Some causes of rapid changes in temperature patterns

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Abstract

It was shown in another recent publication by the author that, for each sunspot cycle, there exists in the surface-atmosphere system (SAS) two quasi-sinusoidal temperature variations each at the frequency of the sunspot cycle. The first of these two variations is much smaller than the other one and is always in phase with the associated sunspot cycle. However, the second of the two variations is relatively huge and is always not in phase with the associated sunspot cycle. Here we illustratively describe how the smaller temperature variations associated with sunspot cycles participate in causing large and rapid changes in temperature patterns.

Furthermore it is noted that El Nino events as well as the processes responsible for switchings of (temperature) amplitude-modulation states into each other are other key causes of rapid changes in temperature patterns. Finally we set up clear relationships between El Nino occurrence patterns and sunspot cycles, and then use these relationships to make an attempt at predicting the expected timing of the next El Nino event. Some physical justification for this attempted prediction is also given. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

Rapid changes in surface/air temperature patterns at a given region may correspondingly give rise to regional changes in cloudiness (and hence surface-level solar radiation patterns), wind velocity patterns (and hence energy inputs into respective wind-driven machines), rainfall (and hence variability of river water needed for running hydropower generators), humidity and sunshine hours. Based upon analyses of past temperature records, recent publications [1, 2] reported illustratively that

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surface/air temperature patterns at regional and global levels undergo large and rapid changes at certain intervals of time. In this paper we propose and justifiably explain physical processes which give rise to these rapid changes in temperature patterns. Furthermore, we attempt to search for methods or techniques by which these rapid temperature changes may be predicted well in advance.

2. Proposed causes of some rapid temperature changes

2.1. Theoretical analysis

As already explained in Refs [3–5], the temperature patterns in the surface-atmosphere system (SAS) consist of constant components, a series of amplitude-modulated structures and a series of noisy or noise-like structures. Let us consider an arbitrary SAS location whose latitude and longitude are \( \phi \) and \( \theta \), respectively. Then the temperature pattern \( P(\theta, \phi, t) \) at this particular location from time \( t = 0 \) up to \( t = L \) may be expressed generally as

\[
P(\theta, \phi, t) = C_0(\phi, \theta) + \sum_{n=1}^{\infty} A_{n\lambda}(\theta, \phi, t) + B_{n\lambda}(\theta, \phi, t)
\]

where \( C_0(\phi, \theta) \) is a time-independent structure, \( A_{n\lambda}(\theta, \phi, t) \) is the \( n \)th amplitude-modulated structure, and \( B_{n\lambda}(\theta, \phi, t) \) is a collection of noise-like structures. It is oscillations at solar frequencies and harmonics thereof as well as frequencies simply related to the solar ones that physically carry out the amplitude-modulating variations in

\[
\sum_{n=1}^{\infty} A_{n\lambda}(\theta, \phi, t)
\]

as elaborated in Njau [4–6].

Now suppose that \( P(\theta, \phi, t) \) is dominated by a single amplitude-modulated pattern (say the one corresponding to \( n = 3 \)) in the sinusoidal amplitude-modulation state (see Ref. [3] for more details about amplitude-modulation states). Then it follows that eqn (1) may be rewritten in the following approximate form:

\[
P(\theta, \phi, t) \approx C_0(\phi, \theta) + A_{3\lambda}(\theta, \phi, t) + B_{3\lambda}(\theta, \phi, t)
\]

\[
= C_0(\phi, \theta) + S_3(\theta, \phi, t) + F_3(\theta, \phi, t) + B_{3\lambda}(\theta, \phi, t)
\]

where \( S_3(\theta, \phi, t) \) is a sinusoidal oscillation at approximately constant frequency and \( F_3(\theta, \phi, t) \) is some temperature structure whose frequencies may vary with time. Of course the justification for splitting \( A_{3\lambda}(\theta, \phi, t) \) into \( S_3(\theta, \phi, t) \) and \( F_3(\theta, \phi, t) \) is simply that \( A_{3\lambda}(\theta, \phi, t) \) is in the sinusoidal amplitude-modulation state as assumed above. Since \( S_3(\theta, \phi, t) \) is sinusoidal, we can express it as \( Q \cos(\omega_0 t + \pi) \), where \( Q \) is an amplitude term, \( \omega_0 \) represents approximately constant frequency and \( \pi \) is a phase term. Since our analysis is tailored for location \( (\theta, \phi) \), the spatial parameters are considered to be stationary. Suppose further that \( F_3(\theta, \phi, t) \) is dominated by a sinusoid
denoted as \( H \cos(\omega t + \beta) \) such that \( H \) is an amplitude term, \( \omega \) represents frequency that may vary with time and \( \beta \) is a phase term. On this basis we may now rewrite eqn (2) as follows:

\[
P_1(\theta, \phi, t) \approx C_0(\theta, \phi) + Q \cos(\omega t + z) + H \cos(\omega t + \beta) + D_1(\theta, \phi, t) + B_1(\theta, \phi, t)
\]

(3)

where \( D_1(\theta, \phi, t) \) is some non-noisy structure that is quite small compared with \( H \cos(\omega t + \beta) \). As detailed in Refs [6, 7], oscillation \( Q \cos(\omega t + z) \) is a \( t \)-dependent signature of a certain sunspot cycle. Therefore this particular oscillation swings approximately in phase with the latter sunspot cycle. We note that the temperature patterns \( P_1(\theta, \phi, t) \) will undergo a rapid and sizeable drop (or decrease) under physical conditions lumped into the following two categories.

2.1.1. Category one

Suppose that from initial time \( t = t_0, \omega = 2\omega_i \) and the resultant oscillation at frequency \( \omega \) has phase term \( \alpha + \beta \). Then eqn (3) may be written in the following equivalent form

\[
P_1(\theta, \phi, t) \approx K_0(\theta, \phi) + [1 + mH \cos(\omega_1 t + \beta)]Q \cos(\omega t + z) + D_1(\theta, \phi, t) + B_1(\theta, \phi, t)
\]

(4)

where \( \omega_1 \approx \omega_i, K_0 = C_0 - H \cos(\alpha - \beta)|_{t = t_0} \) and

\[m = \frac{2}{Q}.
\]

In physical terms, what eqn (4) implies is that the associated temperature patterns have been in such a form that conditions are set for some of the constant (i.e. zero frequency) energy to be pushed into taking an active part in amplitude-modulation processes. Obviously the oscillation \( H \cos(\omega t + \beta) \) in eqn (4) is practically derived from oscillation \( H \cos(\omega t + \beta) \) whenever the (variable) frequency of the latter equals \( \omega_1 \). Then the resultant oscillation interacts with the sunspot-associated oscillation \( Q \cos(\omega t + z) \) as shown in eqn (4). The sinusoidal variations of \( Q \cos(\omega t + z) \) closely mimic those of the associated sunspot cycle and hence may be deduced directly from the latter cycle. On the other hand, the sinusoidal variations of \( H \cos(\omega_1 t + \beta) \) may be deduced from corresponding temperature records. The physical causes of oscillations \( Q \cos(\omega t + z) \) and \( H \cos(\omega_1 t + \beta) \) in the SAS are given later on in the paper.

Suppose we start by assuming that from \( t = t_0 \) onwards, both temperature oscillations \( Q \cos(\omega t + z) \) and \( H \cos(\omega_1 t + \beta) \) exist in non-antiphase form at the location \((\theta, \phi)\). As long as this non-antiphase condition is maintained, pattern \( P_1(\theta, \phi, t) \) will not undergo a major and rapid drop. But if it happens after \( t = t_0 \) that the two temperature oscillations are out of phase (i.e. are at a phase difference of 180°) with each other, \( P_1(\theta, \phi, t) \) will take the following form

\[
P_1(\theta, \phi, t) \approx K_0(\theta, \phi) + Q \cos(\omega t + z) + H \cos(2\omega_1 t + \beta + z) + D_1(\theta, \phi, t) + B_1(\theta, \phi, t) - H
\]

(5)
As a result (e.g. compare eqns (3) and (5)), \( P_L(\theta, \phi, t) \) will undergo a rapid drop or decrease equal to \( [1 + \cos(\omega t)]H \) irrespective of the value of amplitude \( Q \). This drop will cancel out as soon as both \( Q \cos(\omega t + z) \) and \( H \cos(\omega t + \beta) \) are no longer out of phase with each other. Since \( Q \cos(\omega t + z) \) is a signature (in the surface-atmosphere system) of the corresponding (tiny) sunspot cycle, the account given above shows how the tiny sunspot or solar cycles can cause rapid and large temperature changes in the surface-atmosphere system (SAS). In recent publications [6, 7], it was shown how these tiny solar cycles also give rise to correspondingly large temperature cycles in the SAS. An illustration of the account just given is provided in section 2.2.

With the condition \( \omega_s \approx \omega_n \), eqn (4) implies existence in the SAS part involved of two approximately sinusoidal temperature variations, one represented by \( Q \cos(\omega t + z) \) and the other represented by \( H \cos(\omega t + \beta) \). What would then be the possible cause(s) of these two quasi-sinusoidal variations coexisting at approximately similar frequencies? This question is answered very well by Ref. [6] which shows that, for each sunspot cycle, an SAS region is normally characterised by two sinusoidal temperature variations each at the frequency of the respective sunspot cycle. Of the two sinusoidal variations associated with a given sunspot cycle, only the smaller variation is always in phase with the latter sunspot cycle [6]. According to the latter reference, the two quasi-sinusoidal temperature variations associated with any sunspot cycle are such that the variation that is always in phase with the sunspot cycle is always quite small compared to the other (relatively huge) variation which is (always) not in phase with the sunspot cycle. As you may have noted, it is assumed in this section that the two temperature quasi-sinusoidal variations associated with an arbitrary sunspot cycle at frequency \( \omega_n \) are such that the smaller variation (which is inevitably in phase with the sunspot cycle) is represented by \( Q \cos(\omega t + z) \). Rapid temperature changes related to \( Q \cos(\omega t + z) \) are also inevitably related to the associated sunspot cycle due to the ‘in phase’ relationship between the two.

### 2.1.2. Category two

Let us now consider a situation in which frequency \( \omega \) in eqn (3) is sufficiently small compared to \( \omega_n \) and assume that the frequency \( \omega \) signal modulates the frequency \( \omega_n \) signal. Then eqn (3) may be written in the form

\[
P_1(\theta, \phi, t) \approx C_0(\theta, \phi) + [1 + kH \cos(\omega t + \beta)]Q \cos(\omega t + z) + D_1(\theta, \phi, t) + B_1(\theta, \phi, t)
\]

since \( \omega_s \approx \omega_n \) and

\[
k = \frac{1}{Q}
\]

If \( Q \cos(\omega t + z) \) and \( H \cos(\omega t + \beta) \) are out of phase with each other by 180°, then \( P_1(\theta, \phi, t) \) in eqn (6) may be expressed as follows:

\[
P_1(\theta, \phi, t) \approx C_0(\theta, \phi) + Q \cos(\omega t + z) + \frac{1}{2} H \cos(\omega t + \beta + z) + D_1(\theta, \phi, t) + B_1(\theta, \phi, t) - \frac{1}{2} H
\]

(7)
A comparison of eqns (3) and (7) clearly shows that in the case of the latter eqn, pattern $P_l(\theta, \phi, t)$ has undergone some rapid decrease whose value is given by $\frac{1}{2} H$.

Obviously, the size of this rapid decrease is independent of the size of oscillation $Q \cos(\omega, t + x)$ which is itself a signature of the corresponding sunspot cycle. The mechanisms which give rise to this signature are detailed in Njau [6, 7]. Note that some conditions exist under which the rapid temperature drop just described can take place without requiring $\omega$ to be very much smaller than $\omega_s$. These conditions are: (i) frequency $\omega$ is less than $\omega_s$ without involving the requirement that $\omega_s \gg \omega$; and (ii) the structure $S_i(\theta, \phi, t)$ is an imperfect sinusoid that has a frequency band (instead of single frequency) centred at frequency $\omega_s$. Suppose that we re-formulate the analysis already given under Category two following very similar procedure with the exception that condition $\omega_s \pm \omega = \omega_s$ changes into ‘$\omega$ is sufficiently larger than $\omega_s$’. The final result would be that pattern $P_l(\theta, \phi, t)$ would undergo a rapid drop equal to $\frac{1}{2} H$ as well. Note that this rapid drop takes place irrespective of the size of $Q \cos(\omega, t + x)$.

As already remarked in the analysis on Category one above, this shows how the tiny sunspot cycles do effect rapid and large changes in SAS temperature patterns. An illustration and hence verification of the rapid decrease process just described above are given in the next section.

2.2. Comparison of theory and actual temperature records

In this section, we present temperature records which illustrate and verify the rapid drop or decrease processes described theoretically in section 2.1. in connection with temperature patterns. The rapid temperature drop described under Category one in section 2.1. is typically illustrated in Figs 1 and 2. As clearly shown in the figures, a temperature drop comparable to the one described in section 2.1. under Category one took place over the 1898–1908 period. The temperature variation envelopes in Figs 1 and 2 (wholly) oscillate at a dominant period of about 95 years. Correspondingly, the

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Fig. 1. A plot of observed annual surface air temperature in the African SADC region and the surrounding area ($0^\circ$–$30^\circ$ S and $10^\circ$–$40^\circ$ E) from 1855 to 1986 expressed as departures from the 1951–1980 mean (solid lines). Dotted lines have been used to indicate upper and lower boundaries of the temperature patterns.
Fig. 2. Observed surface temperature trends in the northern hemisphere (23.6° N–90° N) from 1880 to 1978 (solid lines) as reported in Ref. [12]. The amplitude-modulation envelope of the temperature variations has been sketched using discontinuous lines.

main sunspot cycle existing across the 1898–1908 time-stretch has a period of about 95 years as well (see Fig. 3). Interestingly, the ~95 years temperature oscillation (Fig. 1 and Fig. 2) and the ~95 years sunspot cycle were out of phase with each other over

Fig. 3. A plot of annual average sunspot number (solid lines) from 1610 up to 1980 as reproduced from Refs [13, 14]. A discontinuous line has been fitted along the peaks of the 11-year sunspot cycle in order to conspicuously reveal out long-period variations.
the 1898–1908 period. It is this ‘out-of-phase’ relationship that triggered the rapid temperature drop, as explained in section 2.1.

An extension of the analysis given in section 2.1. (under category one) may be used to explain the rapid rise in the temperature patterns shown in Fig. 2 which took place at about the year 1960. A close examination of the (discontinuous line) sunspot oscillation in Fig. 3 and the main temperature oscillation in Fig. 2 shows that these two oscillations were antiphase to each other from about 1940 up to about 1960. Then they turned into inphase variation mode at about 1960. A simple extension of the analysis given in section 2.1 (under Category one) shows that such an antiphase to inphase variation switch would correspondingly trigger a rapid rise (instead of rapid drop) in the temperature patterns involved, as illustrated in Fig. 2. Note that some relatively slight temperature rise at about the year 1960 is also noted in Fig. 1 for similar reasons.

One of the temperature drops described in section 2.1 (under Category two) is illustrated in Fig. 4. It is visibly noted in this figure that this particular rapid temperature drop occurred over the 1971–1976 period. If we disregard this rapid temperature drop, it is clear that the main modulating frequency \( \omega_m \), which characterises the temperature patterns in Fig. 4, is fairly small compared with the frequency of the 11-year sunspot cycle. Note that the latter cycle and the temperature oscillation at frequency \( \omega_m \) are out of phase over the 1971–1976 period. And as already explained in section 2.1, the latter period should coincide with some rapid drop in appropriate temperature patterns as actually verified in Fig. 4. So far we have not yet succeeded in clearly identifying from temperature records the second (and last) temperature drop discussed in section 2.1. under Category two. This is partly because what appear

![Fig. 4. A plot of monthly minimum temperature at Mbarara (0°30'S, 30°29'E) from 1960 up to 1985 as well as from 1990 to 1991 (solid lines). Discontinuous lines have been used to sketch out amplitude-modulation envelopes formed by the temperature variations. The arrow-headed lines indicate durations of the falling phases of the 11-year sunspot cycle.](image-url)
(in temperature records) to be such drops are often heavily intermingled with other variations from which it is rather difficult to decouple sufficiently.

3. El Nino events and climatic switches as causes of rapid temperature changes

As detailed in Ref. [5], the processes responsible for rapid switches from one temperature amplitude-modulation state into another are also major causes of rapid changes in temperature patterns. These rapid switches which are also termed ‘climatic switches’ may be predicted on the basis of the information given in Ref. [5]. El Nino events are also key causes of fairly rapid temperature changes in (at least some of) the regions involved. The theory and other details regarding El Nino events were given recently by Njau [4, 8]. Since the issue of El Nino predictability is not yet settled, we devote the rest of this section to this particular issue.

As early as 1961, Berlage [9] proposed a method for predicting El Nino events. His method, which is related to the 00-year sunspot cycle, may be summarised as follows:

“When the sunspot number drops below 13 an El Nino occurs, followed by a series of 7-year occurrences, but when the lowest sunspot year occurs after only a 6-year or 8-year interval, another 7-year sequence begins.”

An application of Berlage’s prediction strategy to the series of El Nino events that have occurred since 1870 shows that this strategy occasionally fails to predict some El Nino events [10]. The reason for the occasional anomaly may easily be deduced from the contents of Refs [4, 8]. According to the latter references, El Nino occurrences are quasi-regular only if the corresponding Temperature Amplitude-modulation States (TAS) in the equatorial belt are quasi-regular. Therefore one way of making reasonable predictions of El Nino events is to first subdivide the time-stretch involved into periods based upon the latter amplitude-modulation states as detailed in Njau [8]. For example, if such a subdivision is done on the time-stretch starting from 1875 up to the present time, the result would be as summarised in Table 1.

It is clear from Table 1 that Berlage [9] was quite correct in tying minima in the 11-year sunspot cycle to El Nino occurrences. It is also apparent that, on the basis of Table 1, the next El Nino event would be expected in the year 2001/2002. In very general terms, some physical justification for this prediction may be given as follows. As detailed in Ref. [8], the TAS along the equatorial belt were approximately regular from 1875 up to 1927 with an exception of the 1892–1917 period. Therefore the time-length 1875–1927 (excluding the 1892–1917 period) was characterised by approximately regular El Nino occurrence pattern. During this particular time-length, an El Nino would occur either during an 11-year sunspot cycle maximum or one year after such a maximum. Some changes in the equatorial TAS occurred over the 1928–1956 period, and these changes culminated in the start of another period (i.e. 1957 expectedly up to ~2004) during which the equatorial TAS have been (and are expected to be) approximately regular. Now from 1957 onwards, each maximum of the 11-year sunspot cycle has coincided with an El Nino event. Simple extrapolation of this
Table 1
Occurrence patterns of El Nino events since 1875 in relationships with the 11-year sunspot cycle. The time periods shown in the extreme left-hand side have been selected on the basis of the account given in Njau [8].

<table>
<thead>
<tr>
<th>Time period</th>
<th>When El Nino events occurred/occur</th>
<th>Time-length between adjacent El Nino events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1875–1891</td>
<td>(i) 0–1 year after each sunspot maximum.</td>
<td>6–7 years</td>
</tr>
<tr>
<td></td>
<td>(ii) 0–1 year after each sunspot minimum.</td>
<td></td>
</tr>
<tr>
<td>1982–1917</td>
<td>No El Nino events occurred apparently due to the considerable cooling in low latitudes that correspondingly took place [1, 2, 8]</td>
<td>—</td>
</tr>
<tr>
<td>1918–1927</td>
<td>(i) 0–1 year after each sunspot maximum.</td>
<td>7 years</td>
</tr>
<tr>
<td></td>
<td>(ii) 0–2 years after each sunspot minimum.</td>
<td></td>
</tr>
<tr>
<td>1928–1956</td>
<td>(i) 2–4 years after each sunspot maximum.</td>
<td>2–8 years</td>
</tr>
<tr>
<td></td>
<td>(ii) 1 year before each sunspot minimum.</td>
<td></td>
</tr>
<tr>
<td>1957–1988</td>
<td>(i) 0–1 year after each sunspot minimum.</td>
<td>3–4 years</td>
</tr>
<tr>
<td></td>
<td>(ii) At each sunspot maximum.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(ii) About 3 years after each sunspot maximum.</td>
<td></td>
</tr>
<tr>
<td>1989–Present time and probably up to 2004 (see Njau [8])</td>
<td>(i) 0–1 year after each sunspot minimum.</td>
<td>2–5 years</td>
</tr>
<tr>
<td></td>
<td>(ii) At each sunspot maximum.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(ii) About 2 years after each sunspot maximum.</td>
<td></td>
</tr>
</tbody>
</table>

occurrence pattern to the next maximum of the latter cycle easily yields the El Nino prediction given above.

4. General conclusions

We have shown how and why certain physical conditions give rise to rapid changes in temperature patterns that are in the sinusoidal state of amplitude modulation. These conditions involve phase relationships between the main modulating oscillations in the temperature patterns and corresponding temperature oscillations that are in phase with sunspot cycles as detailed in the text. It is interesting to note that these sunspot-related rapid changes in temperature fit well into the other temperature changes related to the ~22-year period variations in the sharpness of the peaks of 11-year cycle pulses reported in Ref. [11]. Indeed a comparison of Fig. 3 and the contents of Ref. [11] shows that, to a reasonable approximation, the amplitudes of the latter (~22-year period) variations are inversely proportional to the discontinuous-line oscillation in Fig. 3. All these findings strengthen further the Sun–weather (or solar–terrestrial) relationships reported in Refs [1–7].
These relationships are strengthened even further by the sunspot-related sequences presented in section 3 with regard to occurrences of El Nino events.

Finally, it is interesting to relate the contents of this paper with those of Ref. [6]. The latter reference shows that for each sunspot cycle (say at frequency $\omega_s$), there exists in the SAS temperature patterns two (separate) quasi-sinusoidal variations both at frequency $\omega_s$. Of these two variations, the smaller variation (hereinafter simply referred to as ‘$S$ variation’) is always in phase with the associated sunspot cycle. But the other variation (hereinafter simply referred to as ‘$H$ variation’) is not only much larger than the ‘$S$ variation’, but it is (always) not in phase with the associated sunspot cycle. Ref. [7] shows that due to its largeness, the ‘$H$ variation’ gives rise to large temperature variations in the SAS at frequency $\omega_s$. Now it is shown in the present paper that despite its relative smallness, the ‘$S$ variation’ contributes in giving rise to large but rapid temperature changes which are not at frequency $\omega_s$ but are short-lived.

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References