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The timing of the Next Little Ice Age

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Summary. — We show that sunspot number variations since 5400 BC are equal to a sum of one constant component K with a value of about 114 annual sunspots, an oscillation with a mean period of 2450 years as well as the 2nd, 3rd, 4th, 5th and 6th (nonlinearly generated) harmonics of this oscillation. Variations of the 11-year sunspot cycles are also equated to a summation of the same constant K and different variable components. Since sunspot numbers indicate the general state of activity of the Sun in a statistical way, this finding implies that the Sun's activity has a constant component upon which some variable components are superimposed. Between two adjacent minima of the 2450 years oscillation, there is a large block of continuously non-zero sunspot number variations pattern whose length is consistently equal to 1700 years. Each of these blocks starts and ends at considerably cool periods of global climate or little ice ages. The last and ongoing block started near the end of the last Little Ice Age (1550–1700 AD) and is expected to end in about the year 3440. On this basis the next little ice age is expected to start at about the latter year.

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

1. – Introduction

According to the Milankovitch theory of ice ages [1], it is the Milankovitch cycles (*i.e.* the cyclic or quasi-cyclic deterministic astronomical variations of the orbital parameters of the Earth) which cause and hence are responsible for the (major) ice ages. These cycles are long cyclic variations of the Earth's orbital arrangements whose periods are about 100000 years, 40000 years and 20000 years. The depths of the last ice age occurred about 20000 years ago, and the next (major) ice age is expected to occur after several thousands of years. All the Milankovitch cycles are entirely calculable and hence future ice ages (associated thereof) can easily be predicted.

Recent findings of large-scale relationships between terrestrial climate and sunspot numbers (*i.e.* numbers of dark spots on the Sun's disc) show that major minima of sunspot number variations coincide with very cold periods of global climate [2, 3]. For each major sunspot number minimum, the corresponding period of very cold conditions

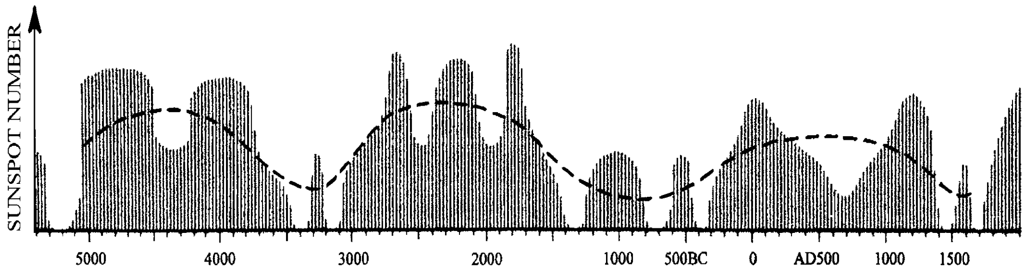

Fig. 1. – A plot of the long-term envelope of possible sunspot cycles since 5400 years BC (see series of vertical lines) as deduced from data on deviations in carbon-14 (from a diagram in ref. [4]). We have used the curve-fitting methods described in ref. [5] in fitting a discontinuous line through the sunspot oscillations at periods less than 1400 years.

in global climate is much shorter than the duration of an ice age (associated with a Milankovitch cycle). As detailed further in sect. **2** of this paper, the last major sunspot number minimum took place between 1400 AD and 1750. AD Note that this last major sunspot number minimum included two well-known periods (*i.e.* the Maunder minimum (1645–1715) and the Sporer minimum (1400–1510)) during which sunspots were completely non-existent or were very few. The very cold period of global climate which coincided with this major sunspot number minimum has been named "Little Ice Age" in the open literature (*e.g.*, see ref. [1]). On this basis, we also refer to the very cold period of global climate which will expectedly coincide with the next major sunspot number minimum as " Next Little Ice Age".

This particular nomenclature helps to differentiate the ice ages associated with Milankovitch cycles (which are simply called "ice ages") from the sunspot-associated ice ages (which are called "Little Ice Ages").

Variations in sunspot numbers are now well related to climatic variations [2, 3]. This implies that we can deduce climatic variation characteristics from corresponding studies of sunspot number variations. In this paper we make use of this sunspot-climate relationship in studying global-climate variations as follows. Firstly we broadly analyse the record of sunspot number variations since 5400 BC. Secondly we establish the salient characteristics of these variations, including the presence of large-scale patterns and major oscillations at periods exceeding 1400 years. Finally we use these large-scale patterns and major oscillations in deducing the onset or starting time of the next little ice age on the basis of the established Sunspot-climate relationships.

2. – Analysis

A graphical representation of variations in sunspot numbers since 5400 years BC is given in fig. 1 using a series of vertical lines. Visual inspection of the sunspot number variations in fig. 1 obviously shows that these variations are dominated by oscillations at periods less than 1400 years. Specific graphical methods do exist by which we can fit a curve through these oscillations (*e.g.*, see ref. [5]). Therefore we used the curve fitting methods described in ref. [5] in fitting a curve through all the sunspot number oscillations with periods less than 1400 years. This particular curve is shown in fig. 1 using a discontinuous line. As clearly displayed in fig. 1, this discontinuous line oscillates at a mean period of 2450 years.

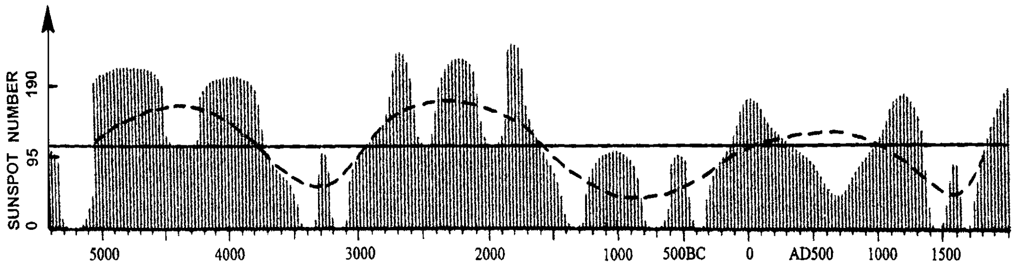

Fig. 2. – Same as fig. 1 but with a solid line drawn horizontally along the value of sunspot number K (see relevant details in the text). Also the vertical axis has been scaled as explained in the text.

For clarity purposes, let us refer to the sunspot number oscillations at periods less than 1400 years in fig. 1 as "short-period oscillations" or in short form as "SPOs". Application of simple signal processing knowledge on fig. 1 shows that all the sunspot number variations in this figure are simply SPOs varying about the discontinuous line, and the latter line varying about a certain constant value K of sunspot number. In this case, sunspot number variability somewhat mimics the motion of a non-linear harmonic oscillator. We compared the post-1900 sunspot numbers shown in fig. 1 with the corresponding numerical values of the yearly sunspot numbers reported in ref. [6]. Then we calibrated the vertical axis of fig. 1 on the separate graph shown in fig. 2, and indicated on this graph the value of K using a solid horizontal line. It is clear from fig. 2 that $K \approx 114$ sunspots per year.

Let us consider the half cycles of the discontinuous line in fig. 2 above and below the solid horizontal line represented by the equation "Sunspot number $S = 114$". The first two half cycles have equal maximum distances from the line $S = 114$. And with exception of the "half" cycle between about 200 BC and about 1200 AD, the remaining half cycles have maximum distances from line $S = 114$ that do not differ by more than 13%. The fact that sunspot number variability contains a specific constant component K and variable components leads us to a rather interesting conclusion about solar activity. Since sunspot number is used as a measure of solar activity in a statistical way, then we can conclude that this activity also contains a specific constant component and variable components.

There is another interesting feature in fig. 2. This figure contains a series of large blocks of continuously non-zero sunspot number variation patterns. These blocks, which tower over the horizontal solid line shown in the same figure, stretch from: 5150 BC to 3450 BC, 3100 BC to 1400 BC, 300 BC to 1400 AD, and 1740 AD onwards. It is obvious that each of these sunspot blocks stretches for 1700 years. On the basis of the sunspot-climate relationships given in ref. [2], the space between adjacent sunspot blocks (which coincides with a minimum in the discontinuous-line oscillation in fig. 1) coincides with a notably cool period of global climate or little ice age. For example, the space between the last two sunspot blocks in fig. 2 coincides with the Sporer sunspot minimum (1400–1510 AD) and the Maunder sunspot minimum (1645–1715 AD), both of which coincided with an extremely cool period of global climate [7]. As detailed later on, the minimum phases of the discontinuous-line oscillation in fig. 1 generally coincide with Little Ice Ages. For example, the duration of the last Little Ice Age is sometimes reported as from 1550 to 1700 AD, and also sometimes reported as from 1350 to 1900 AD (*e.g.*,

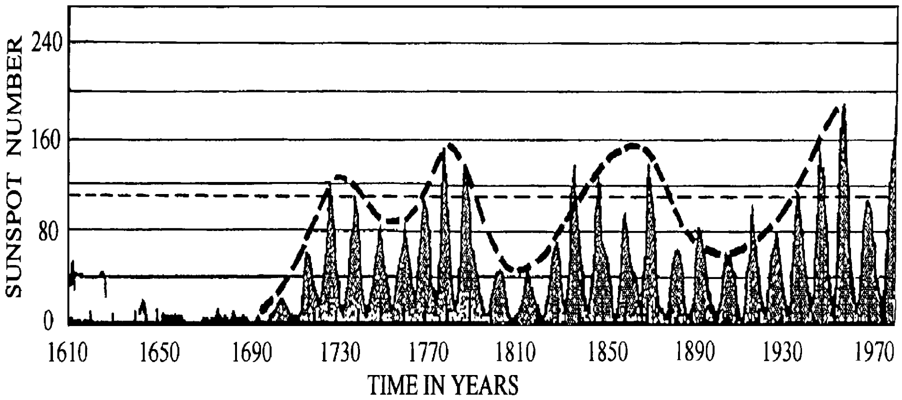

Fig. 3. – A plot of annual average sunspot number (solid lines) from 1610 up to 1980 as reproduced from ref. [8]. We have fitted a thick discontinuous curve through the peaks of the 11-year sunspot cycles using the curve-fitting methods described in ref. [5]. Also a thin discontinuous line has been drawn horizontally along the sunspot number K such that $K = 114$ annual sunspots.

see ref. [1]). These two durations lie in the last minimum phase of the discontinuous-line oscillation in fig. 1. Sunspot blocks form a consistent series in figs. 1 and 2 because they are the ones which form the maximum or peak parts of the (2450 years period) discontinuous-line oscillation in fig. 1. Since two adjacent sunspot blocks are separated by a notably cool period of global climate or little ice age, it is implicit that a sunspot block expectedly starts and stops at a notably cool period of global climate or little ice age. The last sunspot block (see fig. 1 or fig. 2) started at the end of the last Little Ice Age which reached its maximum during the 17th century. Since this block is expected to last for 1700 years, it will expectedly end at about the year 3440 AD. On the basis of the account given above, we would expect the next little ice age to start at about the year 3440 AD. Reconstructed temperature records dating as far back as 3431 BC (*e.g.*, see ref. [7]) show that it is only the starting and ending phases of sunspot blocks which coincide with or are close to little ice ages.

Let us proceed by looking again at the oscillations (earlier termed SPOs) which vary about the discontinuous-line oscillation (DLO) in fig. 2. From 5050 BC to 2920 BC, the DLO makes one complete oscillation while the SPOs make three complete oscillations (about the 2450 years line). Then from 2920 BC to about 200 BC, the DLO makes approximately one complete oscillation while the SPOs make approximately five complete oscillations (about the DLO). And from about 200 BC to about 1800 AD, the DLO makes approximately one complete oscillation while the SPOs make approximately three complete oscillations. From 200 BC to 1300 AD, the period of the SPOs is about 1200 years. Also from 3700 BC to 1600 BC., the DLO makes one complete oscillation while the SPOs make four complete oscillations (about the DLO). And from 670 AD to 1570 AD, the DLO makes 0.25 of a cycle while the SPOs make 1.5 cycles. The approximate picture gathered here is that the SPOs are simply 2nd, 3rd, 4th, 5th and 6th harmonics of the DLO. Consequently, therefore, the sunspot number variations in fig. 1 or fig. 2 are simply superimposition of the constant component K, the DLO (at period 2450 years) as well as the 2nd, 3rd, 4th, 5th and 6th nonlinearly generated harmonics of the latter.

It should be noted that we can simply establish an approximate form of the conclusion mentioned above (about the starting point of the next little ice age) using a different approach as follows. It is already established in ref. [2] that the sunspot oscillations shown in fig. 3 using a thick discontinuous line vary at similar frequencies but in anti-phase mode with global mean surface air temperature. But a comparison of the contents in ref. [1] with those in ref. [2] shows that the 2450 year solar oscillation (discussed earlier in this paper) together with its 2nd, 3rd, 4th, 5th and 6th harmonics vary at similar frequencies and in phase with global mean surface air temperature. This realisation (which is also evident from basic theoretical considerations) implies that relatively very cold phases of global climate (*i.e.* little ice ages) occur during the "minimum periods" of the 2450 years solar oscillation at the times during which the harmonics of the 2450-year oscillation are also at minimum phases. What we mean here by "minimum period" of the 2450 years solar oscillation is the time distance between the earliest and last zero sunspot number points in the minimum phase of the oscillation. On the basis of this definition, the mean length of all the minimum periods of the 2450 years oscillation shown in figs. 1 and 2 is about 580 years. Now since the centre of the last minimum period of the 2450 years solar oscillation is at about 1560 AD, the centre of the next minimum period will be at about 4010 AD. Then the starting point of this minimum period (which apparently coincides with the start of the next little ice age) is located at about the year $[4010 - 1/2(580)]$ AD $=$ 3820 AD. This date (*i.e.* 3820 AD) does not differ from the date obtained earlier (*i.e.* 3440 AD) by more than 11%. Note that since the time length between now and the year 3440 AD or 3820 AD is too small compared with the periods of the Milankovitch cycles (which are associated with occurrences of (major) ice ages), we did not have to involve the latter cycles into our analysis concerning the next little ice age.

Finally it is worth noting that from 5030 BC onwards, each complete cycle of the 2450-year oscillation (see fig. 1 and fig. 2) apparently has its own set of harmonic oscillations. For example: i) from 5030 BC to 2960 BC, the fundamental oscillation is accompanied by the 3rd harmonic; ii) from 2960 BC to 50 AD, the fundamental oscillation is accompanied by the 5th harmonic; iii) from 50 to 1810 AD, the fundamental oscillation is accompanied by the 2nd harmonic; and iv) From about 3700 BC to 1600 BC, the fundamental is accompanied by the 4th harmonic. We should then take note of the following. Although in i) above one complete oscillation in the DLO coincides with three complete oscillations of the SPOs (the latter being termed 3rd harmonic of the DLO), the three oscillations in this 3rd harmonic are not of equal periods. They vary in period from about 830 years to about 450 years. Similarly the 4th and 5th harmonics (of the DLO) have individual cycles whose periods vary, respectively, from about 400 to 650 years and from about 300 to 720 years. Along the same pattern, the DLO makes 0.25 of a cycle from 670 AD to 1570 AD while the SPOs correspondingly make 1.5 cycles. This implies that the SPOs in this case are the 6th harmonic of the DLO. But surprisingly the period of the SPOs (*i.e.* 6th harmonic in this case) varies, going as low as about 210 years between 1300 AD and 1800 AD. The general picture reflected here is that the processes responsible for generating sunspot number variations mimic nonlinear harmonic oscillators as implied in ref. [6].

As clearly illustrated in figs. 1 and 2, the sunspot "blocks" essentially form during the upper half-cycles of the 2450-year oscillation as would be expected. A comparison of figs. 1, 2 and 3 shows that each of the sunspot blocks and in fact all the shaded structures in figs. 1 and 2 contain 11-year sunspot cycles. In summary, the analysis already given above has apparently unearthed the following new picture about the Sun and sunspots in particular. When the mechanisms responsible for generating and sustaining sunspots are at equilibrium, the peak-to-peak amplitude of the 11-year sunspot cycles stays at K

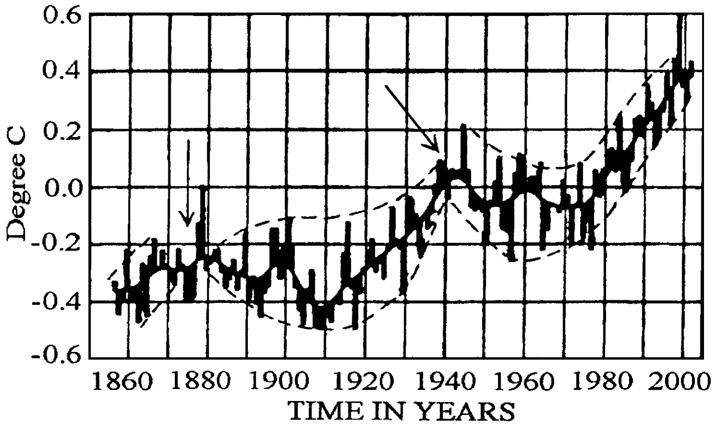

Fig. 4. – A plot of global mean surface temperature over the period 1856 to 2001 (see ref. [10]). The bars represent annual values as departures from the 1961–1990 mean. Also the smooth curve shows the result of filtering the annual values to reveal long-term fluctuations. We have used discontinuous lines to sketch out the amplitude-modulation envelopes or states of the temperature variations using the curve-fitting methods described in ref. [5]. The arrow-headed lines show timings of major changes in the amplitude-modulation envelopes. All these timings coincide with the times at which the thick and thin discontinuous lines in fig. 3 cross each other.

(*i.e.* at about 114 annual sunspots). But due to modulating oscillations inside the Sun at a fundamental period of 2450 years and its 2nd, 3rd, 4th, 5th and 6th harmonics, the amplitude is varied (about value K) from zero to about 246 annual sunspot numbers. Another set of sunspot-modulating oscillations (at relatively shorter periods) which also give rise to variations about the equilibrium value K is reported in ref. [9]. And as illustrated in the text, some significant climatic changes take place on the Earth whenever the sunspot number variation curve crosses the equilibrium value K.

3. – Conclusion

We have shown that variations of sunspot numbers since 5400 BC are simply represented by a summation of a 2450 years oscillation with its 2nd, 3rd, 4th, 5th and 6th harmonics and a constant component K whose numerical value is 114 yearly sunspots. On the basis of this establishment together with the sunspot-climate relationships detailed in refs. [2, 3], it is deduced that the next little ice age is expected to start at about the year 3440 AD. It seems that K is a new constant for the Sun, and that the level or line defined as "Sunspot number = K" seems to be an "equilibrium" level or line. If this is the case, we should expect that even variations in the 11-year sunspot cycles should take place about this "equilibrium" level or constant. Indeed correctness of this expectation is proved by fig. 3. This figure clearly illustrates that the peaks of the 11-year sunspot cycles do oscillate in varying amplitude and period about the equilibrium line represented by: "Sunspot number = K", where $K = 114$ annual sunspots. Note that the latter equilibrium line is equal to the horizontal solid line shown in fig. 2. What is additionally interesting about the equilibrium line represented by "Sunspot number = K" in fig. 3 is the following. The timings at which this particular line meets with the thick discontinuous line (in the same fig. 3) coincide with occurrences of major changes

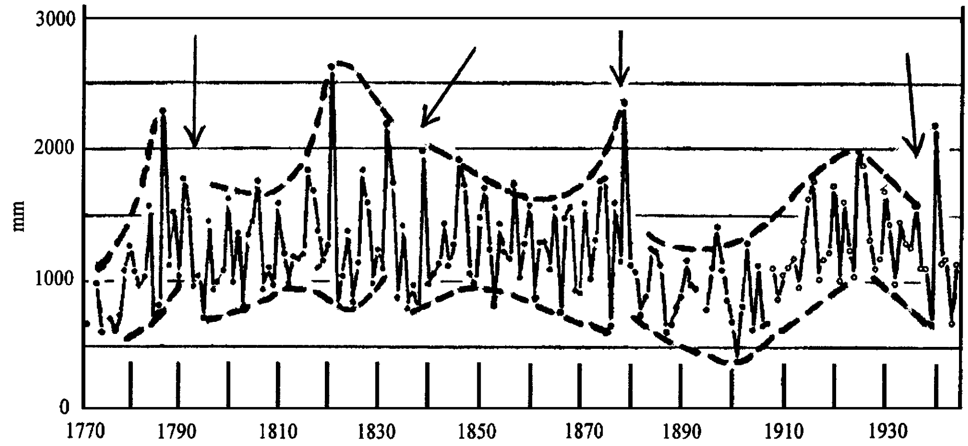

Fig. 5. – A plot of annual rainfall at Seoul, South Korea from 1770 up to 1944 (solid lines) as reported by Flohn [11]. Discontinuous lines have been used to sketch out the amplitude-modulation envelopes formed by the solid-line variations using the curve-fitting methods described in ref. [5]. Major changes in the amplitude-modulation envelopes are shown by arrow-headed lines. Note that these major changes coincide with the times at which the thin and thick discontinuous lines in fig. 3 cross each other.

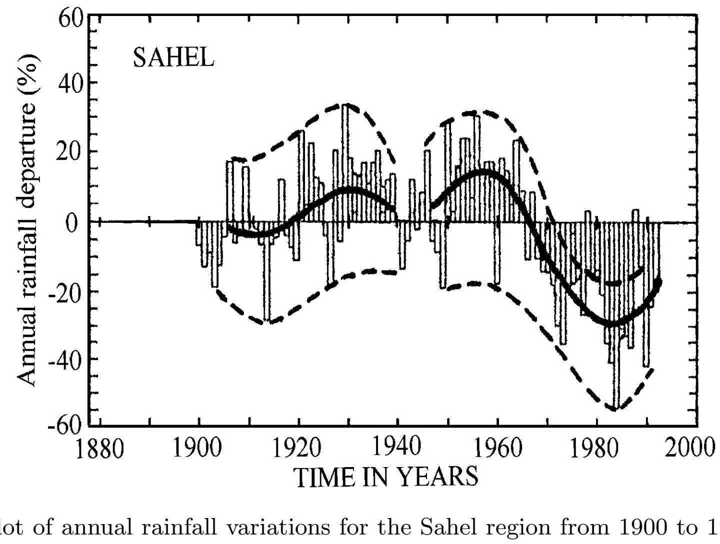

Fig. 6. – A plot of annual rainfall variations for the Sahel region from 1900 to 1993 (expressed as departures from the 1951-80 mean) as reported in ref. [12] (see thin solid lines). The mean of the rainfall variations is plotted in thick solid lines. In addition, discontinuous lines have been fitted along the maxima patterns as well as the minima patterns of the rainfall variations using the curve-fitting techniques described in ref. [5]. Note that a large and rapid change took place at about 1940 in the phase and amplitude of the oscillatory amplitude-modulation envelope. This change coincides with a timing at which the thin and thick discontinuous lines in fig. 3 cross each other.

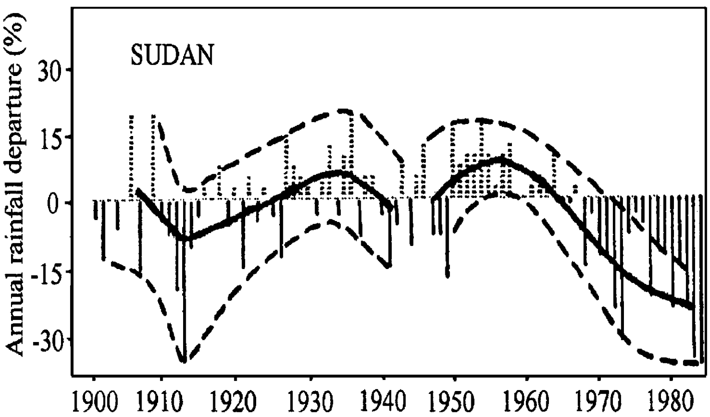

Fig. 7. – A plot of annual rainfall variations for the Sudan region just south of the Sahel region from 1900 to 1985 (vertical solid and cross-patterned lines) as reported in ref. [13]. The mean of the rainfall variations is plotted in thick solid lines. In addition, discontinuous lines have been drawn through the maxima patterns as well as the minima patterns of the rainfall variations using the curve-fitting techniques described in ref. [5]. Note that at about 1940, a large and rapid change in the phase and amplitude of the amplitude-modulation oscillatory envelope took place. This change coincides with a timing at which the thin and thick discontinuous lines in fig. 3 cross each other.

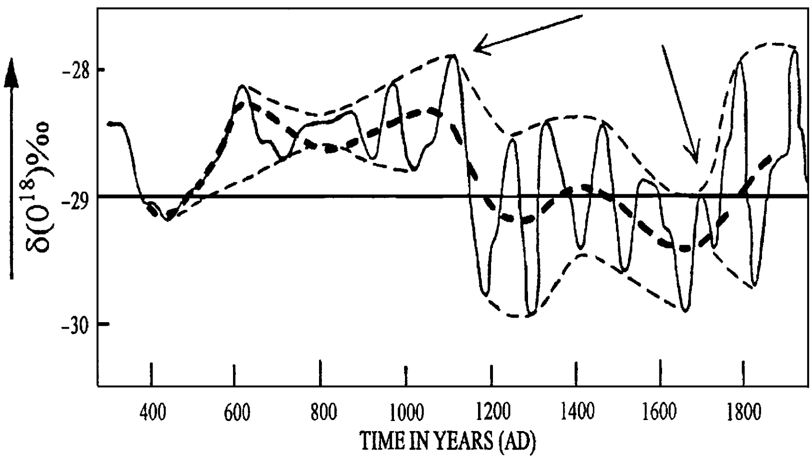

Fig. 8. – Oxygen isotope variations in northwest Greenland from 300 AD, arranged to be read as equivalent to a temperature curve (see solid line) as reported in ref. [7]. The thick discontinuous line represents what is left after the solid-line variations are low-pass filtered in order to remove all variations at periods less than 180 years. Also thin discontinuous lines have been used to sketch out the amplitude-modulation envelopes of the solid-line variations by means of the curve-fitting methods described in ref. [5]. The arrow-headed lines show timings at which the amplitude-modulation envelope changes from one mode (or state) into a different mode (or state).

in global temperature patterns (see fig. 4), in regional temperature variation patterns (*e.g.* see fig. 8) as well as in rainfall patterns in different regions (*e.g.* see figs. 5, 6 and 7 as typically representative examples). A comparison of fig. 2 (in this paper) and fig. 8 (in ref. [2]) also shows clearly that major changes in long-term temperature patterns in California (dating as far back as 5400 BC) coincide with the timings at which the discontinuous line in fig. 2 (in this paper) meets with the equilibrium line represented by "Sunspot number = K" in the same figure. Indeed coincidences of major global and regional climate changes on the one hand and meeting points of the "equilibrium" line and the discontinuous line in fig. 2 on the other hand have been verified by the vast heap of meteorological data (from all the continents) which are at our disposal. The same can be said regarding coincidences of major global and regional climate changes on the one hand and meeting points of the thick discontinuous line and the thin discontinuous line in fig. 3 on the other hand. The specific illustrative cases given above are only few representative examples which we have picked up randomly. As a last verifying illustration, let us look at temperature variations in Greenland (fig. 8). A comparison of figs. 2 and 8 clearly shows that the amplitude-modulation envelope of Greenland temperature variations changes from one mode (or state) into a different mode (or state) whenever the discontinuous line and the "equilibrium" line in fig. 2 cross each other. Simple forward extrapolation of fig. 3 shows that the thin and thick discontinuous lines in the same figure will meet during the early years of this century. On the basis of the account given above, we would, therefore, expect that a major change in the amplitude-modulation envelope of global mean air temperature variations will take place during the early years of this century as implied in ref. [2].

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