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PERIODICAL CHANGES OF PRECIPITATION IN POLAND AND THEIR CAUSES

The purpose of the paper was to determine periodical changes of precipitation in Poland, namely the amplitudes and the extremum values of cycles.

Chronological series of annual precipitation totals were analysed as recorded for: Warsaw (1813-1980), Giżycko (1838-1986), Cracow (1850-1987), Wrocław (1859-1980) and the mountain of Śnieżka (1885-1980).

The problem of periodical changes of precipitation in Poland was partly solved in the framework of M.A. theses prepared in the Division of Climatology of the University of Warsaw under the direction of J.Boryczka (Dębska 1986, Łopata 1990).

Harmonic components — consecutive elements of the Fourier series, resulting from the arbitrary breakdown of the length of chronological series into parts — $n, \frac{n}{2}, \frac{n}{3}, ...,$ (Kaczorowska 1962, Ewert 1984) do usually not coincide with the true periods of precipitation. On the other hand, spectral analysis (autocorrelational) has limited scope of applicability (periods shorter than $\frac{n}{2}$) .Longer periods are being determined with decreasing precision, i.e. on the basis of lower and lower numbers of measurement results. Thus, for instance, B.Brazdil and K.Kożuchowski (1986) discovered in Poland a short precipitation cycle of 3.4 years.

The method of consecutive sinusoids of regression is not subject to this kind of limitation of applicability (see Boryczka 1984):

$$P = a_o + b \cdot \sin\left(\frac{2\pi}{\Theta} t + c\right)$$

By changing the periods of the sinusoid $\Theta = 1,...,$ we obtain the series of amplitudes, $b = b_1, ..., b_n$ — i.e. the so-called spectrum of oscillations, optimal in the statistical sense (in the sense of the least squares).

True periods, Θ , are the local maxima of the spectrum of oscillations (these are the maxima of the multiple correlation coefficient values).

The true periods of precipitation in Warsaw, Giżycko, Cracow, Wrocław and on the Śnieżka (together with amplitudes *b* and phase delays *c*) are presented in Table 1.

Table 1

Cycles of annual precipitation totals in Poland

Warsaw (1813-1980)				Giżycko (1838-1986)				Cracow (1850-1987)				Wrocław (1859-1980)				Śnieżka (1885-1980)			
Θ	*b*	*c*	F	Θ	*b*	*c*	F	Θ	*b*	*c*	F	Θ	*b*	*c*	F	Θ	*b*	*c*	F
6	28	-2.53	2.5	8	25	2.19	1.5	12	29	-0.37	2.3	5	34	-1.60	3.4	5	96	-0.30	3.0
12	22	-1.64	1.6	13	29	-0.20	2.1	14	34	0.26	3.3	10	36	1.89	3.9	10	110	0.09	4.0
16	36	-1.10	4.1	19	25	-1.14	1.5	23	31	1.28	2.7	16	29	1.57	2.4	14	75	1.53	1.8
19	32	0.92	3.2	28	36	-0.78	3.2	30	54	2.38	8.5	30	25	2.53	1.8	21	79	-2.56	1.9
58	31	-2.93	3.1	46	46	0.88	5.8	63	45	2.61	5.3	42	35	2.74	3.8	38	101	1.99	3.2
112	30	-0.86	2.7	126	18	2.54	0.7					73	33	2.86	2.8	46	48	-3.05	0.7

Verification of the periods determined was performed through application of the Fisher-Snedecor test (F) of 2 and n-3 degrees of fredom. Critical values of the test F at the significance level of 0.05 and 0.10 are 3.1 and 2.4 (the calculated values of Fisher-Snedecor characteristics are also given in Table 1).

It is interesting to note that precipitation in the localities of Western Poland: Śnieżka (1885-1980) and Wrocław (1859-1980), is subject to the most important oscillations in the 10-year period. Equations of the regresion sinusoids, describing these cycles, are as follows:

$$P = 1256 + 110.10 \cdot \sin\left(\frac{2\pi}{10}t + 0.094\right) \qquad [\text{Śnieżka}]$$

$$P = 538.6 + 35.83 \cdot \sin\left(\frac{2\pi}{11}t + 1.894\right) \qquad [\text{Wrocław}]$$

Amplitudes of changes (Śnieżka= $2b = 220 \cdot 10^{-3}$ m, Wrocław: $2b = 72 \cdot 10^{-3}$ m) are significant at the confidence level of 95%, since the values calculated, i.e. F = 3.99 and F = 3.86 are bigger than the critical value of 3.1.

10-year precipitation cycles on Śnieżka and in Wrocław are synchronous with the 11-year cycle of solar activity. Maxima of these sinusoids coincide with the years of maxima of solar activity:

Solar activity	— 1907	1917	1928	1937	1947	1957	1968	1979
Śnieżka (*P*)	— 1906	1916	1926	1936	1946	1956	1966	1976
Wrocław (*P*)	— 1907	1917	1927	1937	1947	1957	1967	1977

It should be noticed, that the time interval between the subsequent maxima of solar activity in the 20th centrury was usually equal to 10 years, and sometimes even only to 9 years. On the other hand, in the first half of the 19th century this interval was longer, amounting to 13 or even 14 years (e.g. 1817-1830, i.e. 14 years, 1871-1883, i.e. 13 years).

This irregular rhythm of solar activity provides a partial explanation for the longer precipitation cycles in Warsaw (12 years), in Giżycko (13 years) and in Cracow (12 years), obtained on the basis of chronological series dating back to the beginning of the 19th century.

The ranges of oscillations in Warsaw and in Cracow for the 12-year cycles were, respectively, $44 \cdot 10^{-3}$ m and $66 \cdot 10^{-3}$ m, the appropriate sinusoids being expressed as:

$$P = 509.2 + 22.38 \cdot \sin\left(\frac{2\pi}{12}t - 1.637\right) \qquad F=1.55$$

$$P = 575.9 + 29.05 \cdot \sin\left(\frac{2\pi}{12}t - 0.366\right) \qquad F=2.32$$

The two series of cycles are synchronous i.e. their minima occur int the same years:

Warsaw	— 1800	1812	1824	...
Cracow	— 1799	1811	1823	...

At the beginning of the 19th centrury these dates correspond to minima of solar activity, while at the beginning of the 20th century — to the maxima.

It is also worth-while noting that there is a cycle of precipitation of some 30 years of length: in Cracow — 30 years, in Wrocław — 30 years, in Giżycko — 28 years. The greatest amplitude of changes, $2b + 108 \cdot 10^{-3}$ m, is observed for the 30-year cycle in Cracow:

$$P = 680.0 + 53.88 \cdot \sin\left(\frac{2\pi}{30}t + 2.382\right)$$

which is significant at the confidence level of 99% (F = 8.45).

Solar activity (W, 1749-1980), as well as eastern circulation (C_E) and western circulation (C_W, 1891-1976), are also subject to the 30-year periodical oscillations (see Boryczka et al. 1990):

$$W = 50.29 + 5.90 \cdot \sin\left(\frac{2\pi}{28}t - 0.043\right) \qquad F=1.25$$

$$C_E = 145.6 + 19.80 \cdot \sin\left(\frac{2\pi}{30}t - 2.156\right) \qquad F=4.92$$

$$C_W = 123.2 + 18.08 \cdot \sin\left(\frac{2\pi}{31}t - 1.304\right) \qquad F=5.38.$$

There is a correlation of dates of appearance of precipitation maxima in Cracow, of maxima of eastern circulation (C_E), of minima of solar activity and of minima of western circulation in the 20th centrury, in the 35-year cycle:

Solar activity	Circulation		Precipitation
W_{min}	$(C_E)_{max}$	$(C_W)_{min}$	P_{max}
1909	1908	1907	1905
1937	1938	1938	1935
1965	1968	1968	1965
1993	1998	2000	1995
2021	2028	2031	2025

There is also a synchronicity of the following cycles: precipitation in Cracow - 63 years, and in Warsaw — 58 years, solar activity — 59 years, as well as meridional circulation (C) — 61 years:

$$W = 50.17 + 12.80 \cdot \sin\left(\frac{2\pi}{59}t - 1.901\right) \qquad F=6.03$$

$$C = 95.09 + 19.68 \cdot \sin\left(\frac{2\pi}{61}t - 1.525\right) \qquad F=14.72$$

$$P = 676.9 + 44.57 \cdot \sin\left(\frac{2\pi}{63}t - 0.607\right) \qquad F=5.27$$

$$P = 569.3 + 30.86 \cdot \sin\left(\frac{2\pi}{58}t - 2.930\right) \qquad F=3.10$$

Precipitation maxima in Cracow in this cycle occur more or less simultaneosly with the maxima of solar activity:

Solar activity	— 1781	1840	1899	1958	2017
Precipitation in Cracow	— 1776	1839	1902	1965	2028

Two secular cycles were also determined with periodicity of more than 100 years — of precipitation in Warsaw (112 years) and in Giżycko (126 years):

$$P = 565.0 + 30.00 \cdot \sin\left(\frac{2\pi}{112}t - 0.861\right) \qquad F=2.68$$

$$P = 578.2 + 17.92 \cdot \sin\left(\frac{2\pi}{126}t - 2.541\right) \qquad F=0.68$$

Only the first of these two cyclical processes is significant at the level of 10%.

Secular minima of precipitation in Warsaw in the 112-year cycle occur during the secular minima of solar activity occurring in the 91-year cycle:

$$W = 48.09 + 18.84 \cdot \sin\left(\frac{2\pi}{91}t - 0.012\right)$$

which is significant at the confidence level of 99% (F = 13.36).

The dates of minima of the secular cycles of precipitation and solar activity are as follows: Wolf numbers - 1816, 1907, 1998,..., precipitation in Cracow - 1799, 1911, 2023,...

The results of the studies and calculations performed indicate that solar activity influences periodical changes of precipitation in Poland through the intermediary of atmospheric circulation, and that this is true for 11-year, 30-year, 60-year and secular cycles.

Analogous periodicity can also be found for the intensity of flows of Polish rivers and for lake retention (Gutry-Korycka, Boryczka 1989).

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