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ATTEMPT AT ANALYSIS OF HOLOCENE CLIMATE CYCLES ON THE BASIS OF LAKE SEDIMENTS

An attempt at reconstruction and forecast of climate changes (precipitation) in southern Poland was made on the basis of a time trend of sediment accumulation in mountainous lakes. Sedimentation of deposits in those lakes depends mainly on water inflow from precipitation. During intensive precipitation (rain and snow) sand flows to the lake along with water from the direct drainage area. In the core of sediments sampled from below the bottom of Lake Wielki Staw (the Karkonosze mountains), N = 604 parts seperated with a thin layer of sand were distinguished. Distances between the sand layers are probably negatively correlated to the sum (frequency) of precipitation. However, an alternative hypothesis may not be excluded that larger distances between sand layers correspond to more abundant precipitation. Intensive precipitation may facilitate sediment accumulation in the lake.

The distances y_1, ... y_N between sand layers occurring at the depth x_1, ... x_N show a sinusoidal variability, which can be described by the following equation:

$$y = a + b \sin\left(\frac{2\pi}{T}x + c\right)$$

where: T — period, b — amplitude, c — phase shift.

Sediment accumulation cycles (y distances) were determined from the condition of smallest squares, changing the sinusoid parameter (period) $T = 1$, 2, ..., 8000 mm. Local maximum values of the multiple correlation coefficient $R[y, y(x)]$, verified by the Fischer-Snedecor test (F) correspond to the sought periods of lake sediment accumulation.

The age of lake sediments, determined by the radioactive carbon method C^{14} at the depth 6.7—6.8 m is estimated at 5400 ± 90 years. (Hel. 1847); thus the trend of their accumulation $\frac{\partial x}{\partial t}$ equals 1.25 mm/year on the average.

The discovered periods of sediment accumulation T_j (mm), expressed in the long thermal cycles of time, were compared with long-term annual precipitation values in southern Poland (meteorological observatory, Wrocław 1859—1979) and the values of the Łaba runoff at the Děčin water-gauge (1851—1968) and the Wolf number (1700—1978), which is presented in Table 1.

Table 1

Cycles of lake sedimentation, runoff, precipitation and Sun activity

Lake sedimentation			Runoff		Precipitation	Wolf number
T (mm)	T (years)	F	T	F	T	T
4	3	4.45	5	5.89	5	11.1
18	14	3.02	10	2.77	10	45
44	35	3.17	15	9.87	16	56
61	49	4.65	22	2.69	30	95
87	70	2.90	30	1.52	42	180
172	138	3.06	47	2.14	73	—
225	180	3.50	101	2.80	—	—

Short cycles (distances between sand layers in the sediments of the lake estimated at 14, 35, 49 years) are similar to the Łaba runoff periods: 15, 30, 47 years. The arithmetic mean of two consecutive periods of sediment accumulation 70 and 138 years (104 years) is similar to the 101-year Łaba runoff cycle. The observed significant cycle of 70 years of lake sediment accumulation is close to a 73-year cycle of precipitation in Poland. Also the 180-year cycle of sediment accumulation is similar to a long precipitation period and equal to the period of Sun activity (180 years).

Accumulation of sediments in the high mountainous lake also shows changes in long cycles (Table 2). Some of the cycles do not differ much from periods of organic substances in sediments of another lake in central Poland, i.e. Lake Wikaryjskie near Płock (Boryczka, Wicik 1983).

Table 2

Long cycles distances between sand layers in sediments of the lake Wielki Staw (Karkonosze mountains)

T (mm)	T (years)	F
400	320	2,40
820	650	3,25
1300	1050	2,46
1700	1350	3,23
2220	1750	2,36
3300	2650	10,30
8000	6400	164,30

Time trend of sand accumulation in lake sediments was described by the following equation:

$$y=f(t)=a_o+\sum_{j=1}^{m} b_j \cdot \sin\left(\frac{2\pi}{T_j}t+c_j\right)$$

where T_j — discovered periods.

Amplitudes b_j and phase shifts c_j were received by minimalizing the square function $E[y-f(t)]^2$.

Changes in the distance between sand layers in sediments of lake are described by the following time trend:

$$\begin{aligned} y= & 1.675 \sin\left(\frac{2\pi}{18}x+1.859\right)+1.964 \sin\left(\frac{2\pi}{44}x-2.707\right)+ \\ & 1.568 \sin\left(\frac{2\pi}{61}x+1.664\right)+1.150 \sin\left(\frac{2\pi}{87}x+2.482\right)+ \\ & 1.858 \sin\left(\frac{2\pi}{225}x-2.826\right)+2.255 \sin\left(\frac{2\pi}{400}x-2.959\right)+ \\ & 1.327 \sin\left(\frac{2\pi}{820}x-1.037\right)+1.469 \sin\left(\frac{2\pi}{1300}x-1.703\right)+ \\ & 0.284 \sin\left(\frac{2\pi}{1700}x-1.811\right)+3.185 \sin\left(\frac{2\pi}{2200}x-1.525\right)+ \\ & 6.484 \sin\left(\frac{2\pi}{3300}x-0.389\right)+16.62 \sin\left(\frac{2\pi}{8000}x+0.925\right)+20.10 \end{aligned}$$

where 1 mm is the unit of sediment thickness (x).

Within the range $-1000 \leqslant x \leqslant 9000$ the curve in Figure 1 is the diagram of the time trend. It is composed of three parts:

6580 ÷ 9000 mm — reconstruction
0 ÷ 6580 mm — approximation
−1000 ÷ 0 mm — forecast

Accuracy of the trend $y=f(x)$ is quite high — the curve is well suited to the results of measurements. Differences between measured distances between sand layers and those calculated from the eqution are distributed similarly to the Gaussian distribution.

Range (mm)	number
< −29.01	2
−29.01 ÷ −19.34	9
−19.34 ÷ − 9.67	23
− 9.67 ÷ 0.0	326
0.0 ÷ 9.67	195
9.67 ÷ 19.34	31
19.34 ÷ 29.01	10
> 29.01	8

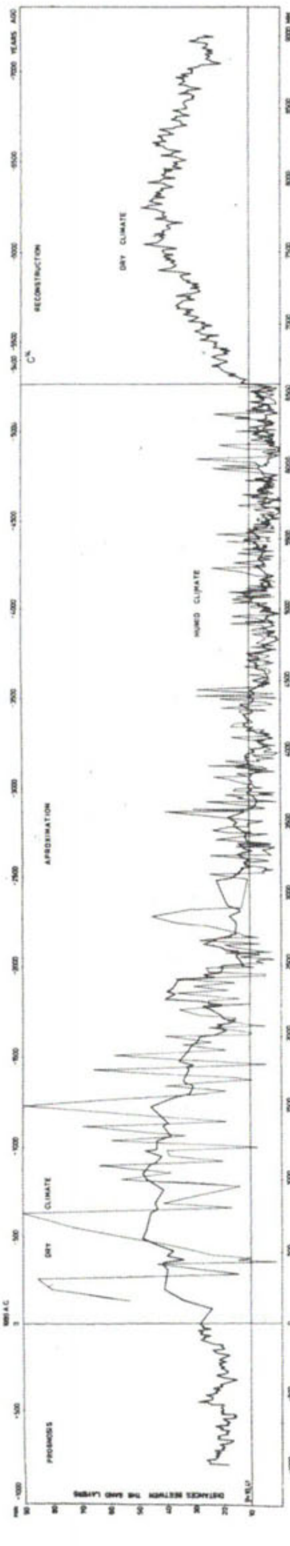

Fig. 1. Time trend of precipitation in southern Poland in Holocene of the basis of sedimentation in Lake Wielki Staw (the Karkonosze Mountains)

The square mean of the differences $y_i = f(x_i)$ is equal to 9.67 mm and the standard error is $\Delta = 9.88$ mm. The multiple correlation coefficient is $R = 0.703$ and the characteristics of the Fischer-Snedecor test is $F = 23.52$. The zero hypothesis $H(\mathrm{R}=0)$, is equivalent to $H(b_1 = ... = b_m = 0)$ is groundless at the level of significance of 1%.

Since the trend of sediment accumulation in the lake is $\frac{\partial x}{\partial t} = 1.25$ cm/10 years, the calendar time calculation t was introduced, assuming that in 1980 $t = 0$.

Assuming that the distance between sand layers in sediments of this lake is negatively correlated with the totals of precipitation, epochs were distinguished which differed with respect to climate humidity.

Crossing the graph of the trend function with a straight line $y = \bar{y} = 10.41$ mm ($\bar{y}$ — arithmetic mean), epochs of dry climate ($\bar{y} > 10.41$ mm) and humid climate ($\bar{y} < 10.41$ mm) were obtained:

years:

$-7500 \div -5300$ — dry climate (reconstruction)
$-5300 \div -3100$ — humid climate
$-3100 \div 0.0$ — dry climate
$0.0 \div 1000$ — dry climate (forecast)

The main minima of the trend curve occurred 4000, 4500, 4900 years ago. Thus a very humid climate occurred at the climate optimum — 4000 years ago. This is also the time of a maximum of organic matter in sediments of Lake Wikaryjskie (Boryczka, Wicik 1983).

For the next thousand years a dry climate should be expected ($y > \bar{y}$) and afterwards it could become more humid.

Since the residual of $y_i = f(x_i)$ has a distribution similar to normal with parameters 0. $\Delta = 9.88$ mm, the hypothetic trend is within the confidence range $f(x) \pm 3\Delta$ with probability of 99.7%

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