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Remarks on astrochronology and time series analysis of Lake Sake varved sediments

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Abstract: *A 4190-yr varve record from lake Saki (Crimea) was recently re-analyzed using five different spectral methods, applied both overall and to separate segments of the record (Xanthakis et al., 1995a). Here we consider its palaeoclimatic implications, spanning much of the Holocene Subboreal and Subatlantic biozones, and compare the spectra with those of planetary-solar orbital and radiation periodicities. Linkage is found with both the data on harmonics of the Earth-Moon Milankovitch parameters, and with harmonics and resonances of (a) the major planets, (b) the proxy solar activity record disclosed by ^{14}C flux in the Stuiver and Braziunas dendroscronological record, and (c) the long-term observations of geomagnetics and auroras. The most significant (>95%) of the Xanthakis et al data are in the ranges 20-25, 44-46, 57-67, 120-130 and 200-250 yr (Liritzis and Fairbridge, 1998). All of these clusters are strongly represented in the spectra of both palaeoclimatic and astronomic frequency series.*

Introduction

A series of annual mud layers going back to 2300 BC in the varved deposits of the salty lake Saki on the west coast of the Crimea (45° 1’ N, 33° 5’ E) has been counted by Schostakowitch in 1934, reproduced by Lamb (1977) who also converted these data to rainfall scale, suggested by Brooks in 1949, thus producing rainfall variations in the Crimea since 2300 BC (Lamb, 1977; fig.16.24, p.408). The layers are presumed mainly due to the run-off from the land caused by the heavier rainstorms; but most of the layers are only a few millimeters thick, and some may have been missed in the counting.

This high resolution record suggests (a) that cyclic variations occur, (b) that a few centuries between AD 800 and 1250 represented a temporary return to moister conditions rather as they were in that area before 2000 BC, both being times of marked wetness setting in western and northern Europe.

In general, the implied wetness variations show some parallel with those which are thought to have occurred in Central Asia and are more often opposed to those over northern and central Europe.

These data have been already analysed but in a 10-yr sampling interval, employing methods of time-series analysis (Maximum Entropy Spectrum Analysis, MESA; Power

Spectrum Analysis using the Blackman-Tukey window, PSA; Fourier, FFT; Autocorrelation and the successive approximations, SA). The results obtained indicated several periods and quasi-periods which superimpose upon each other, ranging between 25 to 1,000 years, attributed to solar-climatic cycles found in other proxy solar-climatic time-series (Xanthakis et al., 1995a). The most significant (>95%) of the data are in the ranges 20-25, 44-46, 57-67, 120-130 and 200-250 yr. All of these clusters are strongly represented in the spectra of both palaeoclimatic and astronomic frequency series.

The quasi-periodic character of some cycles are probably due to the irregular of hard to predict rainstorms and the extreme persistent occurrences of blocking of the westerlies (large stationary anticyclones or cyclones) in the sector of the northern hemisphere between 20° and 80° E.

In the present work a similar analysis is applied to sub-records of Saki varves on an annual basis. The obtained periods together with the earlier ones (Xanthakis et al., 1995a) are discussed in relation to their palaeoclimatic implications, spanning much of the Holocene Subboreal and Subatlantic biozones, and compare the spectra with those of planetary-solar orbital and radiation periodicities. Linkage is found with both the Berger and Loutre data on harmonics and resonances of (a) the major planets, (b) the proxy solar activity record disclosed by ^{14}C flux in the Stuiver and Braziunas dendrochronological record, and (c) the long-term observations of geomagnetics and auroras.

Spectrum analysis results

The spectrum analysis methods employed are MESA, FOURIER (FFT), and Autocorrelation. Desription of the methods are made elsewhere (Xanthakis et al., 1995a; Liritzis, 1990; Liritzis et al., 1995).

The analysed annual varves sub-records are: 2190 - 2091 BC, 1890 - 1791 BC, 890 - 841 BC, 780 - 849 AD, 1250 - 1290 AD. Table 1 gives the results of the periodic analysis.

The data present several cycles; the biannual cycle, ~5 yr, ~7 yr, 8-11 yr, 14-16 yr and trends of 20-25 yr and ~50 yr. The obtained (quasi-) periods are not stationary; thus for similar number of data in different sub-records (different time intervals) some periodic terms are either slightly shifted or are not present (e.g. the presence of ~10 yr in the interval 2190-2091 BC, and its absence or of very low significance in the interval 1890-1791 BC).

COMPARISON WITH OTHER PROXY SOLAR-PLANETARY-CLIMATIC DATA

The present periodic analysis together with the longer terms obtained earlier (Xanthakis et al., 1995a) comprise of the following periodic components: ~2, ~7, 8-11, 14-16, 20-25, 44-46, 57-67, 120-130, 200-250, ~330, ~563, ~660 and ~1000 years, with significance >90% were obtained.

Similar periods in other proxy climatic data include; (a) aurorae of 20-30, 40-60, 80-130, 200 years (Liritzis, 1990), (b) sunspot numbers of 10-12, 22, 40-60, 80, 200 years (Schove, 1983; Kane and Trivedi, 1985; Attolini et al., 1985; Jelbring, 1995), (c) Danish raised bogs of 11, 22, 200 years (Dansgaard et al., 1971), (d) tree-ring and ^{14}C variations of 8-9, 10-12, 13-15, 22-25, 45, 125, 200 (Sonett and Suess, 1984; Liritzis and Kosmatos, 1995), (e) ^{10}Be, ^{18}O in polar ice and in thermoluminescence (TL) of marine sediments of 11, 22, 50 years (Castagnoli et al., 1984), (f) geomagnetic intensity from lake sediments and ceramics of 100-130, 200 years and higher ones (Xanthakis and Liritzis, 1991), (g) in solar flares of 1.7-2, 1 , 9, 11 yr (Ichimoto et al., 1985; Liritzis et al., 1999).

Otherwise, a generalised expression has been found between sunspot numbers Rz, planetary geomagnetic index Kp, solar wind streamers derived from coronal holes and the solar flares, as well as the number of aurorae for the last three solar cycles (Liritzis et al., 1986, 1987).

Periodic and quasiperiodic terms are found ranging from low (years) to long (centuries to millennia) for all the so far analysed proxy solar-climatic data series. Its frequency bands depend upon the length of the analysed record. A similar conclusion applies for the geological time scales considering terrestrial movements (Liritzis, 1993).

TABLE 1

Spectrum analysis of some subsets of lake Saki, Crimea, annual mud thickness layers for distinct subsets. Periods are arranged in columns of similar (within errors) length. Methods used are MESA, FFT, PSA, Autocorrelation.

1) 2190-2091 B.C. N=100 yrs

Method	**periods, yrs**							
MESA, all record	25+3	13.5+0.2	9+0.5	7	5	3.5	2.7	2
1st half	25	-	9	6.7	5	3.6	2.7	2
2nd half	28.5	-	10+1.5	-	5.5	-	-	2
FOURIER (FFT)	20	12.5	8.3±1.5	6.7	5	-	2.6	2.1
AUTOCORRELATION	19						2.6	

* underlined are the very high variance peaks.

2) 1890-1791 B.C., N=100 yrs

MESA, all	50	16.7+2	-	-	5.4	3.8 , 3.6	2.2
1st half	40	14.5+1.5	-	6.7	5	3.7	3.3-2.7
2nd half	-	16.6+2.5	-	-	5.6+0.3	3.8	-
FFT	50	16.6(>90%)	-	-	5.3(90%)	3.8(90%) 3.6	3 (75-90%)
AUTOCORR.		16					

3) 780-849 A.D., N=70 yrs

MESA, all	50+15	15.4+0.4	(10.5±0.1)	7.7+0.3	-	3.7+0.1	3	-
1st half	-	14+2	-	7.4+1	-	-	3	2
2nd half	-	13.6+1	-	7+0.5	-	3.8	3.1	2.5
FFT	50±20	14.3±2	-	8.3±2(>90%)	5.9±1(90%)	3.6(<90%)	3 (<90%)	2.5

4) 890-841 B.C., N=50 yrs

MESA, all	-	14.3±2	-	8.3+1	6+0.5	-	3.8	2-3
FFT	-	-	-	8.3	-	4.2	3	2.3
AUTOCOR.	-	-	-	7-8	-	4-5		

5) 1250-1290 A.D., N=50 yrs

MESA, all	-	10.5+0.5	-	5	4	-	2.4	2
FFT	50	10+2	-	5	3.8	2.9	2.3	2
AUTOCOR.					4±0.2			

CLIMATIC SPECTRA AND SOLAR/PLANETARY IMPACT

The longest and most closely studied instrumental climatic data (temperatures) are those obtained since 1659 from Central England (and spectrally analysed: Plaut et al. 1995; Dettinger et al., 1995). A comparison of these spectra with long-term planetary-solar periodicities discloses an astronomical connection, the quadrature alignment of the major planets around the Sun. The most important of these return at intervals of 3336 (= 1/7 x Precessional period of 23,354 yr) and 6672 years, with connecting quarters at 556 yr (Stacey, 1963, 1967). The Dettinger et al., spectra can be compared with harmonics of the 3336 yr period, disclosing a match of high precision (<0.03 "error"); with the exception of two values at a 0.5 difference, but this is normal in conjunction/opposition situations (Table 2).

TABLE 2
Lake Saki varve spectra (Xanthakis et al., 1995a) and present data, analyzed as harmonics of solar/planetary cycle 3336.3653 yr, and compared with temperatures and sunspot numbers.

Plant-Ghil-Vantard value (yr)	Dettinger et al., value (yr)	3336.36 harmonic (yr)	"Error"	Currie (1972) Sunspot spectra	Xanthakis et al.,(1995a) &present data of Lake Saki
25.0	26.3	26.0653 or 26.27055	0.02945	[25.3, Jelbring]	26
14.2	14.5	14.5059	0.0059	14.7	15±1
---	9.6	9.60104	0.00104	9.52	9.5±1.5
7.7	7.5	7.49744	0.00256	---	7±0.3
5.2	5.2	5.20087	0.00087	---	5±0.5
---	4.7	4.6991	0.0009	4.76	---

A comparison is offered with sunspot spectra by Currie (1973), which he divided into two sets, 1749-1853 and 1854-1957. On a millennial basis, the first set approaches the long-term averages, whereas the second is biased by the very high solar activity of the present century. Dettinger's value of 26.3 compares with Jelbring's (1995) 2600 yr averaging which gives 25.3 and 24.3 (different epochs).

In the dynamic sense, the 5-25 yr variability of Lake Saki varves and mid-latitude temperature variations (U.K.) appears to be felt also in the high-latitude data from the Greenland ice core GISP-2 (Taylor et al., 1993). Here, electrical conductivity reveals an alteration between dusty and less-dusty atmospheric conditions on a less than 5 to 20 yr time-scale, a condition figuratively referred to as the "flickering switch". Climatologists have long recognized a higher than one year change in mode of the jet stream, with shifts in the principal pressure cells e.g. the North Atlantic Oscillation (e.g. Lamb, 1977). Improved satellite-based observations seems to indicate a geomagnetic (solar wind) forcing through the polar vortex which is seen to shift to and fro between a westerly and easterly symmetry. This oscillation is probably responsible for many of the multiplicity of cycles observed.

Concerning this multiplicity, it has been found that all of them appear to be interlocked in a mesh of resonances and harmonics that rest on primary planetary dynamics, as designated by beat frequencies (re. 'network of periodicities' repeatedly found in most data sets analysed through the 'successive approximations' method of analysis, Xanthakis et al., 1995a) (see, Tables 3 and 4).

Thus, for the periodic terms obtained for lake Saki varves, there exist a remarkable coincidence with periodic terms attributed to harmonics of the inner solar spin rate, the sunspot numbers and planetary resonances (Fig.1, see notes to figure).

Primary among the latter in the Saturn-Jupiter beat (19.8593 yr), but also, as a major perturbing influence is the in-out motion of the Moon and its changing orbital tilt which generates a tidal/apsides beat frequency of 17.3769 yr. Both are commensurable with the 3336.36 yr fundamental tone (x192 and x168) (see, Tables 2 and 4).

Regarding the relation between lake Saki varve periods in the range 24-200 years with solar parameters, there seems to exist a correlation; with sunspot correlation code (after, Jelbring, 1995), the ratio to inner sun spin, and examples of planetary (?) forcing i.e. planetary periodicities that may provide torques on Sun's photosphere (Table 3).

TABLE 3

Examples of Lake Saki varves, with proposed solar and planetary similarities.

Period (yr)	***Sunspot*** Correlation Code (1)	***Ratio to Inner*** Sun Spin (2)	***Planetary (?)*** Forcing Examples (3)
24.2	Y	348 (24.1886)	76x0.31723 (EMeL)
27.9	V	400 (27.803)	5x5.56 (JEVL)
29.0	G	417 (28.985)	91x0.31723 (EMeL)
33.2	F	478 (33.224)	1055x0.31723 (EMeL)
41.7	E	600 (41.7045)	173x0.24085 (Me p.)
50.1	D	720 (50.045)	9x5.56 (JEVL)
79.0	C	1136 (78.9606)	249x0.31723 (EMeL)
133.0	B	1914 (133.0375)	24x5.56 (JEVL)
200.0	A	2878 (200.043)	36x5.56 (JEVL)

NOTES:

(1) Sunspot spectral peaks (code: Jelbring, 1995)

(2) Ratio to n=1 (0.0678785 yr=SSR) for spin rate of inner Sun. Over long term of 1 million years all planetary periods conform to this mean solar sidereal spin rate.

(3) Examples of planetary periodicities that may provide torques on Sun's photosphere (Me p. is for Mercury period, other capitals are initials of planets).

TABLE 4

Earth-Moon Beat Frequency (17.376902 yr), showing relationship to (a) fundamental tones (resonances) up to 26.90445 Myr; and (b) to Milankovitch parameters (mean insolation) up to 36.43305 Myr.

EARTH/MOON Beat Frequency

(E/MOON principal tide: 18.03 yr; Apsides 8.849 yr)

17.376902 yr

SOLAR CYCLE	x2=34.7538
11.1212 yr=	x4=69.5076=UJVL; 219xEMeL(0.317383)
=2x5.56061 (JEVL)__x100)__	x6=104.261
	x8=139.015=7xSJL; 87xEVL(1.59786)
	x12=208.523=15xUJV; 657xEMeL
	x24=417.045=21xSJL; 261xEVL; 1314xEMeL
	x32=556.061=28xSJL; 348xEVL
	x48=834.091=42xSJL; 522xEVL

SOLAR QUADRATURE	**SJL**	**SJL/USL Resonance**
development:	**19.8593**	19.8593/45.392 (16:7)
556.061 yr	x28	**317.744 yr**
x2 = 1112.12	x56	
x3 = 1668.18	x84	
x4 = 2224.24		x7=2224.24=161xUJL(13.815)
x6 = 3336.36		x4=3336.36=261xNJL(12.783)
x8 = 4448.49	x224	
x12 = 6672.73	x336	
x18 = 10,009.08	x504	

FUNDAMENTAL TONES **(Resonances)**:	**MILANKOVITCH** PARAMETERS **(mean insolation)**
93,418.228 yr (x9.3)	**23,354.59 yr** (17.3769x1344)
x12	**41,009.49 yr** (17.3769x2360)
= **1.121018 Myr** (x112)	
	93,418.228 yr (17.3769x5376)
x24	
= **26.90445 Myr** (x2688=336x8)	x39
(1,548,288 x EM Beat Freq.)	**36.43305 Myr**

NOTES: 1) Using the Helmholtz formula for beat frequency (see, Fairbridge and Sanders, 1987), for planets, the commensurabilities for interplanetary lap rates of the Moon, are calculated as $C=L_t x L_a/(L_t-L_a)=17.37763$ yr, where L_t= principal tide cycle, L_a= apsides cycle of the Moon. This value is for AD 1950 data, and it is adjusted to 17.376902 to conform to our 10^6 yr long-term mean.

2) Milankovitch parameters have been calculated by Berger, by extrapolation of multiple terms that govern Earth-Moon motions. They have been worked out also independently by assuming that their long-term periods conform to the same principle as all planetary periods (see, Fairbridge and Sanders, 1987). In as much as the two fundamental lunar parameters (the nodal cycle of 18.03 yr and apsides cycle of 8.849 yr) develop a beat frequency of 256 x SSR or 0.0678785 (=17.376902 yr), then we are persuaded that the Milankovitch variables must have long-term means corresponding to the same Earth-Moon motions. Thus, all important solar and planetary cycles resonate with them (e.g. the 41,009.49 yr orbital tilt or ecliptic cycle, it is exactly commensurable with the 139.015 yr SJ/EV cycle times 295.000 (see Table above)

On a longer (geological scale) the impact of Earth's orbitals on the climate is quite well documented. (Berger, 1988; Xanthakis et al., 1995b). The relationship between the solar sunspot cycle (SSC) and solar quadrature development, with the Earth/Moon beat frequency (17.3769 yr), Saturn-Jupiter Lap, Uranus-Saturn Lap, the Fundamental Tones (resonances) up to 26.90445 Myr, and the Milankovitch parameters (mean insolation) up to 36.43305 Myr, is presented in Table 4.

The above planetary dynamics and earth-moon linkage, which relate to the Sun's orbit around the center of mass (barycenter), are new perspectives, which contribute to our understanding of the cyclic solar forcing functions on the Earth's climate and other terrestrial geophysical phenomena linked to climate change. (Fairbridge and Sanders, 1987; Liritzis and Galloway, 1995).

CONCLUSION

The 4190-yr varve record from Lake Saki (Crimea) has analysed as a total set on time intervals of decades and on four annually counted sub-sets, using different spectral methods applied both overall and to separate segments of the record. The obtained significant periodicities or quasi-periodicities are; ~2, ~5, ~7, 8-11, 14-16, 20-25, 44-46, 57-67, 120-130 and 200-250 years, as well as longer ones up to 1000 years.

Linkage is found for the periodic variation of lake Saki varve thickness with both the Berger and Loutre data on harmonics of the Earth-Moon Milankovich parameters, and with harmonics and resonances of (a) the major planets, (b) the proxy solar activity record disclosed by ^{14}C, the sun's spin rate, and sunspot numbers and (c) the long observations of geomagnetics and auroras. All the above clusters of periodic terms are strongly represented in the spectra of both palaeoclimatic and astronomic frequency series.

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