display a periodicity of about 22 years. Note that: i) the ST patterns before 1908 display maxima at 1877 and 1900 as well as a minimum at 1890; ii) the ST patterns between 1908 and 1944 display minima at 1916 and 1935 as well as a maximum at 1924; and iii) the NAT patterns stretching onwards from 1944 display nodes at 1947, 1968 and 1990 as well as antinodes at 1955 and 1979. When put together, points i), ii) and iii) above imply the presence of a pattern variation with a period of about 22 years.

The next minimum of the discontinuous-line oscillation in fig. 1 is expected to occur at about 2004/5. Now on the basis of the short account given above, we expect the ST patterns in fig. 3 to change to NAT patterns at or close to 2004/5. The anomalous global warm spell which occurred in July-August 2003 indicates that the anticipated change from ST patterns to NAT patterns just mentioned above has just started. The structure of the 2002 temperature patterns in fig. 3 shows that a switch thereafter from the ST into NAT patterns should indeed be signalled by a rapid and large increase in the temperature patterns.

It has already been shown previously (*e.g.*, see ref. [10]) that a very high positive correlation exists between global mean temperature and the frequency of the 11 year sunspot cycle (see fig. 7). The thick-line oscillation in fig. 7 varies at a main frequency that is equal to that of the second harmonic of the thick-line oscillation in fig. 8. While the former oscillation has adjacent minima at *about* the years 1890 and 1960, the latter oscillation has a minimum at 1894 and an adjacent maximum at 1958. It is also worth noting that the averaged annual global temperature variations shown by a smooth curve in fig. 2 of ref. [4] display a very high positive correlation with the discontinuous-line oscillation in fig. 8 of the present paper.

The high sunspot-temperature correlation displayed in fig. 7 may easily be explained on the basis of the contents of refs. [1,4]. Whenever the 11 year sunspot cycle is reflected in terrestrial temperature patterns, the implication is that there is a spatial arrangement (or packing) of 11 year temperature oscillations along the corresponding surface-atmosphere

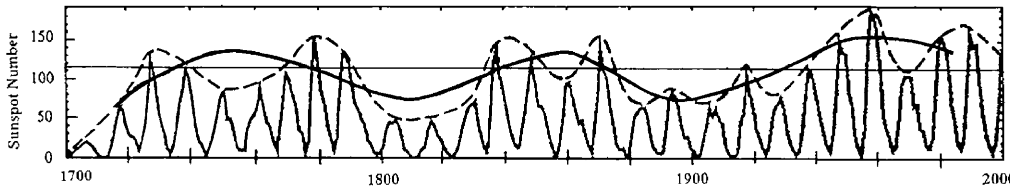

Fig. 8. – A plot of yearly sunspot numbers series from 1700 up to 2000 (thin solid lines) as reported in ref. [11]. A discontinuous line has been fitted through the maxima of the thin solid-line variations (which represent the 11 year sunspot cycle) using the curve-fitting methods given in ref. [3]. A thick-line curve has been fitted through the (long-term) mean of the discontinuous-line variations using the curve-fitting methods given in ref. [3]. Also a horizontal solid line has been drawn through the annual sunspot number value of 114.

system with specific spatial wavelengths. Since these temperature oscillations are generally stronger near the earth's surface than higher up in the atmosphere, their common constant component increases with their frequency consistently with fig. 7. Specifically a high frequency results into a closer packing of more oscillations, and hence a higher constant component. On the other hand, a low frequency results into a sparser packing of fewer oscillations, and hence a lower constant component. The amplitudes of the above-mentioned temperature oscillations at different frequencies are commonly determined by factors in the Earth-Atmosphere System (EAS) as well as the constant component of earthward solar energy (*e.g.*, see ref. [1] for more details). These amplitudes are, therefore, constant for frequencies that are not too different from each other as well as similar EAS conditions. Since greenhouse gases injected into the atmosphere introduce a change in the EAS conditions, these gases effectively change the amplitudes of the sunspot-related oscillations in the EAS as detailed in refs. [1, 9].

3. – Conclusion

We have shown that the 11 year sunspot cycle and its second harmonic have been dominantly reflected in monthly values of global surface air temperature since 1990. Also largely reflected in the latter temperature are the discontinuous-line oscillation and the thick-line oscillation in fig. 8. Apparently this finding may be used to make predictions of future changes in global temperature since predicted variations in the 11 year sunspot cycle have been made up to year 2007 (*e.g.*, see fig. 2).

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