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New findings on the spectrum of solar activity and related climate changes

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Summary. — It was established in a recent publication that annual sunspot numbers since 5400 BC are fully represented by a series of 11-year cycles (with constant peak-to-peak amplitude of 114 annual sunspot number) which is continuously amplitude-modulated by an oscillation with mean period of 2450 years, together with its (nonlinearly generated) harmonics. Here it is shown that the latter oscillation together with its harmonics take the form of two continuously alternating states. One of the states consists of a main oscillation at a period of 2050 years together with its third and higher harmonics. The other state consists of a main oscillation at a period of 2750 years together with its fifth and higher harmonics. Each state switches over to the other state after one complete cycle of its main oscillation. This new information, together with established Sun-Climate relationships, shows that there will expectedly be three little ice ages in close succession between the years 3440 AD and 4550 AD. The first of these three little ice ages has already been predicted in a recent publication through a different method.

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PACS `96.40.Kk` – Solar modulation and geophysical effects.

1. – Introduction

In a recent publication [1], variations of the solar (or sunspot) cycles since year 5400 BC were analysed partly in order to establish all significant periodicities that characterise these variations. Some of the important findings of this analysis may be summarized as follows. Variations in annual sunspot numbers since 5400 BC are fully represented by a series of 11-year sunspot cycles (with a constant peak-to-peak amplitude of 114 annual sunspot number) which is then continuously amplitude-modulated by an oscillation with a mean period of 2450 years, together with its harmonics. Further research on this aspect has an unearthed presence of frequency-modulation processes and other new details about the above-mentioned amplitude-modulating pattern (*i.e.* the $\sim$ 2450 years oscillation and its harmonics) as well as related climatic variations. The aim of this paper is to present and briefly discuss these new details.

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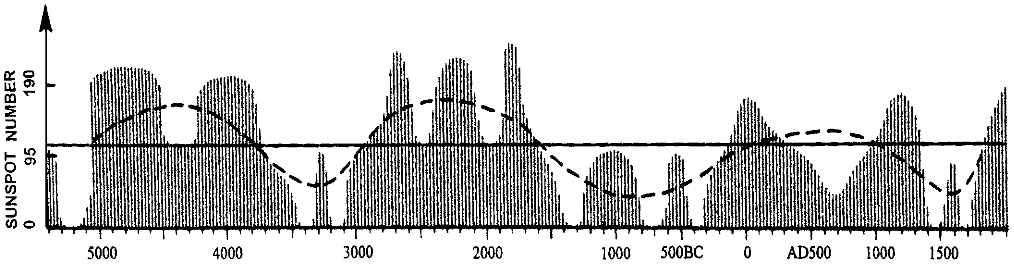

Fig. 1. – A plot of the long-term envelope of possible sunspot cycles since 5400 years BC as deduced from data on deviations in carbon-14 (from a diagram in ref. [2]). A discontinuous-line curve has been fitted through the oscillations at periods less than 1400 years using the curve-fitting methods given in ref. [3]. Also a straight horizontal line is drawn through the value of annual sunspot number equal to 114.

2. – Analysis

Although fig. 1 has been analysed before (*e.g.*, see ref. [1]), we decided thereafter to re-analyse it using a different method in order to discover any new information that was not detected before. The different method that was used is as follows. We selected a stretch $s(t)$ of the record in fig. 1 which starts from year 5050 BC (*i.e.* at the beginning of the discontinuous line) and proceeds onwards such that t represents time in years. Initially the length of $s(t)$ was 1900 years. Then we spectrally analysed $s(t)$ using the Maximum Entropy Method and noted the peaks present in the resulting power spectrum. The length of $s(t)$ was increased by 200 years, and spectral analysis work (upon the new lengthened $s(t)$) was computed. We continued increasing the length of the latest $s(t)$ in steps by 200 years, and after each step the power spectrum of the longest $s(t)$ was obtained. The process was similarly continued in steps until a power spectrum with relatively sharpest peaks was attained. At this particular point, the sharpness of the peaks in the power spectrum decreases if the length of $s(t)$ is decreased or increased. This particular point was reached when the latest (or longest) $s(t)$ stretched from 5050 BC up to 3000 BC. Now we repeated the whole (step-to-step spectral analysis) process mentioned above, but this time the initial $s(t)$ stretches for 1900 years from year 3000 BC. What finally resulted was that a power spectrum with relatively sharpest peaks was obtained when the latest and longest $s(t)$ stretched from 3000 BC up to 250 BC. Finally we started with a new $s(t)$ stretching for 1900 years from 250 BC, and repeated the step-by-step spectral analysis process mentioned above. The version of the longest $s(t)$ whose power spectrum displayed relatively sharpest peaks is that which stretches from 250 BC up to 1800 AD. We could not continue the process further because the portion of the record after 1800 AD is too short.

The results just given above show that the record in fig. 1 is divided into spectrally different sections, each longer than 1900 years. The first of these sections stretches from 5050 BC to 3000 BC. This section will hereinafter be referred to as "Section 1". The other sections (*i.e.* Section 2 and Section 3) stretch from 3000 BC to 250 BC and from 250 BC to 1800 AD, respectively. Section 1 is characterised by a 2050-year oscillation and its third harmonic only. Section 2 is characterised by a 2750-year oscillation and its fifth harmonic only. And Section 3 is (spectrally) a repeat of Section 1 because it is characterised only by a 2050-year oscillation and its third harmonic. On this basis, we shall hereinafter refer to “Section 3” simply as a repeated “Section 1”. It was also found that the power spectrum of the record stretching from 3580 BC to 2800 BC is approximately identical to that of the record stretching from 1380 AD to 2000 AD. This somehow strengthened our credence or hypothesis that a (spectral) repeat of Section 2 starts at 1800 AD. The general picture gathered here is that the record in fig. 1 is (spectrally) made up of two alternating “states” which can be noted in fig. 1 even by a mere visual inspection. One state (called “state 1”) consists of a 2050-year oscillation with its third harmonic, and the other state (called “state 2”) consists of a 2750-year oscillation with its fifth harmonic. On this basis, the latter state stretches onwards from 1800 AD. If this is true, then we would expect that the next zero minimum will start forming at a time-distance of 3000 BC → 1370 BC, that is, 1630 years after 1800 AD. This expectation shows that the starting point of the next zero minimum is located at (1800+1630) AD = 3430 AD. We note that the latter date is approximately equal to date 3440 AD which was calculated for the same purpose in ref. [1] using a different method. Indeed this approximate equality is yet another indication which gives additional proof for the conclusion reached earlier in this paper that a (spectral) repeat of “state 2” starts at year 1800 AD. This repeated (spectral) version of “state 2” is expected to end in 4550 AD, and by its nature precipitate three zero minima in close succession between 3430 AD and 4550 AD. As detailed in refs. [1, 6], each of these three minima will expectedly coincide with a little ice age. The first of these three little ice ages has already been predicted in ref. [1] to start at about 3440 AD.

On the basis of the Sun-Climate relationships given in refs. [1, 6, 11-13], a stretching of “State 2” from 1800 AD implies that a major global cooling trend will expectedly start at about 2150 AD. The start of this cooling trend is indeed inevitable even in the presence of man-generated greenhouse gases in the atmosphere. This is because the latter gases only vary the amplitudes of “natural” global temperature variations in a somehow directly proportional manner [12]. Before proceeding further, it is worth noting here that it is the average of the 2050-years periodicity of “State 1” and the 2750-years periodicity of “State 2” which gives the ∼ 2450-years periodicity reported in ref. [1]. Indeed the two periods at 2050 years and 2750 years are reflected in long terrestrial temperature records as a broad peak centred at a period of ∼ 2450 years [7, 8].

The portion of the record in fig. 1 onwards from 1800 AD has been blown up and expanded in order to reveal finer details. This expanded and blown-up version is displayed in fig. 2. The envelope shown in fig. 2(b) by discontinuous-line curves was extrapolated backwards using additional data from ref. [9] and found to have the next node before 1700 at year 1690. With adjacent nodes of years 1690 and 1900 (see fig. 2(b)), this particular envelope shows that the solid-line variations in fig. 2(b) are amplitude-modulated by a 210-year oscillation. We can measure the degree of this amplitude-modulation process using a standard factor known as “modulation index”. According to standard amplitude-modulation theory [10], the modulation index, M, of the amplitude-modulation process mentioned above with reference to fig. 2(b) is given as

$$M = \frac{A-1}{A+1}\,, \tag{1}$$

where

$$A = \frac{\text{Amplitude at an antinode}}{\text{Amplitude at a node}}\,.$$

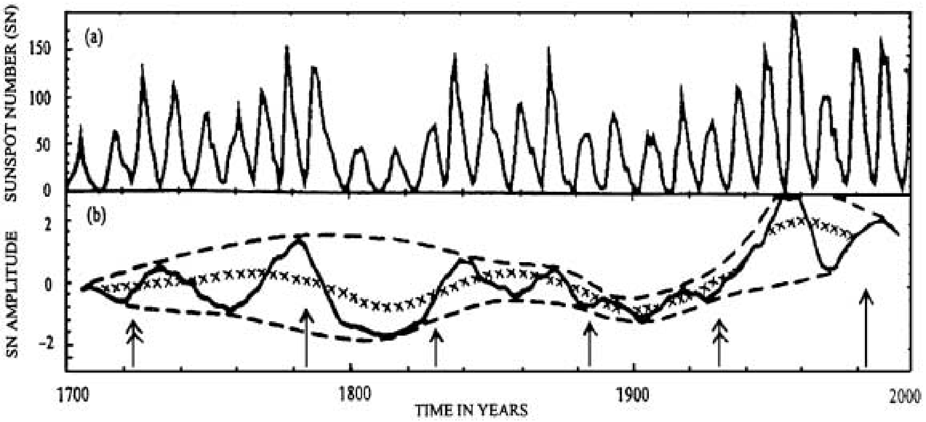

Fig. 2. – A plot of: (a) yearly sunspot numbers series from 1700 to 2000 as reported in refs. [4,5]; and (b) instantaneous amplitudes of the pulses or cycles in (a) using a solid-line curve. A discontinuous-line curve has been fitted along the maximum points as well as along the minimum points of the solid-line curve in (b) using the curve-fitting methods given in ref. [3]. Also a series of crosses has been fitted through the mean about which the solid-line curve in (b) oscillates. This curve-fitting work has been done with the aid of the curve-fitting methods given in ref. [3].

Since $A = 4.8$, then $M = 65.5\%$. This value of M represents a very significant amplitude modulation process. This is because the modulation indices used in the popular amplitude-modulation (AM) Radio Broadcasting Stations commonly range in value from $\sim 0\%$ up to 100%.

Another oscillation plotted in fig. 2(b) is that represented by a series of crosses. This particular oscillation is a second harmonic of the 210-years oscillation mentioned above as may be noted in fig. 2 (b) even by a mere visual inspection. Also shown in the latter figure is that the solid-line oscillations constitute a (nonlinearly generated) third harmonic of the oscillation represented by a series of crosses. What is particularly interesting in fig. 2(b) is that the 210-year oscillation also frequency-modulates the solid-line oscillations, giving rise (in the latter) of maximum frequency, f_{n}, at a node and minimum frequency, f_{a}, at an antinode. We can assess the degree of frequency modulation involved in this case by means of a parameter R called "modulation index". According to standard textbooks on frequency-modulation systems [10], the value of R is given as

$$R = \frac{1/2(f_{\mathrm{n}} - f_{\mathrm{a}})}{f_{\mathrm{m}}}, \tag{2}$$

where f_{m} is the frequency of the 210-year oscillation. On the basis of measurements of f_{a} and f_{n} made in fig. 2(b) together with the known value of f_{m}, the computed value of $R = 2.9$. This value of modulation index represents a substantial degree of frequency modulation. This is shown by the comparative fact that the most common modulation indices used in amateur FM systems, TV sound systems, and FM Broadcast systems are 1, 1.67 and 5, respectively. Due to the frequency modulation impressed on it by the 210-year oscillation, the solid-line oscillation in fig. 2(b) has a nonstationary period which varies from ~ 22 years to over 50 years. The analysis on fig. 2 already given clearly shows that, at least the end part of "State 1" includes harmonics of the 2050-years oscillation at orders higher than the third order. By implication, it would also appear that, at least the end part of "State 2" includes harmonics of the 2750-year oscillation at orders higher than the fifth order. Unfortunately we could not get sunspot number records with which we could test this implied inference.

As detailed in refs. [6, 11, 12], the frequency modulation mentioned above, as well as all other variations in sunspot number mentioned earlier in this paper, are significantly reflected in climate variations. All the climate variation patterns related to frequency-modulated solar (or sunspot) activity are nonstationary since they do not have stable periods. Besides, climate variation patterns related to amplitude-modulated solar activity also become nonstationary whenever the nonlinearly levels in the surface-atmosphere system undergo changes. This second cause of nonstationarity in climate variation patterns is discussed in details in refs. [11-13].

3. – Conclusion

A deeper analysis of the long sunspot number record reported in refs. [1,6] has yielded new periodicities and other variability characteristics of solar activity. The new periods are those at 2050 years and 2750 years whose mean is approximately equal to the $\sim$ 2450-years periodicity reported in ref. [1]. The new variability characteristics include: two variation pattern states whose continuously alternating sequence makes up the record mentioned above; and continuous frequency-modulation imposed by a $\sim$ 210-years oscillation on its sixth harmonic. Climatic changes associated with these solar activity variations have also been obtained using established Sun-Climate relationships and presented in the text. In particular, some predicted variations in solar activity that stretch up to 4550 AD have been presented together with their correspondingly related climate changes.

REFERENCES

[1] Njau E. C., this issue, p. 133.
[2] Eddy J. A., *Climate Change*, **1** (1997) 173.
[3] The curve-fitting toolbox at `www.mathworks.com/nncurvefitting` visited on 24/04/2004.
[4] Paul M. and Novotna D., *Phys. Rev. Lett.*, **83** (1999) 3406.
[5] Internet `http://science.nasa.gov/headlines/news.archive.htm` visited on 29/11/2003.
[6] Njau E. C., *Nuovo Cimento C*, **26** (2003) 23.
[7] Van Andel T. H., *New Views on an Old Planet* (Cambridge University Press, Cambridge) 1994.
[8] Peixoto J. P. and Oort A. H., *Physics of Climate* (American Institute of Physics, New York) 1992.
[9] Wallace J. M. and Hobbs P. V., *Atmospheric Science* (Academic Press, New York) 1977.
[10] Taub T. and Schilling D. L., *Principles of Communication Systems* (McGraw-Hill Book Company, New York) 1986.
[11] Njau E. C., *Proc. Indian Nat. Sci. Acad. A*, **66** (2000) 415.
[12] Njau E. C., *Proc. Indian Nat. Sci. Acad. A*, **66** (2000) 451.
[13] Njau E. C., *Nuovo Cimento C*, **22** (1999) 739.