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CYCLIC TEMPERATURE AND PRECIPITATION FLUCTUATIONS IN POLAND IN THE 19th-21st CENTURIES

Abstract: The objective of the work is to determine the periodicity and trends of change in air temperature and precipitation in Poland in the time period of the 18th-20th centuries, together with the forecast for the 21st century. There are interesting diagrams of the temporal changes of solar activity and North Atlantic Oscillation (NAO) indicator, with the forecast reaching the year 2100. The forecasts were obtained on the basis of interpretations of the Wolf number and NAO indicator cycles, determined with the method of "regression sinusoids". The fluctuations of the air temperature and precipitations during winter in Warsaw and in Cracow are closely correlated.

Key words: air temperature, precipitations, NAO, spectra, periods, tendency, solar activity, forecast.

The aim of the study is to determine the range of temperature and precipitation fluctuations in Warsaw and Cracow (Cracow) in the last two centuries. The paper also demonstrates the synchronicity of cyclic climate fluctuations in Poland, using these cities as the example, and provides a forecast concerning the likely changes in temperature and precipitation in the 21st century.

The research on long measurement sequences indicates that in Warsaw, as in other Polish cities (Cracow 1826-1990), Wrocław 1851-1980) and Europe (England 1659-1773, Prague 1771-1980, Geneva 1826-1990, Zurich 1864-1980, Potsdam 1893-1992), several temperature cycles with significant amplitudes can be observed. These are the 3-5, 7-8, 10-13 and 73-113 year cycles, and the planetary cycle lasting 178.9 years [1,2,9,15,16].

Their presence in nearly all chronological sequences (monthly and seasonal values) is a proof that this cyclicity represents a feature of the temperature fields in Poland and Europe.

The spectrums and cycles of temperature, precipitation, NAO index and solar activity were determined using the "regression sinusoid":

$$y = f(t) = a_0 + b\sin(2\pi\, t/\Theta + c)$$

where: Θ – period, b – amplitude, c – phase displacement, t – period, and the sinusoid period Θ changing every 0.1 year.

The sequence of the values of residual variance ε^2, corresponding to the presumed cycles Θ – is the spectrum of y variable, whereas periods Θ are the local minima of the residual variance ε^2

SYNCHRONICITY OF CYCLES OF TEMPERATURE, PRECIPITATION, ATMOSPHERIC CIRCULATION AND SOLAR ACTIVITY IN POLAND

An important issue in the contemporary studies of climate changes is the identification of actual, natural climatic, astronomic and geological periods. A similar periodicity of 'effects' and alleged 'causes' allows identifying the natural factors which, along with the random element (atmospheric circulation) are responsible for the main cooling and warming phases of the Earth's climate.

Time sequences of temperature in Europe are characterised by a close-to-4-year periodicity, with the range of changes $\Delta T = 2b$:

Table 1.

The close-to-4-year cycles of air temperature in Europe

	Winter		Spring		Summer		Autumn		Year	
	Θ	ΔT	Θ	ΔT	Θ	ΔT	Θ	ΔT	Θ	ΔT
Warsaw	3.5	1.18	4.0	0.75	3.9	0.78	4.7	0.66	4.7	0.51
Cracow	3.3	0.28	4.0	0.32	3.9	0.50	4.1	0.34	4.5	0.25
Prague	3.5	1.21	4.4	0.55	3.9	0.61	4.7	0.66	4.7	0.41
Geneva	3.8	0.65	3.9	0.48	3.9	0.53	3.7	0.47	3.9	0.29
England	3.8	0.48	3.7	0.29	3.1	0.36	4.3	0.29	5.2	0.21

A similar 3.0-4.8 year periodicity can be observed in seasonal and annual sums of precipitation:

Table 2.

The close-to-4-year cycles of precipitation in Poland

	Winter		Spring		Summer		Autumn		Year	
	Θ	ΔP	Θ	ΔP	Θ	ΔP	Θ	ΔP	Θ	ΔP
Warsaw	4.8	21.0	3.6	25.0	3.4	40.0	2.6	21.8	3.6	68.6
Cracow	4.0	16.4	3.5	35.0	2.9	54.8	3.4	36.4	3.4	61.2
Wrocław	3.5	15.8	3.0	24.0	3.2	38.0	3.7	27.4	3.3	65.6

The range of changes as compared to seasonal sums e.g. in Warsaw is: winter – $P = 98$ mm, $\Delta P/P = 21.4\%$, summer – $P = 216$ mm, $\Delta P/P = 11.6\%$.

Atmospheric circulation shows a similar periodicity: E macrotype, longitudinal (according to the classification proposed by Wangenheim-Girs, 1891-1776) and cyclonal (according to Osuchowska Klein, 1901-1975).

A similar 3.1 and 5.5-year periodicity with an amplitude of $\Delta h = 2.2$ and 2.9 cm can be observed in the time sequences of the average Baltic Sea level, whereas the 3.1-year cycle of the maximum annual levels has the highest amplitude Δh_{max} = 12.6 cm.

It should be said at this point that these close-to-4-year cycles are probably due to the strongest, 4.0-year period (R = 0.37) of the Earth's planetary tidal forces in the years 1700-2000, which are combined with much stronger tidal forces of the Moon and the Sun.

In Europe (and Poland), the close-to-8-year cycles of air temperature with high amplitudes $\Delta T = T_{max} - T_{min}$ prevail:

Table 3.

The close-to-8-year cycles of air temperature in Europe

	Winter		Spring		Summer		Autumn		Year	
	Θ	ΔT	Θ	ΔT	Θ	ΔT	Θ	ΔT	Θ	ΔT
Warsaw	8.3	1.52	7.8	0.81	7.1	0.57	6.5	0.62	7.7	0.59
Cracow	8.3	1.50	7.9	0.42	7.8	0.30	7.9	0.30	8.3	0.46
Prague	7.7	1.23	6.9	0.71	8.4	0.45	7.5	0.43	7.8	0.48
Geneva	8.5	0.68	7.8	0.53	7.8	0.41	6.8	0.47	7.4	0.40
England	7.7	0.49	6.9	0.31	8.3	0.29	7.3	0.36	7.4	0.26

In Warsaw, the range of temperature fluctuations in winter in the 8.3-year cycle is ΔT = 1.5°C, and the annual mean (7.7-year period) – 0.6°C.

The 7.7-8.3-year temperature cycles in Europe (in winter) are influenced mainly by a similar, 7.4-year cyclicity of cyclonal types (R = 0.41) and 7.8-year cyclicity in case of longitudinal circulation (R = 0.32).

In the time sequences of Wolf numbers in the years 1748-1993 and 1700-1993, 8.1-year and 8.5-year periods were observed, with the amplitudes $\Delta W = 2b$ = 21.2 and 23.5, whereas the DVI (Dust Veil Index) value had a period of 7.9 years.

The period with the same length was identified in the variability of the Solar System parameters in the years 1700-2000: the Sun's acceleration of 7.8 years, and the planetary tidal forces on the Sun.

The 8.84-year cycles of the period of revolution of the perigee-apogee lines on the Moon's orbit can have a major influence on atmospheric circulation. The horizontal component of the resultant of the Moon's and Sun's forces is significant and is probably the cause of the close-to-8-year cyclicity of atmospheric circulation.

The close-to-8-year cycle of temperature (atmospheric circulation) is the prevalent one in summer because the effects of the planetary tidal forces on the Sun overlap (due to the fluctuations in solar activity – the solar constant) with much stronger tidal forces of the Moon and the Sun.

Little is known about the tides of the Earth's atmosphere, owing to the complicated movement of the Moon (its variable orbit). The vertical component of the tidal forces of the Moon and the Sun is small as compared to gravitational acceleration and can lead to minute changes in the atmospheric depth (stretching). On the other hand, the horizontal component operating for a longer period has probably an important role to play in the circulation of oceanic waters (sea currents, including El Niño) and high and low pressure movements (Boryczka 1998).

The close-to-11-year cycles of temperature, associated with the 11-year sunspot cycle were identified long ago. The 10-15-year temperature periods and amplitudes (in °C) in selected cities, by seasons and for a given year, are shown below:

Table 4.

The close-to-11-year cycles of air temperature in Europe

	Winter		Spring		Summer		Autumn		Year	
	Θ	ΔT	Θ	ΔT	Θ	ΔT	Θ	ΔT	Θ	ΔT
Warsaw	11.9	0.5	11.2	0.7	11.3	0.3	11.4	0.2	11.1	0.3
Cracow	11.3	0.7	11.2	0.7	11.4	0.3	10.8	1.0	11.3	0.3
Prague	11.8	0.5	11.2	0.6	11.7	0.2	11.1	0.2	11.4	0.2
Geneva	11.1	0.4	11.2	0.4	11.3	0.4	11.2	0.1	11.1	0.2
England	11.2	0.5	11.1	0.2	11.1	0.2	11.2	0.2	11.1	0.2

In this cycle, the range of temperature fluctuations is normally two times higher in winter (0.4-1.0°C) than in summer (0.1-0.4°C).

It was revealed that the close-to-11-year periodicity of seasonal sums of precipitation in Poland is also statistically significant:

Table 5.

The close-to-11-year cycles of precipitation in Poland

	Winter		Spring		Summer		Autumn		Year	
	Θ	%	Θ	%	Θ	%	Θ	%	Θ	%
Warsaw	10.1	25.9	12.0	23.7	11.2	13.8	10.2	10.6	11.3	9.5
Cracow	9.8	12.3	10.2	18.7	10.3	12.9	10.9	17.1	9.8	5.4
Wrocław	9.9	17.4	10.2	27.4	9.7	16.7	9.9	13.2	9.8	13.9

The range of fluctuations in the seasonal sum of precipitation in the 9.8-12.0-year cycles as compared to the average values for the years 1861-1990 (P) is wider in winter than in the summer (and exceeds ¼ of the P sum). The relative amplitudes $(P_{max} - P_{min})P^{-1}$ are as a rule higher in winter than in the summer, and their annual sums remain within the 5.4-13.9% range.

The close-to-11-year periods of temperature and precipitation are undoubtedly caused by the 11-year cycle of solar activity (and of the solar constant):

Table 6.

The close-to-11-year cycles of Wolf numbers and solar constant

Wolf numbers		Solar constant	
Θ	ΔW	Θ	$\Delta s/s$ %
10.0	48.3	10.1	0.35
0.51	44.7	10.5	
11.0	60.1	11.1	0.94
12.0	32.2	11.9	0.29

The equation for the 11-year cycle (average for the years 1700-1993) of the solar constant with a minimum residual variation $\varepsilon^2 = 7.1 \cdot 10^{-5}$ and the correlation coefficient R = 0.609 is the following:

$$s = 1.9435+0.009163\sin(2\pi t/11.1-1.9549)$$

The range of changes in the solar constant in the 11-year cycle accounted for nearly 1% of the average value 1.94 $\mathrm{cal \cdot cm^{-2} \cdot min^{-1}}$ in the years 1700-1993. In individual 11-year sunspot cycles, the solar constant does not increase by more than 2.5% [10]. The 9-14-year cyclicity of the solar activity is probably linked with the revolution periods of the four largest planets around the Sun. The 11.86-year cycle of Jupiter's revolution prevails in the time sequences: of the resultant of the planets' gravitational impact on the Sun (11.8 years, R = 0.40), the total moment of momentum of planets (11.9 years, R = 0.75) and dispersion of the mass of planets in the Solar System (11.9 years, R = 0.58).

It should also be emphasised that the close-to-11-year periodicity is present in the time sequences (1680-1980) of volcanic eruptions, DVI value (log DVI) – Θ = 11.4 years, R = 0.31; volcanic activity (log $DVI/\Delta t$) Θ = 11.7 years, R = 0.29 and the time span Δt between consecutive explosive eruptions Θ = 12.1, R = 0.21.

A similar periodicity of geological, astronomical and climatological variables indicates that periodicity is linked with gravitation.

INFLUENCE OF THE NORTH ATLANTIC OSCILLATION (NAO) ON THE CLIMATE OF WARSAW AND CRACOW

The climate of Central Europe (including Poland) is mainly influenced by two main centres of atmospheric pressure: the Azorean High and the Icelandic Low. These two pressure areas, associated with the differences in the temperature of water in the North Atlantic Ocean and that of the land, are negatively correlated. This means that if the pressure in the Azorean High increases, the pressure in the Icelandic Low will fall, and vice versa. This phenomenon is known as the North Atlantic Oscillation – NAO.

With a high longitudinal pressure difference, that is a high northward pressure gradient, the air from the Atlantic moves along the parallels from the west eastwards, to Poland. During a low pressure period in the Azorean High (and the accompanying pressure increase in the Icelandic Low), the horizontal pressure gradient can be oriented eastwards or westwards. Then, the air moves along the meridians (longitudinal circulation) southwards or northwards, which means that the air coming to Poland moves in from either of these directions.

The direction and velocity of the air movement is an effect of balancing out between the force of the pressure gradient, the Coriolis effect and the centrifugal force (and the force of surface friction and the turbulence viscosity near the Earth's surface). At higher altitudes, the direction of the gradient wind is distorted by the air temperature field, with the horizontal gradient oriented towards the North Pole – by the so-called thermal wind (which also blows from the west to the east).

During the research, the NAO index was used. It was defined by Phil Jones et al. as a standardised pressure difference at the sea level between Gibraltar and south-west Iceland.

In the NAO index spectrums for the years 1825-1997, the following periods Θ (*R* – correlation coefficient) are present:

Table 7.

The periods of the North Atlantic Oscillation (NAO index) in 1825-1997.

Spring		Summer		Autumn		Winter	
Θ	*R*	Θ	*R*	Θ	*R*	Θ	*R*
6.5	0.22	7.8	0.17	7.3	0.22	7.8	0.27
11.1	0.13	10.3	0.20	8.8	0.17	8.3	0.24
13.4	0.21	11.1	0.09	16.6	0.24	11.3	0.13
23.9	0.19	13.8	0.14	24.2	0.20	15.5	0.17
45.5	0.16	39.5	0.14	29.9	0.20	37.1	0.16
106.3	0.09	83.2	0.17	75.3	0.16	105.1	0.7

In the NAO index spectrum for winter, similarly to the spectrums of temperature in Warsaw (1779-1998) and Cracow (1826-1995), the close-to-8-year cycle prevails. This is also the solar activity cycle (8.1) years and the solar acceleration cycle (7.75 years).The maxima of these close-to-8-year cycles fall, approximately speaking, for the same years.

CLIMATE CHANGES FORECASTS FOR WARSAW AND CRACOW IN THE 21ST CENTURY

One of the important issues in the studies of climate changes and their causes is to identify synchronous cycles for air temperature, precipitation and zonal circulation (the NAO index), which determine the advection of air masses from the Atlantic Ocean. Cycles are determinist components in measurement series, which allow forecasting of climatic changes in the coming years.

As yet, the mechanisms of the advection of changes in the Solar System to the Earth-atmosphere system are not known (other than the solar constant). However, the detected periodicity of climatological variables, including the close-to-100 and close-to-200 cycles, can be used to reconstruct the climate in the recent centuries and to forecast the climate for the 21st century.

The graphs of temporal changes for solar activity (Wolf numbers, Fig. 1) and the NAO index (Fig. 2) are quite interesting, so as the forecasts until

2100. The reconstructions and forecasts were obtained on the basis of the interferences of the cycles observed: Wolf numbers and the NAO index:

$$y = a_o + \sum b_j \sin(2\pi t/\Theta_j + c_j),$$

where: Θ_j, b_j, c_j – are parameters of statistically significant cycles (at the relevance level of 0.05).

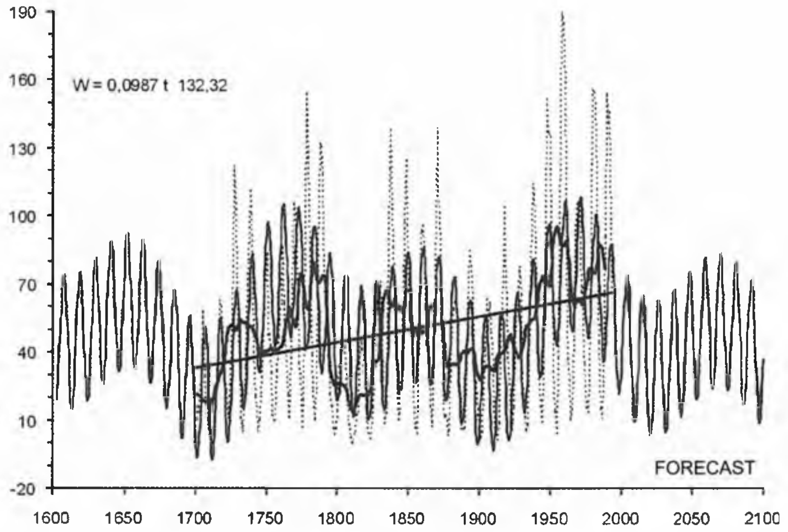

Fig. 1. Changes of Wolf numbers in the years 1600-2100 as per interferences of cycles (bold line – observed values)

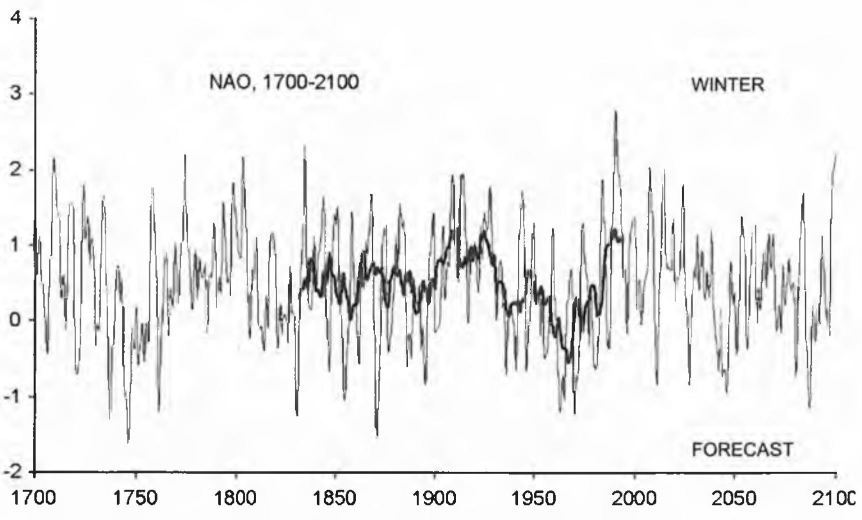

Fig. 2. Changes of Wolf numbers in the years 1700-2100 as per interferences of cycles (bold line – observed values)

The temperature forecasts for winter in Warsaw and Cracow were made using a similar approach (Fig. 3), which was also applied to forecast the winter sums of precipitation in Warsaw and Cracow (Fig. 4)

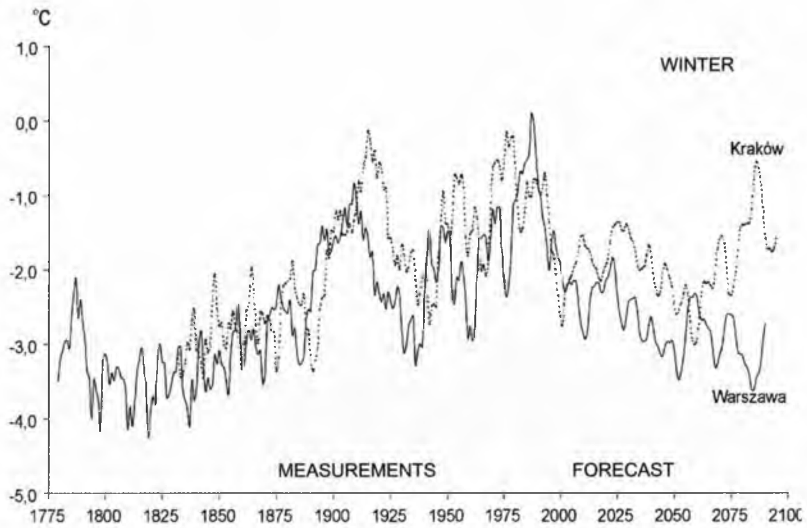

Fig. 3. Changes of air temperature in Warsaw and Cracow. Forecast until 2075 (as per interferences) – winter

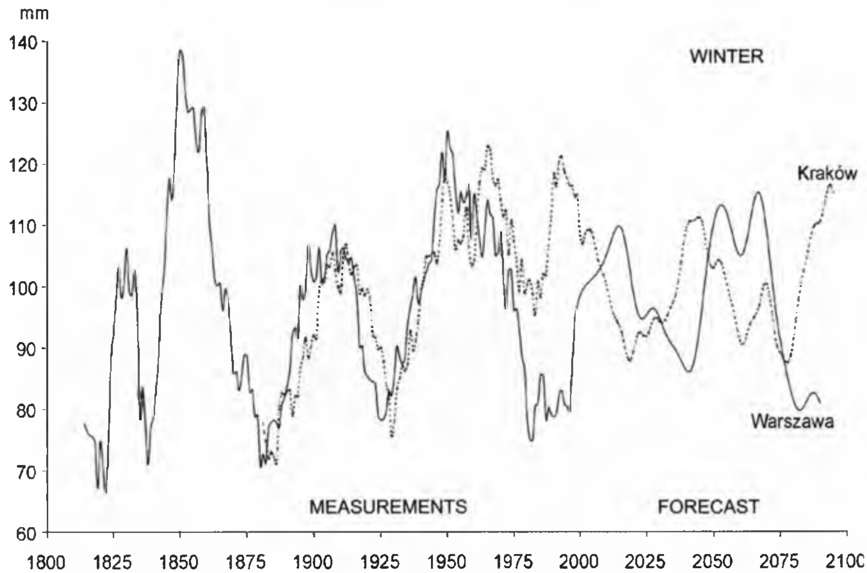

Fig. 4. Changes of winter precipitation sums in Warsaw and Cracow. Forecast until 2075 (as per interferences)

The forecasts were based on the assumption that the extrema of the observed cycles with relatively high (significant) amplitudes will be repeated in a similar way as in the 18th-20th centuries. The 178.9-year planetary cycle provides a strong premise for such an assumption. After a lapse of 178.9 years, the values of the Solar System parameters are repeated (the distance of the centre of mass in the Solar System, solar acceleration, the resultant of the planets' gravities). After a lapse of 179 years, the graphs showing the changes of Wolf numbers (and the solar constant) in the years 1700-1879 and 1880-2000 are almost wholly congruent. The time span between the absolute maxima of Wolf numbers (1778, 1957) is 179 years, which approximately represents periodicity in the mathematical sense $f(t + 178.9) = f(t)$.

The time sequence of Wolf numbers in the years 1700-2100 (with the main maxima in 1778 and 1957) can be obtained if we take into account the moments of mass of the four largest planers (Jupiter, Saturn, Uranus, Neptune) – the modulation of the moments of mass of the closer planets by the further ones.

It can be assumed that solar activity (solar constant) is influenced by the gravitational fields of these planets.

The close-to-180-year cycle is present in the longest measurement series of temperature and precipitation.

The 180-year cycle is repeated many times in the chronological sequences of the paleotemperature of lake deposits dating back about a dozen thousand years.

The NAO index forecast for winters in the 21st century was obtained on the basis of the predefined periods in the years 1826-1997: 2.4; 5.0; 5.8; 7.8; 8.3; 15.5; 21.5; 37.1; 71.5; 105.1 years. The overlapping of these cycles indicates that during the winters of 2001-2100 the NAO index is very likely to fall. This means that zonal circulation is expected to be reduced, resulting in a weaker warming impact of the Atlantic Ocean on the climate of Europe (and Poland) in winter. The NAO index forecasts for the 21st point to the forthcoming, natural cooling of Europe's climate.

What can be seen as a meaningful finding of this research is the logical consistency of the falling trends forecasted for the 21st century: solar activity (solar constant), NAO index, which determines the severity or mildness of winters in Poland, and the forecast for air temperature alone (cooling in the 21st century).

The coldest winters in Warsaw and Cracow (average consecutive 11-year values of temperature reaching about -4°C) can be expected around 2050, and will be slightly milder than in the early 19th century, owing to a growing role of anthropogenic factors. At the same time, colder summers (with the average consecutive 11-year values of temperature reaching about 17.5-18.0°C) are expected to occur earlier, in the second decade of the century.

During the first half of the 21st century, the sums of winter precipitation in Warsaw and Cracow are likely to oscillate around the century's average.

In summer, the precipitation sums in Warsaw will approximate the average sums, and will significantly exceed these in Cracow.

The forecasting methods were also verified using a short, 30-year measurement series in Zamość in the years 1951-1980 (Stopa-Boryczka, Boryczka 1998). The extrapolated values of the time sequence – the resultant of the 3.25; 7.75; 12.6-year cycles in the years 1981-1990 (beyond the approximation range 1951-1980) – are similar to the results of temperature measurements in the decade 1981-1990. What attracts particular attention is the synchronicity of the extremes of the relatively stable air temperature in Zamość with the minima and maxima of solar activity in the 11-year cycles. The maxima of air temperature fall for the years of the sunspot maxima: 1957, 1968, 1979, 1989.

In Europe, the time sequences for air temperature in the recent centuries indicate that the contemporarily observed climate warming can largely be caused by natural reasons. In this context, the nearly wholly congruent regression lines for standardised values of solar activity and air temperature in Warsaw in the years 1779-2000 are also of some importance: $W' = 0.0037t - 6.956$, $T' = 0.0047t - 8.940$ (Fig. 5).

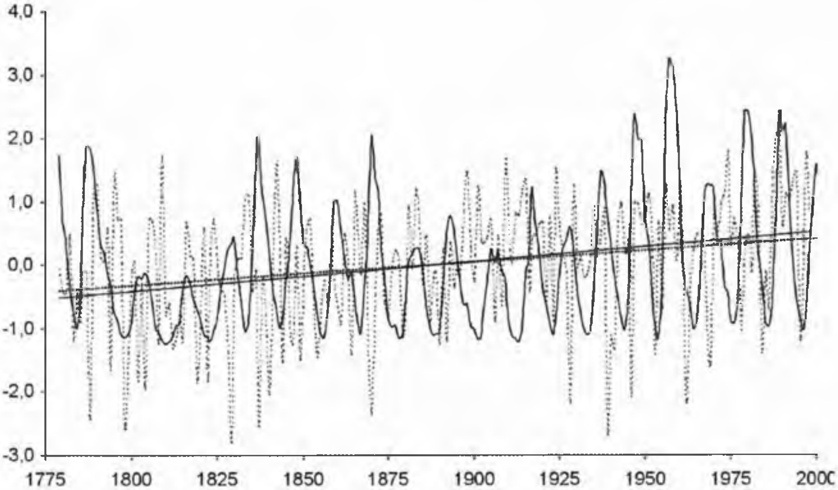

Fig. 5. Congenial regression lines for straights of Wolf numbers and air temperature in Warsaw in the years 1779-2000 (of the standardised annual average values)

The observable growing trend in the air temperature, mostly in winter, is simply the result of an overlapping of the natural cycles. For instance, the more and more warmer winters in Warsaw – by 1.03°C/100 years in the years 1779-1990 – result from an overlapping of several cycles: 3.5; 5.5; 8.3; 12.9; 18.0; 38.3; 66.7; 113.1; and 218.3 years. Their resultant (regression line) can explain a temperature increase during the winter by 0.93°C/100 years, while the anthropogenic variable accounts for a mere 0.1°C/100 years. Similarly, warmer and warmer winters in Geneva (0.05°C/100 years), Prague (0.25°C/100 years) are due to an overlapping of cyclical temperature fluctuations.

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