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# AIR TEMPERATURE VARIABILITY IN POLAND IN THE YEARS 1951-1990

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**Abstract:** The paper concerns the problem of spatial (geographic) differentiation of air temperature variability (the cyclical components and the trends) within the area of Poland in the years 1951-1990, and the conditioning of this differentiation. It was established, on the basis of 58 chronological temperature series, that there exist a couple of cyclical components (of approximately 2, 3, 6, 8, 10, 14, and 16 years of periodicity), featuring a significant scope of fluctuations, which can be deemed a property of temperature field in Poland. The synchronicity (coincidence of periods and extremes) of the approximately 8- and 11-year periodicity components of temperature change and the fluctuations of solar activity may constitute an evidence for the solar source of conditioning of the changes. The direct cause of the short-term variability of temperature field in Poland is constituted by the respective atmospheric circulation cycles. The superposition of the cycles identified explains only a part of temperature trend represented by a linear regression equation.

**Key words:** air temperature, short-term variability, trends, Poland.

The purpose of the present report is to determine the spatial differentiation of temporal changes in air temperature within the area of Poland and their conditioning. The analysis was applied to the periodicity and to the trend of changes of the climate element studied. The notion of periodicity, conform to the indications of the WMO (*Climatic change*, 1996), is understood as denoting the rhythmic changes of temperature, characterized by the constancy of time intervals between the consecutive maxima and minima. The trend was defined as the linear dependence on time.

The numerous studies were carried out in search of cyclicity, both in the course of particular meteorological elements and in the general changes of climate. They indicate the existence of many differing periods, sometimes characteristic for the relatively limited areas, sometimes proper for the whole zones of the Earth or the globe as such. The commonly accepted are the daily and annual cycles, brought about by the revolution of the Earth, and its circular motion around the Sun. Identification and physical explanation of the causes of longer periods (cycles) belongs to the issues debated until now.

The cyclicity of air temperature has until now been studied most frequently in individual locations of Poland (and Europe), as a rule through the measurement series of different lengths, analysed with various methods, and limited usually to the same periods of time. This made it impossible to give the answer to the question whether the temperature field in Poland is uniform in terms of cyclical changes. The dispersion of periods, amplitudes, and dates of extremes of the cycles identified, have not been known, nor whether these are synchronous. The question has until now been comprehensively treated only in the case of the annual cycle (see, e.g., Ewert, 1979).

The thermal conditions of the area of Poland were described with the chronological series of monthly averages of air temperature values from 58 weather stations of the Institute of Meteorology and Water Economy (IMGW) for the period 1951-1990. Out of these, the series of seasonal and annual average temperatures were established.

Atmospheric circulation for this period (1951-1990) was characterized by the analogous time series of the frequency (day number) of the macrotypes of zonal circulation: western [W] and eastern [E], as well as southern [S], of the air masses flowing over Poland (according to the classification of Osuchowska-Klein, 1978, 1991). Likewise, the pressure settings - cyclonic and anticyclonic, as well as the types of circulation (A, CB, D, $C_2D$, $E_0$, E, $E_1$) were distinguished. By using the symbols indicating the direction of advection (N, S, E, W), and the nature of the pressure setting in a given circulation type (a - anticyclonic, c - cyclonic), the notation adopted by the author of the classification mentioned can be written down as follows: A - Wc, CB - NWc, D - SWc, $C_2D$ - Wa, $E_0$ - NEc+Ec, E - NEa, $E_1$ - SEa+Ea. Statistical analysis was also applied to the chronological series of the seasonal and annual values of the NAO (North Atlantic Oscillation) indicator (Jones, Jonsson, Wheeler, 1997). The data were acquired through the computer network. Likewise, the cyclical components were determined for the course of the Wolf number values, characterizing solar activity (Boryczka et al., 1997).

The parameters of the particular cycles: periods $\Theta$, amplitudes $b$ and phases $c$ were determined with the method of J.Boryczka (Boryczka, 1993; Boryczka et al., 1992) of the "regression sinusoids"

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

The method consists in the approximation of the chronological series (in terms of least squares) of measurement results $y_1, y_2, \ldots, y_n$, obtained in the time instances $t_1, t_2, \ldots, t_n$, with the consecutive regression sinusoids. By changing the period of sinusoids with the step of $\Delta\Theta = 0.1$ (or $\Delta\Theta = 1/12$ of the year) the series of the rest variance $\varepsilon^2$, of the correlation coefficient $R$, and of the cycle parameters $\Theta$, $b$, and $c$ were obtained. The periods shown in the tables are the local minima of the rest variance (local maxima of correlation coefficient). The sequences of amplitudes *b* characterize the scopes of oscillations of the variable analysed in particular cycles.

The cycles were verified with the Fisher-Snedecor test at the significance levels of 0.05 and 0.10 ($\alpha = 0.05$, $R^{kr} = 0.39$; $\alpha = 0.10$, $R_{kr} = 0.34$). The periods determined with the method of "regression sinusoids" are the mean periods in the measurement series. They were determined by eliminating the dominating annual cycle, caused by the fluctuations of the declination of the sun (±23°26').

In order to determine the dispersion of the cycle parameters - periods, amplitudes and phases - the spectra of air temperature in the range of 2.1 - 30 years were determined for each of the 58 localities accounted for and compared.

The diagrams and tables account for the results concerning six localities. Their selection resulted from the intention of a possibly ample representation of the differences in the analysed forms of variability of air temperature on the area of Poland.

Spectral analysis showed that there are several cyclical components featuring significant ranges of oscillations in the seasonal and annual courses of air temperature in Poland. These are the 2-, 3-, 6-, 8-, 10- and 14-16-year cycles. Their presence in all the chronological series and their synchronicity on the area of Poland (similar periods and phase conformity of oscillations), especially of the 8-year cycle, imply that such cyclicity is the property of the air temperature field in Poland (see Table 1).

In the winter season, within the area of Poland (except for the mountain station of Kasprowy Wierch) the 7-6-year cyclicity dominates, with oscillation amplitudes ranging between 2.0 degree for Kasprowy Wierch and 4.5 degree for Suwałki, see Table 2.

Thus, for instance, the 7.8-year cycle of air temperature during winter in Warsaw is described with the following sinusoid equation:

$$T = -2.05 + 2.11\sin((2\pi/7.8)t + 1.66)$$

The relative oscillations of temperature in this cycle, related to the interval $\pm s$, amount to 65-88%. The correlation coefficients $R$ change in the range 0.46-0.64 and are significant at the significance level < 0.05. Thus, this cycle explains the variance of temperature in 21-41%. The highest values of air temperature in this cycle occurred on the area of Poland in the years expressed as $1958 + \Theta k$, where $k = 1, 2, \ldots$ . The dispersion of the close-to-8-year period within Poland is equal in winter to 0.2 year (7.6-7.8 years).

The cyclicity of air temperature of this length of period appears in all seasons and in the year as a whole, being a significant cycle (significance level of 0.05), dominating in Poland also during spring, as well as in the majority of the time series analysed - in autumn.

Attention should be paid to the coincidence of appearance of the minima and maxima of the 8-year cycle of air temperature in winter and spring, and in the year as a whole. This demonstrates the decisive role of the winter season in the shaping of the average temperature in a year, resulting from the high variability from year to year of the

**Table 1** Periods and amplitudes *T* of the annual average of air temperature in selected localities in Poland in the years 1951-1990 (Θ - the level of significance of 0.10, Θ - the level of significance of 0.05)

| Localities | Θ ≈ 2 years | | | Θ ≈ 3,5 years | | | Θ ≈ 6 years | | | Θ ≈ 8 years | | | Θ ≈ 10 years | | | Θ ≈ 15 years | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Θ | Δ*T* | % | Θ | Δ*T* | % | Θ | Δ*T* | % | Θ | Δ*T* | % | Θ | Δ*T* | % | Θ | Δ*T* | % |
| Kołobrzeg | 2,2 | 0,7 | 42 | 3,6 | 0,8 | 48 | 5,9 | 0,8 | 48 | 7,7 | 1,4 | 84 | 10,2 | 0,4 | 24 | 14,3 | 0,7 | 42 |
| Suwałki | 2,2 | 0,9 | 48 | 3,6 | 0,9 | 48 | 5,9 | 1,0 | 54 | 7,8 | 1,5 | 80 | 10,2 | 0,5 | 27 | 15,5 | 0,6 | 32 |
| Warsaw | 2,2 | 0,8 | 48 | 3,6 | 0,8 | 48 | 5,9 | 0,9 | 54 | 7,7 | 1,5 | 91 | 10,3 | 0,4 | 24 | 15,8 | 0,5 | 30 |
| Wroclaw | 2,2 | 0,7 | 47 | 3,6 | 0,7 | 47 | 5,9 | 0,8 | 54 | 7,6 | 1,4 | 94 | 10,2 | 0,5 | 33 | 14,6 | 0,4 | 27 |
| Zamość | 2,2 | 0,9 | 55 | 3,6 | 0,6 | 37 | 5,8 | 0,8 | 49 | 7,6 | 1,4 | 85 | 10,4 | 0,6 | 37 | 15,9 | 0,7 | 43 |
| Kasprowy Wierch | 2,2 | 0,6 | 45 | 3,6 | 0,9 | 68 | 6,0 | 0,5 | 38 | 7,7 | 0,8 | 60 | 10,4 | 0,4 | 30 | 14,2 | 0,4 | 30 |

Θ - period; *T* - amplitude; % - relative range of temperature variations in the cycle, with respect to the interval $T \pm \sigma$, where *T* - average value, and σ - standard deviation, temperature values in winter (and spring) months in comparison with the remaining seasons of the year. This is expressed through the fact that the amplitudes of air temperature in the winter cycles are more than twice as big as in the corresponding cycles of other seasons.

**Table 2** The parameters of the close-to-8-year cycle of air temperature in particular seasons in Poland

| Locality | Winter (XII - II) | | | | | Spring (III - V) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Θ | Δ*T* | % | R | Date(max) | Θ | Δ*T* | % | R | Date(max) |
| Kołobrzeg | 7,7 | 3,5 | 82 | 0,58 | 1958 | 7,5 | 1,8 | 74 | 0,55 | 1959 |
| Suwałki | 7,8 | 4,5 | 84 | 0,60 | 1958 | 7,7 | 1,7 | 60 | 0,44 | 1959 |
| Warsaw | 7,8 | 4,2 | 85 | 0,61 | 1958 | 7,7 | 1,7 | 67 | 0,48 | 1959 |
| Wrocław | 7,7 | 3,9 | 88 | 0,64 | 1958 | 7,6 | 1,4 | 64 | 0,46 | 1959 |
| Zamość | 7,8 | 4,0 | 80 | 0,58 | 1958 | 7,7 | 1,6 | 60 | 0,42 | 1959 |
| Kasprowy Wierch | 7,6 | 2,0 | 65 | 0,46 | 1958 | 7,9 | 1,1 | 46 | 0,34 | 1959 |

| Locality | Winter (XII - II) | | | | | Spring (III - V) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Θ | Δ*T* | % | R | Date(max) | Θ | Δ*T* | % | R | Date(max) |
| Kołobrzeg | 7,8 | 0,8 | 61 | 0,45 | 1958 | 6,9 | 1 | 68 | 0,5 | 1954 |
| Suwałki | 7,1 | 0,5 | 26 | 0,18 | 1959 | 7 | 1 | 56 | 0,4 | 1954 |
| Warsaw | 7,3 | 0,5 | 29 | 0,22 | 1959 | 7,1 | 1,2 | 70 | 0,49 | 1954 |
| Wrocław | 7,5 | 0,7 | 46 | 0,35 | 1959 | 7 | 1,2 | 68 | 0,49 | 1954 |
| Zamość | 7,1 | 0,4 | 27 | 0,19 | 1959 | 7,2 | 1,3 | 70 | 0,49 | 1953 |
| Kasprowy Wierch | 7,5 | 0,6 | 37 | 0,25 | 1958 | 7,4 | 1,3 | 52 | 0,36 | 1953 |

Θ - period; Δ*T* - amplitude; % - relative range of temperature variations in the cycle, with respect to the interval $T \pm \sigma$, where *T* - average value, and σ - standard deviation; *R* - correlation coefficient; Date(max) - the years of occurrence of cycle maxima (Data(max) + *k*Θ, where *k* = 1, 2, ...)

The comparison of the years of appearance of the extremes of the 8-year cycle with years of occurrence of the highest and lowest measured values - in the time series of air temperature - shows their high coincidence (in some cases the difference amounting to at most 1-2 years). An example is provided by the recent exceptionally cold winters, which took place in Poland in the years of the minima of the winter 8-year cycle, in 1985 and 1987, as well as by the exceptionally warm winters, which occurred in the years 1989 and 1990, namely in the years of the maxima of this cycle (Fig. 2).

In summer the scope of air temperature changes in the 7.1-7.8-year cycles is smaller (26-61%), and the maximum occur one year later than in the winter cycle: 1958-59 + *k*Θ (multiplicity of the period). In this cycle, as a rule, a warm summer follows a warm winter, and a cold summer follows a frosty winter.

Although in case of summer the spectra of air temperature on the whole area of Poland (the 58 localities) feature high similarity (appearance of the same local minima of the rest variance), this area is differentiated in terms of the dominating frequency of oscillations. In western, south-western and partly in central Poland the 6-year cycle dominates, in the north-east - the 2.2-year cycle, at the Baltic Sea coast - the 7.7-year cycle, in the Carpathian Mts. - the 4.8-year cycle. In some localities (the eastern part of the Pomeranian Lakeland and the Lublin Polesie) this is the 3.2-3.6-year cycle. Let us mention that these periods appear and are significant (at the significance level of 0.10) in the remaining seasons of the year, characterized by a wide range temperature changes, expressed through the significant cyclical components of the annual average of the air temperature (Table 1).

The specific nature of the particular seasons of the year in terms of the periodical changes of air temperature is therefore represented through definite differences in the dominating frequency, though the same periods (approximately) appear in all the seasons considered and for the whole year, and are characteristic for the whole area of Poland (Table 3). As mentioned already, the range of cyclical variations of temperature is in winter more than two times bigger than in summer. The relative variations are, as a rule, bigger as well.

**Table 3** Significant cyclical components in particular seasons and in the whole year in Poland (according to decreasing amplitudes)

| Locality | Winter (XII-II) | | | Spring (III-V) | | | | Summer (VI-VIII) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Kolobrzeg | 7,7 | 15,7 | 3,1 | 7,5 | 2,2 | 5,9 | | 7,8 | 3,2 | 2,2 |
| Suwałki | 7,8 | 16 | 3,1 | 7,7 | 5,9 | 3,6 | | 2,2 | 4,2 | |
| Warsaw | 7,8 | 3,1 | 16,3 | 7,7 | 5,9 | 3,6 | 2,2 | 2,2 | 5,9 | 3.9* |
| Wrocław | 7,7 | 16,3 | | 7,6 | 3,6 | 2,2 | 6 | 6 | 2,2 | 7,5 |
| Zamość | 7,8 | 3,1 | 16,5 | 5,8 | 7,7 | 2,2 | | 4,8 | 3,7 | 2.2* |
| Kasprowy W. | 16 | 7,6 | | 3,6 | 2,2 | 2,9 | 7,9 | 4,8 | 2,2 | 5,9 |
| | Autumn (IX-XI) | | | Year (I-XII) | | | | | | |
| Kołobrzeg | 6,9 | | | 7,7 | 5,9 | 3,6 | | | | |
| Suwałki | 2,9 | 7 | 4 | 7,8 | 5,9 | 2,2 | | | | |
| Warsaw | 7,1 | 2,9 | | 7,7 | 5,9 | 2,2 | | | | |
| Wrocław | 7 | 3,3 | 3 | 7,6 | 5,9 | 2,2 | 3,6 | | | |
| Zamość | 7,2 | 2,9 | 3,2 | 7,6 | 2,2 | 5,8 | | | | |
| Kasprowy W. | 7,4 | 4,1 | | 3,6 | 7,7 | 2,2 | | | | |

* statistically insignificant periods

In the attempt to identify the causes of cyclicity of air temperature contained between 1 and 30 years, the similarity of the spectra was analysed (and the synchronicity of the cycles was proven) of the air temperature on the one hand (effects), and, on the other hand, of atmospheric circulation and solar activity (supposed causes) - see Boryczka (1993). For this purpose, the univariate regression was applied as well, and the respective equations were identified.

It can be supposed that the cause for the 7.6-to-7.8-year winter cycle of the air temperature field in Poland is constituted by the 7.8-year cycle of solar activity (*W* - Wolf numbers) in the years 1951-1990:

$$W = 74.4 + 35.30 \sin((2\pi/7.8)t + 2.14) \qquad R = 0.43$$

This is evidenced by the synchronicity of these cycles (similar periodicity and conformity of the oscillation phases). The maxima of, for instance, winter values of air temperature in the 7.6-to-7.8-year cycles on the area of Poland occur during the maxima of the Wolf numbers in the 7.8-year cycle in almost the same years, 1951 + $(\Theta/2\pi)(\pi/2-c)$:

| | | Cycle | Maxima | | | | |
|---|---|---|---|---|---|---|---|
| Solar activity (Wolf numbers) | | 7.8 years | 1958 | 1965 | 1973 | 1981 | 1989 |
| Air temperatures: | Kołobrzeg | 7.7 years | 1958 | 1966 | 1974 | 1981 | 1989 |
| | Suwałki | 7.8 years | 1958 | 1966 | 1974 | 1981 | 1989 |
| | Warsaw | 7.8 years | 1958 | 1966 | 1974 | 1982 | 1989 |
| | Wrocław | 7.7 years | 1958 | 1966 | 1974 | 1981 | 1989 |
| | Zamość | 7.8 years | 1958 | 1966 | 1974 | 1982 | 1989 |
| | Kasprowy Wierch | 7.6 years | 1958 | 1966 | 1973 | 1981 | 1989 |

Similarly, the maxima of the close-to-10-year winter cycle of air temperature in many localities occur in the years of an intensified solar activity, close to the winter maxima of the Wolf numbers (Fig.1): 1958 (the absolute maximum of $W_{max}$ = 202.3 since 1700), 1968, 1980, 1989:

| | | |
|---|---|---|
| Warsaw | - the 10.3-year cycle | 1959, 1969, 1979, 1990 |
| Zamość | - the 10.3-year cycle | 1959, 1969, 1979, 1990 |
| Kasprowy Wierch | - the 10.1-year cycle | 1959, 1969, 1979, 1989 |

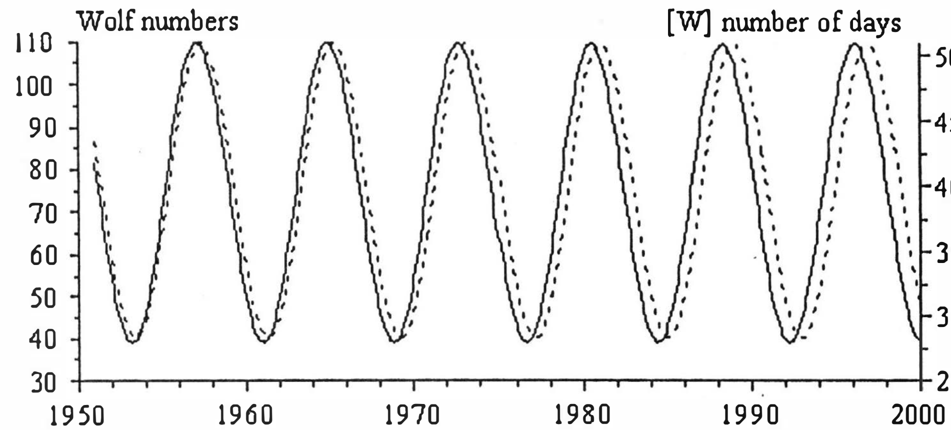


Fig. 1 The 10.3-year cycle of air temperature in Warsaw (solid line) and the changes in solar activity (broken line - Wolf number values) in the winters of 1951-1990.

The shift in the dates of extremes may result from the fact that the solar constant in the close-to-11-year cycle attains its highest value for the Wolf numbers from the interval 80-100, and not during the maxima of solar activity (Kondratev, Nikolsky, 1982).

The coincidence of the close-to-8- and close-to-11-year components of air temperature and the fluctuations of solar activity may constitute the evidence for the solar conditioning of these changes. It is interesting that in the period analysed (1951-1990), when compared to the 200-year series, the solar cycle of 7.8 years comes forth as very strong. It most probably explains the domination of the close-to-8-year cycle of air temperature after the year 1920 - a change in the thermal features of climate in Europe.

The studies conducted allow expect that the cyclical changes in air temperature on the area of Poland are conditioned by the respective cycles of atmospheric circulation. This is demonstrated by the synchronicity of the thermal cycles and the cycles of macrotypes and types of circulation (similarity of periods and coincidence of the cycle extremes), especially in winter (Table 4). Strong dynamics of circulation in winter entails in moderate latitudes significant fluctuations of air temperature.

A particular role in shaping of air temperature field in Poland is played by some macrotypes and types of circulation. The scope of fluctuations of air temperature in the cycles is being deformed by the surface relief and the altitude above the sea level (mainly in the warmer half of the year), as well as by the influence of the Baltic Sea (primarily in autumn and winter).

**Table 4** The cycles of changes in the NAO indicator, the frequencies of selected types and macrotypes of atmospheric circulation, and the temperatures of the air in Poland in winter in the years 1951-1990 (⊝ - significance level of 0.10; ⊝ - significance level of 0.05)

| | NAO indicator | Circulation types | | | Macrotype *W* | Air temperature | | |
|---|---|---|---|---|---|---|---|---|
| | | E (NEa) | D (SWc) | A (Wc) | | Kołobrzeg | Warsaw | Zamość |
| Periods in years | 2,3 | 2,2 | **2,2** | 2,5 | 2,2 | 2,4 | 2,2 | 2,2 |
| | 3,2 | **3,1** | 3,9 | **3,1** | **3,1** | 3,1 | 3,1 | 3,1 |
| | 4,6 | 4,1 | 4,8 | 4,6 | 4,6 | 4,6 | 4,6 | 4,6 |
| | 5,4 | 5,2 | 5,8 | 5,3 | 5,4 | 5,4 | 5,4 | 5,4 |
| | **7,6** | 7,6 | 8 | 8,1 | **7,9** | **7,7** | **7,8** | **7,8** |
| | 10,3 | 9,9 | 10,1 | - | 11,6 | 10,2 | 10,3 | 10,3 |
| | 15 | 17,1 | **15,2** | - | 16,4 | **15,7** | 16,3 | 16,5 |

Thus, for instance, in winter, the close-to-8-year variability of air temperature is caused directly by the blocking types of circulation: the north-western cyclonic (CB), the north-eastern and eastern cyclonic ($E_0$), the north-eastern anticyclonic (E), and the macrotypes of western zonal circulation (western [W] and eastern [E]), as indicated by the synchronous cycles (Fig.2):

$$T_{Warsaw} = -2.05 + 2.11\sin((2\pi/7.8)t + 1.66) \qquad R = 0.61$$
$$[W] = 39.61 + 11.31\sin((2\pi/7.9)t + 2.01) \qquad R = 0.59$$
$$[E] = 24.85 + 9.11\sin((2\pi/7.8)t - 1.50) \qquad R = 0.52$$

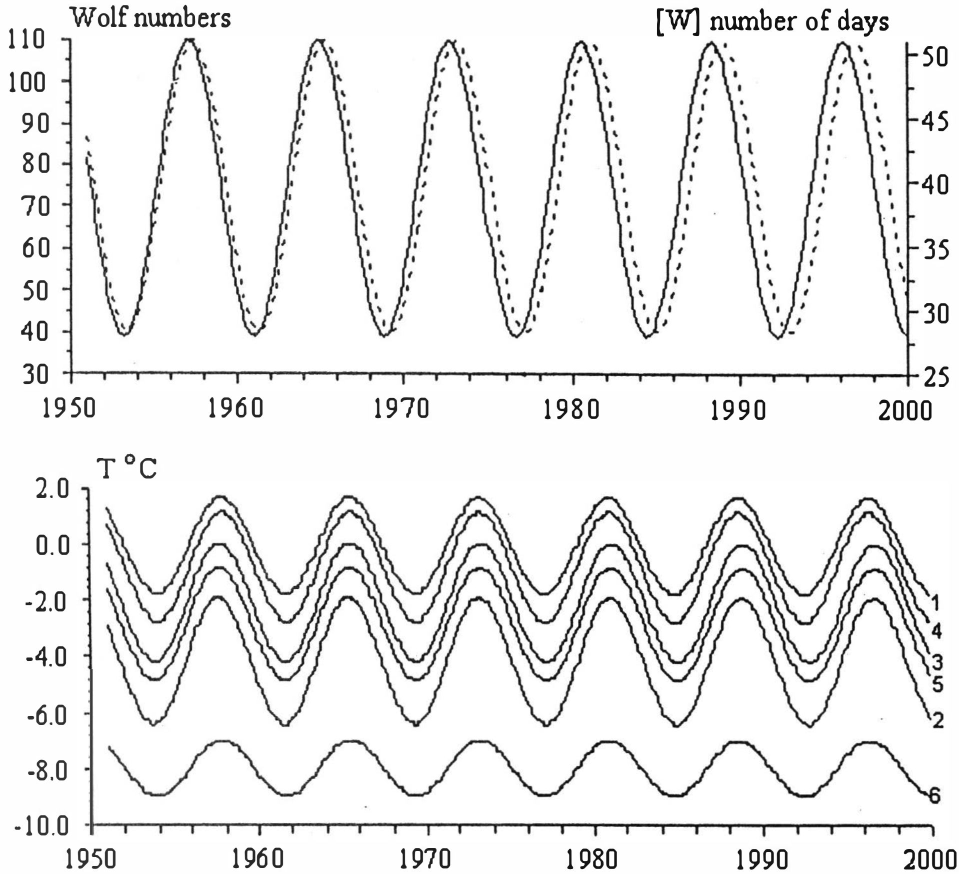


**Fig. 2** The close-to-8-year cycle of solar activity (solid line: Wolf numbers), western zonal circulation [W] (broken line), and air temperature in selected localities in Poland (1-Kolobrzeg, 2-Suwalki, 3-Warszawa, 4-Wroclaw, 5-Zamość, 6-Kasprowy Wierch) in winter in the period 1951-2000

Here are the dates of extremes of these cycles and of the 7.8-year cycle of solar activity:

| | | | | | |
|---|---|---|---|---|---|
| Air temperature in Warsaw $T_{max}$ | 1958 | 1966 | 1974 | 1982 | 1989 |
| Western zonal circulation $[W]_{max}$ | 1958 | 1966 | 1974 | 1982 | 1989 |
| Eastern zonal circulation $[E]_{min}$ | 1958 | 1966 | 1974 | 1982 | 1989 |
| Solar activity $W_{max}$ | 1958 | 1965 | 1973 | 1981 | 1989 |

The statistically significant relation between the thermal conditions in Poland and the atmospheric circulation is also indicated by the direct, linear dependence of air temperature on frequency of occurrence of some types and macrotypes of circulation. Here are the equations of the regression lines of air temperature in Warsaw with respect to the western [W] and eastern [E] circulation macrotype, as well as the north-eastern anticyclonic circulation type E in winter:

$$T = -6.25 + 0.320\,[W], \qquad R = 0.578$$
$$T = 1.04 - 0.373\,[E], \qquad R = 0.615$$
$$T = -0.19 - 0.706E, \qquad R = 0.538$$

It must be mentioned that the maxima of air temperature and the western zonal circulation in winter occur in the years of the highest values of the NAO indicator in the respective 8-year cycle, which is dominating in this season of the year. This cycle is described with the regression equation:

$$NAO = 0.20 + 1.04\sin((2\pi/7.6)t + 1.06) \qquad R = 0.57$$

Interesting observations are also provided by the comparison of the cyclical components in the course of the NAO indicator, characterizing the intensity of zonal circulation, with the dominating frequencies of temperature fluctuations in other seasons. The 8-year period dominates - besides the winter season - also in the chronological series of the NAO for the summer, when it is also the cycle exerting the strongest influence on the variability of air temperature on the coast of the Baltic Sea. The close-to-8-year cycle does not occur in the course of the NAO indicator in spring, though it is dominating between December and March:

$$NAO = 0.24 + 0.91\sin((2\pi/7.6)t + 1.11) \qquad R = 0.59$$

The 3-4-year cyclicity, established in the chronological series of the summer values of air temperature, is present in the sequences of frequency of the following circulation types: north-eastern and eastern cyclonic ($E_0$), the south-eastern and eastern anticyclonic ($E_1$), as well as the anticyclonic and cyclonic ([A] and [C]) pressure settings:

$$T_{Warsaw} = 17.42 + 0.41\sin((2\pi/3.9)t + 0.61) \qquad R = 0.34$$
$$E_0 = 9.04 + 3.05\sin((2\pi/3.7)t + 1.79) \qquad R = 0.36$$
$$[C] = 31.82 + 6.04\sin((2\pi/3.9)t - 2.38) \qquad R = 0.41$$

It is highly probable that the close-to-6-year cycle of air temperature in summer (dominating in north-western, western, and partly central Poland) is associated with the 6-year period of oscillations of the north-western cyclonic circulation (CB):

$$T_{Wroclaw} = 17.19 + 0.49\sin((2\pi/6.0)t + 0.23) \qquad R = 0.47$$
$$CB = 13.25 + 2.94\sin((2\pi/6.0)t - 2.76) \qquad R = 0.37$$

It ought to be noted that the macrotype [C] and the types CB and $E_0$ of atmospheric circulation are the main factors behind the cool summer seasons.

The study here reported allowed also to determine the trends in air temperature in Poland in the years 1951-1990 on the basis of regression lines $T = A_0 + At$, i.e. as the values of coefficients $A$ given in the following table:

| Locality | Winter | Spring | Summer | Autumn | Year |
|---|---|---|---|---|---|
| Kołobrzeg | 0,31 | 0,46 | 0,2 | 0,12 | 0,28 |
| Suwałki | 0,22 | 0,33 | -0,38 | -0,15 | 0,02 |
| Warsaw | 0,34 | 0,34 | -0,23 | -0,06 | 0,11 |
| Wrocław | 0,37 | 0,37 | -0,15 | -0,05 | 0,11 |
| Kasprowy Wierch | 0,29 | 0,29 | -0,25 | -0,16 | 0,03 |

Generally, in the years 1951-1990 in Poland winters have been becoming increasingly warm ($A>0$) by 0.2-0.4 degree per decade, while summers have been getting cooler by 0.1-0.4 degree per decade ($A<0$). The biggest increase of temperature in winter occurred in south-western Poland, while the biggest cooling in summer took place in the eastern part of the country. The average annual temperature has been increasing by 0.03-0.3 degree per decade. It is interesting to note that the trend of the average annual air temperature on the peak of Kasprowy Wierch (1991 meters a.s.l.), where anthropogenous influences are very limited, is null.

The progressing warming of the winter season results directly from the increasing frequency of days with the south-western cyclonic circulation (D). The cooler summers are, on the other hand, caused by the increase of the number of days with the north-western cyclonic (CB) and north-eastern as well as eastern cyclonic ($E_0$) circulation types.

The superposition of the cycles determined, $T = f(t)$, explains only a part of the trend in air temperature, defined by equation $T = B_0 + Bt$ ($T$ - superposition of cycles), while the difference of trends $a = A - B$ can be assigned the not determined longer natural cycles of air temperature and the anthropogenic factors (the anthropogenic part of the greenhouse effect and the urban heat island). The part $A - B$ of the increasing trend in the annual average of air temperature in Poland, not explained by the known cycles (along with the anthropogenic component) is contained in the interval 0.0-0.17 degree per decade.

The results of the studies conducted on the basis of data from 58 localities in Poland are conform to the characteristics of periods distinguished for some localities in Poland (Morawska-Horawska, 1992; Boryczka et al., 1992; Kożuchowski, Marciniak, 1994). Simultaneously, it is worth mentioning that the determined cyclical components display a high similarity to the periods of temperature oscillations given in the earlier publications, concerning single measurement series in Europe and the northern hemisphere (Landsberg, 1980; Boryczka, 1993; Kożuchowski, 1996). Similar periods are characteristic for a significant area in Europe (Malcher, Schönwiese, 1987; Boryczka, 1993).

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## Resume

### Zmeny teploty vzduchu v Poľsku v rokoch 1951-1990

Veľký počet prác sústreďuje svoju pozornosť na hodnotenie vývoja jednak jednotlivých meteorologických prvkov, jednak všeobecných zmien klímy. Predložený príspevok je zameraný na problém priestorovej (geografickej) diferenciácie zmien teploty vzduchu na území Poľska v rokoch 1951-1990. Výsledky predloženej štúdie sú založené na báze dát z 58 lokalít Poľska.

Všeobecne povedané, v rokoch 1950-1990 sa zimné teploty v Poľsku zvýšili o 0,2-0,4 stupňa za jednu dekádu, zatiaľ čo letá sa stali chladnejšie o 0,1-0,4 stupňa za jednu dekádu. Najvyššie zvýšenie zimných teplôt bolo namerané v juhozápadnom Poľsku, naproti tomu najvyššie ochladenie v lete bolo zaznamenané vo východnej časti krajiny. Priemerná ročná teplota sa zvýšila o 0,03-0,3 za dekádu. Je zaujímavé poznamenať, že tento trend zvyšovania priemerných ročných teplôt nebol pozorovaný na vrchu Kasprowy Wierch (1991 m), kde sú antropogenné vplyvy veľmi malé. Na tomto vrchu sa "zmena" priemernej ročnej teploty rovnala nule.

Pri porovnaní získaných výsledkov s výsledkami iných prác urobených v Európe, resp. na severnej pologuli zisťujeme, že vyššie uvedené výsledky sú signifikantné pre podstatnú časť Európy.