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VARIABILITY OF MAXIMUM DAILY AIR TEMPERATURE IN THE ZONE OF THE POLISH BALTIC SEA COAST*

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A b s t r a c t. Monthly average and maximum daily temperatures of the air in the period of 1956-2005, recorded at 9 meteorological stations situated along the coastal zone, were used in the study. Variability and frequency of maximum daily temperature, time trends and relationships of average air temperature were determined. Using the quantile method, extremely low (a 5% quantile) and extremely high (a 95% quantile) values of maximum daily air temperature were calculated, and the assessment of thermal conditions for Kołobrzeg station, was carried out year by year according to 11 quantile intervals. In the first half of the year (excluding June), a distinct increase in the maximum daily air temperature was observed, statistically significant in January (3.3^{o}C/50 years) and in April (4.1^{o}C/50 years), and there was a slight decrease in the temperature in autumn, mainly in September. The lowest monthly average air temperatures occurred in the western part of the coast in February, and in the north-eastern part in January during the period from March to November. The highest values of maximum daily air temperature of >20^{o}C can occur along the seaside – from April to October >25^{o}C, and from May to September >30^{o}C; in winter these values do not exceed –1.0^{o}C. The value of maximum daily air temperature in winter (December-March) is significantly affected by the atmospheric circulation from over the North Atlantic (NAO). At the seaside, the maximum daily air temperature gets higher and higher and less variable. Over the Polish coast of the Baltic Sea 3 zones of differentiated values of maximum daily air temperature can be distinguished.

K e y w o r d s: maximum temperature, linear trends, variability, zones

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INTRODUCTION

Variability of the climate, so characteristic of the whole country, is also clearly distinguished along the zone of Polish coast of the Baltic Sea, especially in late autumn, in winter and in early spring (Atlas... 2004, Przybylak 2006). Variability of the climate with regard to temperature can be reflected by the alternate occurrence of very cool winters (e.g. 1969/70, 1978/79, 2005/06) and very warm (1989/90, 2006/07) and cold (e.g. 1977, 2000), and hot summer months (1982, 1994, 2002 and 2006). Extreme weather phenomena are most often related to the occurrence of a given atmospheric circulation and baric system. For these reasons their occurrence is as predictable as is the atmospheric circulation (Marsz 2001, Miętus et al. 2004). Among the unfavourable meteorological factors
observed in Poland, a significant meaning has the extreme air temperature that has a limiting effect on, among other things, the economic activity and the conditions of recreation and medical care on the Baltic Sea coast, the characteristic of which is, similarly to the mountains, increasing recreational and spa tourism (Atlas... 2001, Błażejczyk 2004, Owczarek 2005, Trepińska 2005).

These are the reasons for which variability and frequency of the occurrence of this temperature is the objective of the analysis in this study and a continuation of the investigations in the Polish coastal zone of the Baltic Sea conducted so far by Prawdzic *et al*. (1960), Koźmiński (2001), Koźmiński and Michalska (2001, 2004), Filipiak (2004), Kożuchowski, Żmudzka (2001), Marsz (2001), *Miętus et al*. (2002) and Owczarek (2005)**.**

MATERIAL AND METHODS

In the study a monthly average and daily maximum air temperature from individual months for 9 meteorological stations were used, taking the years 1956-2005 as a basic period for Świnoujście, Kołobrzeg, Koszalin, Ustka, Łeba, Hel, Gdańsk and Elbląg and the years 1956-2000 for Darłowo (Fig. 1). The data were taken from Miesięczne Przeglądy Agrometeorologiczne (Monthly Agrometeorological Reviews), Morskie Komunikaty Hydrologiczno-Meteorologiczne (Marine Hydrological and Meteorological Forecasts) and from Archiwum IMGW (IMGW Archives). The collected material was used to work out basic statistical characteristic features as well as trends of changes in the maximum temperature during a multi-annual period and its deviations from the norms in the successive 10- year periods.

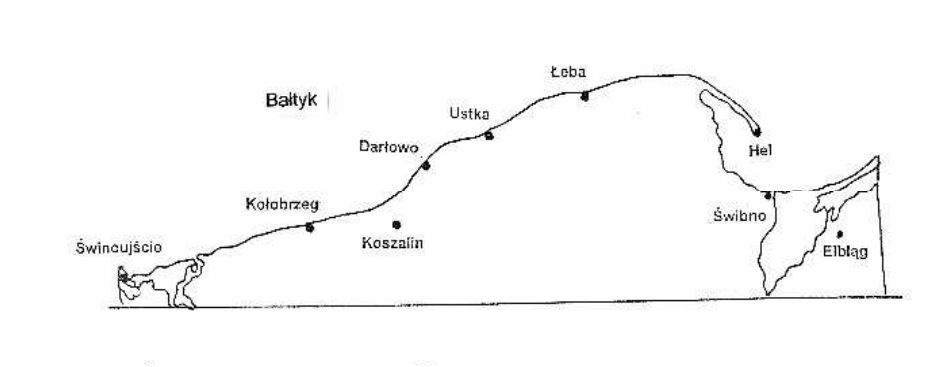


Fig. 1. Distribution of meteorological stations on the Polish Baltic coast

One of the ways of assessment of meteorological phenomena is the determination of values of meteorological elements referred to as "normal" and differing from them (Lorenc 2000). For this purpose, a classification with quantile intervals applied was carried out in this study with reference to the daily maximum temperature (Owczarek 2005). Quantiles were defined from 5 to 95% with a step every 5%, and then the division of full variability range of maximum temperature was made at a given station into 11 quantile intervals, from extremely low (5% quantile) to extremely high (95% quantile). Achieved in this way characteristics of thermal conditions at the given station in the form of a calendar (from 1956 to 2005) can be continued with reference to next years. In this study, calendar of thermal conditions for Kołobrzeg station is included. Relationships between daily maximum air temperature (dependent variable – y) and years of study and monthly average air temperature (independent variable – x) were determined using the method of correlation and single regression. Statistical significance of the relations was examined by means of the Fisher-Snedecor test (F), adopting the levels of confidence of $\alpha = 0.05$ and 0.01. The strength of relationship between the studied variables was defined by the correlation coefficient (r), and the degree of their matching – by the determination coefficient (R^2).

ANALYSIS OF RESULTS AND DISCUSSION

Thermal conditions of the air in the area of the Polish coast of the Baltic Sea depend mainly on the distance from the Atlantic Ocean atmospheric circulation and from regional physiographic factors such as the shape of the shore line and the vicinity of deeper sea regions (Gdańsk Bay and the region between Darłowo and Kołobrzeg). As a result, the further along the coast eastwards, the lower the average annual temperature of the air: from 8.4^o in Świnoujście to 7.7^{o}C in Łeba,

Gdańsk and Elbląg (Tab. 1). In all the seasons of the year, the lowest air temperatures are recorded in the north-western part of the coast, the most protruded into the Baltic Sea part of the land (about 80 km) as compared to the western part, situated in the "shade" of Rugia island. Assessment of the lowest values of monthly air temperature shows that in the western part of the coast they were recorded mainly in February, whilst in the north-eastern in January. Whereas, in the analysed period of 50 years the highest average monthly temperature was observed, at most of the stations, in August. The largest variability of the average monthly air temperature occurs in winter months, particularly in February (standard deviation varies from 2.6 to 2.9), and the smallest - in summer months, particularly in June – from 0.9 o 1.1, at a very small spatial differentiation.

In the Polish coastal zone of the Baltic Sea the highest average annual temperatures of air (Tab. 2) are recorded in the western part (19.2° and 19.3°C), then around the Bay of Gdańsk (19.0°C), and the lowest average annual air temperatures occur in the north-eastern part of the coast (18.6°C). Among the 9 analysed stations, relatively low average annual air temperature (17.1°C) was characteristic of Hel, situated on the Hel Peninsula. The highest monthly averages of maximum daily air temperature are recorded in July, and the absolutely highest, in the analysed period of 50 years, occurred in August (particularly in 1992) – from 35° in Hel to 38°C in Kołobrzeg and in Ustka. From March to November, absolutely high temperatures > 20°C can occur on the coast from April to October, when they can amount to >25°C, whereas from May to September >30°C, apart from the station in Hel, the characteristic of which are lower values of this temperature. In winter, particularly in February, the maximum daily air temperature can assume values of about 0° (from –0.4° in Darłowo to 1.0°C in Świnoujście), and in Elbląg even to –1.0°C. Such low values of this temperature occurred in the western and central parts of the coast in 1963, and in the eastern part in 1986.

Out of the 4 seasons of the year the largest differences of maximum daily air temperature on the coast are observed in spring, from 17.3° in Hel to 20.5°C in Świnoujście, and in summer – from 26.9° to 29.1°C, and the lowest in autumn – from 17.3° in Hel to 19.0°C in Kołobrzeg and Ustka. Noteworthy is the occurrence of higher values of the maximum daily temperature in spring, as compared to autumn, opposite to the average temperature when spring is colder than autumn and the temperature varies from 2.3° Świnoujście to 3.4°C in Hel.

The differences in the values of daily maximum temperature between the discussed seasons of the year are lower than in the values of the average temperature and they vary from 0.1° in Hel to 1.7°C in Elbląg and in Koszalin.

Table 1. Average monthly air temperature (a) highest (b). lowest (c) and standard deviation (d). Years 1956-2005. Darłowo* 1956-2000

Station/Month		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Świnoujście	a	–0.1	0.3	3.0	6.6	11.5	15.3	17.3	17.2	13.9	9.5	4.5	1.2	8.4
	b	4.8	6.1	7.0	10.2	13.9	17.5	19.9	20.6	16.9	12.2	7.2	4.7	9.8
	c	–7.0	–7.5	–1.2	3.8	8.9	13.6	14.5	14.7	11.4	6.7	0.8	–5.2	6.9
	d	2.8	2.9	2.0	1.4	1.3	0.9	1.3	1.2	1.2	1.3	1.5	2.1	0.8
Kołobrzeg	a	–0.2	0.2	2.7	6.3	10.9	14.7	17.1	16.9	13.6	9.4	4.5	1.2	8.1
	b	4.5	6.2	7.1	10.0	14.9	18.1	20.5	21.0	15.9	12.7	7.3	4.5	10.0
	c	–7.0	–7.4	–1.3	2.9	8.3	12.5	14.6	14.2	11.0	6.3	0.5	–5.9	6.4
	d	2.8	2.9	2.0	1.5	1.6	1.1	1.4	1.3	1.1	1.3	1.6	2.2	0.9
Koszalin	a	–0.7	–0.3	2.5	6.6	11.6	14.9	16.8	16.6	13.1	9.0	4.0	0.6	7.9
	b	4.2	5.7	6.6	11.0	15.6	17.6	20.3	20.7	16.8	12.4	7.0	3.9	9.8
	c	–8.3	–7.6	–1.5	3.4	8.4	12.7	13.9	13.8	10.5	5.8	0.1	–6.1	6.4
	d	2.9	3.0	2.1	1.6	1.6	1.2	1.5	1.4	1.3	1.4	1.6	2.2	0.9
Darłowo*	a	–0.4	–0.3	2.1	5.8	10.3	14.2	16.7	16.7	13.4	9.4	4.5	1.1	7.8
	b	4.2	5.8	6.3	10.3	13.4	16.1	19.1	19.4	16.0	12.0	7.0	4.1	9.4
	c	–7.3	–7.3	–1.6	2.8	7.7	12.2	14.4	14.8	10.6	6.5	0.5	–5.8	6.4
	d	2.8	2.9	2.0	1.5	1.5	1.1	1.1	1.0	1.1	1.3	1.6	2.1	0.8
Ustka	a	–0.3	–0.1	2.3	5.8	10.4	14.4	16.8	16.8	13.6	9.4	4.6	1.2	7.9
	b	4.4	6.1	6.5	9.8	13.1	17.5	19.1	19.7	16.3	12.3	7.2	4.2	9.7
	c	–7.1	–6.8	–1.5	2.6	7.6	12.2	14.3	14.1	10.8	6.3	0.5	–5.7	6.3
	d	2.8	2.9	2.0	1.4	1.4	1.1	1.2	1.2	1.2	1.3	1.6	2.1	0.8
Łeba	a	–0.5	–0.4	1.9	5.6	10.3	14.2	16.7	16.5	13.2	9.1	4.3	0.9	7.7
	b	4.0	5.3	6.0	9.9	13.9	16.4	19.0	19.7	15.6	11.8	6.8	4.0	9.2
	c	–7.7	–6.9	–1.8	2.4	7.4	12.4	14.3	14.0	10.8	6.0	0.2	–5.6	6.2
	d	2.7	2.8	2.0	1.4	1.5	1.0	1.2	1.1	1.1	1.3	1.6	2.0	0.8
Hel	a	–0.2	–0.3	1.9	5.5	10.4	14.7	17.2	17.2	13.8	9.5	4.7	1.4	8.0
	b	4.0	5.1	6.1	8.9	14.1	17.1	19.6	20.5	16.4	12.0	7.6	4.2	9.4
	c	–7.3	–6.1	–2.3	2.8	7.6	12.9	14.8	14.9	11.5	6.8	0.3	–3.6	6.4
	d	2.4	2.6	1.9	1.2	1.5	1.0	1.3	1.2	1.1	1.2	1.5	1.8	0.8
Gdańsk	a	–1.5	–1.0	1.9	6.2	11.4	15.2	17.2	16.9	13.2	8.7	3.6	0.1	7.7
	b	3.7	5.1	6.4	9.9	15.0	17.8	20.2	19.6	15.7	11.7	6.3	4.2	9.3
	c	–11.4	–8.1	–2.6	3.4	7.6	12.8	13.7	14.8	10.1	5.2	–1.3	–5.9	5.6
	d	3.2	3.2	2.3	1.4	1.6	1.2	1.5	1.3	1.3	1.4	1.7	2.3	0.9
Elbląg	a	–2.0	–1.4	2.0	7.1	12.5	15.7	17.4	17.1	13.1	8.6	3.4	–0.4	7.7
	b	3.4	5.1	6.3	11.7	16.6	18.6	20.6	19.7	16.2	12.2	6.8	3.2	9.3
	c	–12.4	–9.8	–2.8	4.1	8.6	13.6	14.2	14.0	10.6	5.6	–1.6	–8.0	6.0
	d	3.3	3.4	2.3	1.5	1.8	1.3	1.6	1.4	1.4	1.5	1.9	2.4	0.9

Table 2. Daily maximum air temperature. average (a). highest (b). lowest (c) and standard deviation (d). Years 1956-2005

Station/Month		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	XII-II	III-V	VI-VIII	IX-XI
Świnoujście	a	7.9	9.2	14.8	20.8	25.8	28.7	29.2	29.5	24.6	19.6	12.4	9.5	19.3	8.9	20.5	29.1	18.9
	b	14.0	17.0	24.0	29.0	32.7	35.3	36.1	37.0	30.0	25.0	19.0	15.0	37.0	17.0	32.7	37.0	30.0
	c	1.0	1.0	6.7	12.3	19.0	23.6	23.3	22.4	19.0	13.0	8.0	3.0	1.0	1.0	6.7	22.4	8.0
	d	3.0	3.8	3.7	3.9	3.3	2.8	3.2	3.2	2.8	2.5	2.0	2.5	1.1	2.2	2.1	2.2	1.5
Kołobrzeg	a	7.7	8.8	14.5	20.5	26.1	28.2	29.5	29.0	24.5	19.9	12.6	9.3	19.2	8.6	20.4	28.9	19.0
	b	13.6	17.8	23.2	28.9	31.7	33.5	35.7	38.0	32.3	26.1	19.5	14.3	38.0	17.8	31.7	38.0	32.3
	c	1.4	0.0	6.6	11.4	18.2	19.7	22.8	20.9	18.3	14.6	8.5	2.7	0.0	0.0	6.6	19.7	8.5
	d	3.0	3.7	3.8	4.2	3.3	3.2	3.3	3.2	3.2	2.6	2.1	2.7	1.0	2.2	2.1	2.2	1.5
Koszalin	a	7.4	8.6	14.7	21.0	26.3	29.0	29.7	29.2	24.6	20.0	12.3	9.0	19.3	8.3	20.7	29.3	19.0
	b	13.0	18.0	23.0	28.2	31.0	35.0	36.0	37.0	34.0	27.3	19.0	14.0	37.0	18.0	31.0	37.0	34.0
	c	1.0	0.4	7.0	15.0	19.1	24.1	21.8	21.3	17.0	13.0	8.6	1.0	0.4	0.4	7.0	21.3	8.6
	d	3.1	3.8	3.9	3.6	2.9	2.5	3.2	3.1	3.2	2.7	2.1	2.8	1.0	2.3	1.9	1.8	1.5
Darłowo	a	6.6	7.6	13.4	19.7	25.3	28.2	28.9	28.8	24.2	19.5	12.1	8.6	18.6	7.6	19.5	28.6	18.6
	b	12.0	17.5	24.7	29.2	31.9	33.6	35.2	37.3	32.3	26.7	19.5	13.3	37.3	17.5	31.9	37.3	32.3
	c	1.0	–0.4	5.8	11.9	15.4	21.5	19.2	21.0	16.3	13.4	8.3	3.1	–0.4	–0.4	5.8	19.2	8.3
	d	2.8	3.8	4.1	4.3	3.7	3.0	3.4	3.3	3.0	2.7	2.3	2.2	1.0	2.2	2.3	2.0	1.6
Ustka	a	7.2	8.4	14.0	20.5	25.7	28.4	29.7	29.2	24.8	19.8	12.4	8.8	19.1	8.2	20.1	29.1	19.0
	b	14.0	18.0	22.0	29.4	32.0	34.8	34.8	38.0	33.0	28.0	20.0	13.0	38.0	18.0	32.0	38.0	33.0
	c	2.0	0.0	6.0	11.3	17.0	20.0	22.0	22.1	17.0	14.0	8.0	3.0	0.0	0.0	6.0	20.0	8.0
	d	3.0	3.9	3.9	4.3	3.5	3.1	3.1	3.0	3.2	2.9	2.2	2.5	1.0	2.2	2.3	1.9	1.6
Łeba	a	6.7	7.6	13.2	20.2	25.4	28.2	29.2	28.3	24.3	19.4	12.2	8.3	18.6	7.5	19.6	28.6	18.6
	b	11.8	16.8	22.6	29.0	32.4	33.7	34.9	37.2	32.1	27.6	20.3	12.7	37.2	16.8	32.4	37.2	32.1
	c	1.6	0.5	4.4	12.0	16.5	21.1	21.2	21.4	15.6	14.0	8.3	3.1	0.5	0.5	4.4	21.1	8.3
	d	2.5	3.6	3.7	4.2	3.4	2.8	3.1	3.0	3.3	2.8	2.2	2.2	1.1	1.9	2.3	1.9	1.7
Hel	a	6.1	6.2	11.7	17.6	22.8	26.1	27.7	27.2	22.9	17.7	11.3	8.0	17.1	6.8	17.4	26.9	17.3
	b	10.4	12.9	20.5	26.2	28.0	31.2	35.0	31.8	27.3	23.2	15.9	11.1	35.0	15.9	28.0	35.0	27.3
	c	1.6	0.2	4.1	12.1	17.0	21.5	22.0	22.9	17.9	13.8	7.6	2.8	0.2	0.2	4.1	21.5	7.6
	d	2.5	2.8	3.7	3.1	2.6	2.2	2.6	2.0	2.3	2.0	1.6	1.9	0.9	1.7	1.8	1.5	1.2
Gdańsk	a	6.8	7.7	14.3	20.6	25.7	28.5	29.6	29.5	24.8	19.9	12.1	8.6	19.0	7.7	20.2	29.2	18.9
	b	12.2	18.0	25.0	31.0	32.0	34.3	36.0	35.8	31.0	28.0	21.0	14.0	36.0	18.0	32.0	36.0	31.0
	c	1.0	0.0	4.0	13.3	19.0	22.0	23.1	25.1	17.0	13.0	8.3	3.0	0.0	0.0	4.0	22.0	8.3
	d	3.0	4.0	4.4	3.7	2.9	2.6	3.0	2.6	3.0	2.8	2.2	2.7	1.2	2.3	2.3	1.8	1.5
Elbląg	a	6.5	7.4	14.1	21.4	26.3	28.8	29.8	29.4	24.9	19.7	12.0	7.9	19.0	7.3	20.6	29.3	18.9
	b	12.0	18.0	22.0	29.0	32.0	33.1	37.0	36.0	30.0	27.0	18.0	13.0	37.0	18.0	32.0	37.0	30.0
	c	1.0	–1.0	4.0	14.1	18.0	25.4	23.0	22.9	18.0	13.0	7.6	2.0	–1.0	–1.0	4.0	22.9	7.6
	d	2.8	3.7	4.4	3.4	2.7	2.0	2.8	2.6	2.7	2.7	2.1	2.7	1.0	2.2	2.0	1.7	1.4

Table 3. Correlation coefficients (a) and direction coefficients of linear trend °C/year (b) and °C/50 years (c) of daily maximum air temperature in 1956-2005

Station/Month		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Świnoujście	a	0.332*	0.279*	0.252	0.319*	0.318*	0.189	0.199	0.296*	-0.166	-0.061	-0.211	0.040	0.494**
	b	0.07	0.07	0.06	0.1	0.07	0.04	0.04	0.06	-0.03	-0.01	-0.03	0.01	0.04
	c	3.4	3.6	3.2	5.0	3.6	1.8	2.2	3.3	-1.6	-0.5	-1.4	0.3	1.9
Kołobrzeg	a	0.344*	0.248	0.210	0.402**	0.288*	0.223	0.130	0.287*	-0.131	-0.074	-0.145	0.060	0.536**
	b	0.07	0.06	0.05	0.1	0.06	0.05	0.03	0.06	-0.03	-0.01	-0.02	0.01	0.04
	c	3.5	3.1	2.7	5.8	3.3	2.4	1.4	3.2	-1.4	-0.6	-1.0	0.5	1.9
Koszalin	a	0.361**	0.260	0.256	0.275*	0.184	0.034	-0.025	0.316*	-0.209	-0.035	-0.093	0.093	0.683**
	b	0.08	0.07	0.07	0.07	0.04	0.01	0.0	0.07	-0.04	-0.01	-0.01	0.02	0.03
	c	3.6	3.4	3.4	3.4	1.8	0.3	0.0	3.3	-2.3	-0.3	-0.7	0.9	1.4
Darłowo	a	0.332*	0.302*	0.167	0.444**	0.184	0.137	-0.036	0.209	-1.194	-0.037	-0.117	0.221	0.470**
	b	0.07	0.09	0.05	0.14	0.05	0.03	-0.01	0.05	-0.04	-0.01	-0.02	0.04	0.04
	c	3.6	4.4	2.6	7.2	2.6	1.6	-0.5	2.6	-2.2	-0.4	1.0	1.8	1.9
Ustka	a	0.360**	0.256	0.216	0.356*	0.157	0.011	-0.051	0.224	-0.188	-0.013	-0.129	0.010	0.373**
	b	0.07	0.07	0.06	0.1	0.04	0.0	-0.01	0.05	-0.04	0.0	-0.02	0.0	0.03
	c	3.7	3.4	2.8	5.2	1.9	0.0	-0.5	2.3	-2.1	0.0	-1.0	0.0	1.3
Łeba	a	0.284*	0.254	0.206	0.348*	0.205	0.034	0.013	0.111	-0.238	-0.076	-0.199	-0.039	0.279*
	b	0.05	0.06	0.05	0.1	0.05	0.001	0.0	0.02	-0.05	-0.01	-0.03	0.0	0.02
	c	2.5	3.2	2.6	5.0	2.4	0.3	0.0	1.1	-2.6	-0.7	-1.5	0.0	1.0
Hel	a	0.324*	0.189	0.094	0.2730.	0.364**	0.011	-0.045	-0.017	-0.222	-0.111	-0.113	0.006	0.225
	b	0.05	0.04	0.02	06	0.06	0.0	-0.01	0.0	-0.03	-0.01	-0.01	0.0	0.01
	c	2.8	1.8	1.2	2.8	3.3	0.0	-0.4	0.0	-1.7	-0.7	-0.6	0.0	0.7
Gdańsk	a	0.279*	0.088	0.237	0.182	0.190	-0.181	-0.078	0.071	-0.309*	-0.045	-0.212	-0.070	0.088
	b	0.06	0.02	0.07	0.05	0.04	-0.03	-0.02	0.01	-0.06	-0.01	-0.01	0.0	0.01
	c	2.9	1.2	3.6	2.3	1.9	-1.6	-0.8	0.6	-3.1	-0.4	-0.6	0.0	0.3
Elbląg	a	0.361**	0.253	0.265	0.147	0.203	0.010	0.0400.	0.340*	-0.144	0.036	-0.036	0.061	0.397**
	b	0.07	0.06	0.08	0.03	0.04	0.0	01	0.06	-0.03	0.01	-0.005	0.01	0.03
	c	3.4	3.2	4.0	1.7	1.8	0.0	0.4	3.1	-1.3	0.3	-0.2	0.6	1.4
Coast zone (9 stations)	a	0.355*	0.248	0.225	0.329*	0.256	0.059	0.026	0.242	-0.203	-0.05	-0.151	0.028	0.390**
	b	0.6	0.06	0.06	0.08	0.05	0.01	0.005	0.04	-0.04	-0.01	-0.02	0.004	0.03
	c	3.3	3.0	2.9	4.1	2.5	0.5	0.25	2.1	-1.9	-0.4	-1.0	0.2	1.3

*significant at $\alpha_{0.05}$ and $\alpha_{0.01}$.

Table 4. Deviation of daily maximum air temperature from the average value in successive 10-year periods (1956-2005)

Station/Month	Decades	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	56-65	–0.5	–0.9	–1.4	–1.5	–1.9	–0.3	0.2	–1.5	0.6	0.2	–0.1	0.0
	66-75	–1.7	–0.8	–0.5	–0.8	–0.6	–0.9	–1.5	–0.5	1.0	0.1	1.4	–1.1
Świnoujście	76-85	–0.4	–1.3	–0.2	–1.3	0.9	–0.2	–1.0	–0.3	0.4	0.4	0.3	0.8
	86-95	1.9	0.3	0.9	2.7	–0.3	0.2	1.8	2.5	–1.9	–0.4	–1.3	0.9
	96-05	0.9	2.7	1.1	0.8	2.0	1.2	0.5	–0.2	–0.1	–0.2	–0.1	–0.5
	56-65	–0.8	–1.0	–1.9	–1.8	–2.1	–0.6	0.0	–1.3	0.4	–0.2	–0.3	0.1
	66-75	–1.4	–0.4	–0.3	–1.3	–0.4	–2.0	–1.0	–1.5	1.3	0.1	0.9	–1.5
Kołobrzeg	76-85	–0.7	–1.2	0.7	–1.2	1.6	0.7	–0.7	0.6	0.5	1.2	0.9	0.7
	86-95	2.0	0.3	1.5	2.7	–0.7	0.8	2.1	2.8	–2.2	–0.5	–1.3	1.0
	96-05	0.8	2.3	0.0	1.6	1.7	1.1	–0.3	–0.6	0.0	–0.5	–0.2	–0.3
	56-65	–0.8	–1.1	–2.2	–0.8	–1.5	–0.2	0.2	–2.3	0.9	–0.3	–0.3	0.0
	66-75	–1.7	–0.4	0.5	–0.8	–0.1	0.2	0.2	0.2	1.3	–0.1	0.7	–1.5
Koszalin	76-85	–0.8	–1.1	–0.2	–1.4	1.5	–0.3	–0.8	0.1	0.4	1.0	0.6	0.6
	86-95	2.4	0.2	1.2	1.9	–0.8	–0.3	1.2	2.6	–2.3	–0.1	–0.9	1.2
	96-05	0.8	2.4	0.7	1.0	0.9	0.6	–0.8	–0.6	–0.4	–0.6	0.0	–0.4
	56-65	–0.9	–1.2	–2.1	–1.3	–1.8	0.8	0.3	–1.4	1.0	–0.6	–0.3	0.4
	66-75	–1.3	0.0	–0.2	–1.4	–0.1	–1.7	0.7	0.2	1.5	0.5	1.0	–1.2
Ustka	76-85	–0.7	–1.6	0.6	–1.5	1.8	0.1	–1.3	–0.1	–0.1	0.7	0.5	0.4
	86-95	1.9	0.4	2.1	2.6	–0.8	0.0	0.9	1.4	–2.6	–0.2	–1.3	1.1
	96-05	1.0	2.5	–0.3	1.6	0.8	0.7	–0.6	–0.1	0.2	–0.5	0.0	–0.5
	56-65	–0.4	–1.0	–2.2	–1.2	–1.6	0.7	–0.1	–0.7	1.2	–0.2	0.1	0.6
	66-75	–1.0	0.0	0.2	–1.2	–0.4	–1.4	0.8	0.1	1.6	0.5	1.2	–1.2
Łeba	76-85	–1.0	–1.9	0.4	–1.6	1.6	–0.2	–1.3	–0.2	–0.1	0.8	0.2	0.2
	86-95	1.6	0.4	1.6	2.2	–0.6	0.1	1.0	1.5	–2.7	–0.5	–1.6	0.8
	96-05	0.6	2.4	–0.1	1.8	1.0	0.8	–0.3	–0.7	0.0	–0.5	0.2	–0.5

	56-65	–0.5	–0.4	–2.4	–0.4	–1.6	0.2	0.4	0.1	0.9	–0.1	–0.3	0.2
	66-75	–1.2	–0.2	1.0	–0.8	–0.6	–0.3	–0.1	0.4	1.0	0.2	0.9	–1.1
Hel	76-85	–0.6	–1.1	0.3	–1.9	0.4	0.2	–0.8	–0.8	–0.4	0.8	0.3	0.6
	86-95	1.7	0.4	1.3	1.8	0.5	–0.4	1.3	0.9	–1.7	–0.2	–1.0	0.8
	96-05	0.6	1.3	–0.2	1.3	1.2	0.3	–0.9	–0.7	0.3	–0.7	0.1	–0.6
	56-65	–0.3	0.0	–2.9	–0.4	–1.7	1.2	0.7	–0.2	1.4	0.0	–0.2	0.7
	66-75	-1.2	0.5	1.1	-0.3	0.5	0.1	0.3	0.2	1.7	0.0	1.5	-1.1
Gdańsk	76-85	-1.3	-2.5	-0.5	-1.9	0.4	-0.9	-1.5	-1.2	-0.5	0.1	0.1	0.4
	86-95	2.2	0.3	1.9	1.8	-0.1	-0.7	1.4	2.2	-2.2	-0.3	-1.1	1.1
	96-05	0.7	1.6	0.5	0.8	0.8	0.3	-0.9	-1.0	-0.4	0.1	-0.3	-1.0
	56-65	-0.9	-1.3	-2.9	0.2	-1.7	0.3	0.5	-1.3	0.6	-0.2	-0.5	-0.1
	66-75	-1.5	-0.2	0.3	-0.8	0.0	-0.2	-0.1	-0.3	1.0	-0.5	0.8	-1.4
Elbląg	76-85	-0.6	-1.2	0.6	-1.8	1.6	-0.3	-1.8	-0.8	0.0	0.9	0.7	0.8
	86-95	2.4	1.0	1.4	1.6	-0.5	-0.6	1.4	2.2	-1.6	0.0	-1.4	1.3
	96-05	0.5	1.7	0.7	0.9	0.5	0.8	-0.2	0.1	0.0	-0.1	0.5	-0.6

At most of the investigated stations during the years 1956 -2005 there was a positive trend of daily maximum air temperature from December to June and in August, including a significant and highly significant one in January, April and August, and a negative insignificant one in July and from September to November (Tab. 3). A growing trend of maximum temperature in February, March and May turned out to be significant for most of the stations at the level of $\alpha = 0.1$, and at a few stations also at the level of $\alpha = 0.05$. The trend of changes in the daily maximum air temperature calculated for 4 seasons of the year and 9 stations along the coast turned out to be increasing highly significantly in spring and significantly in winter, whereas in summer a slight positive trend could be noticed and a negative one in autumn (Fig.2). Such a large increase in this temperature in spring is determined, among other things, by progressing increase in the number of sunny hours, particularly in May (Koźmiński, Michalska 2006), while in winter it is related to an increase in the cyclone activity and an inflow of oceanic masses from the north west and the west (Girjatowicz 2007, Marsz 2001). The progressing increase in the maximum air temperature in the region of Bydgoszcz was also indicated by Żarski *et al*. (2007), a particularly significant one during the warm half of the year (0.56°C/10 lat), and a lower one during the cold half of the year (0.24°C/10 years). Similar results of studies obtained by Cebulak and Limanówka (2007) confirm a growing trend of maximum temperature in 1951-2005, in a considerable area of the country, including also the number of very hot days with 35°C.

Interesting are estimates of the changes in the daily maximum temperature during the whole period of 50 years. The largest growth in this temperature occurs in April, when it amounts to 4.1°C/50 years for the whole coast, reaching the highest values in Darłowo (7.2°C) and in Kołobrzeg (5.8°C). Also the results of studies by Żarski *et al.* (2007) show that out of the considered months, the largest increase in the maximum air temperature was in the region of Bydgoszcz in April – 0.91°C/10 years. Another month with a large increase in the maximum temperature in the coastal zone is January – from 2.5° in Łeba to 3.7°C in Ustka, at average for the whole coast at 3.3°C per 50 years. The further along the coast eastwards, the lower the average annual gain of the daily maximum air temperature which, during the studied period of 50 years, ranged from 0.7°C in Hel to 1.9°C in Świnoujście, showing a more distinct warming of the western part of the coast.

Figure 3 illustrates the frequency of occurrence of the daily maximum air temperature during a year (worked out on the basis of data from the stations in Świnoujście, Ustka and Elbląg) in adopted temperature intervals of every 5°C in two periods: 1956-1980 and 1981-2005. Two maxima of the frequency of occurrence of this temperature are marked, one within the interval of 5°-10°C and another, more distinct, in the interval of 25-30°C. The course of frequency of the

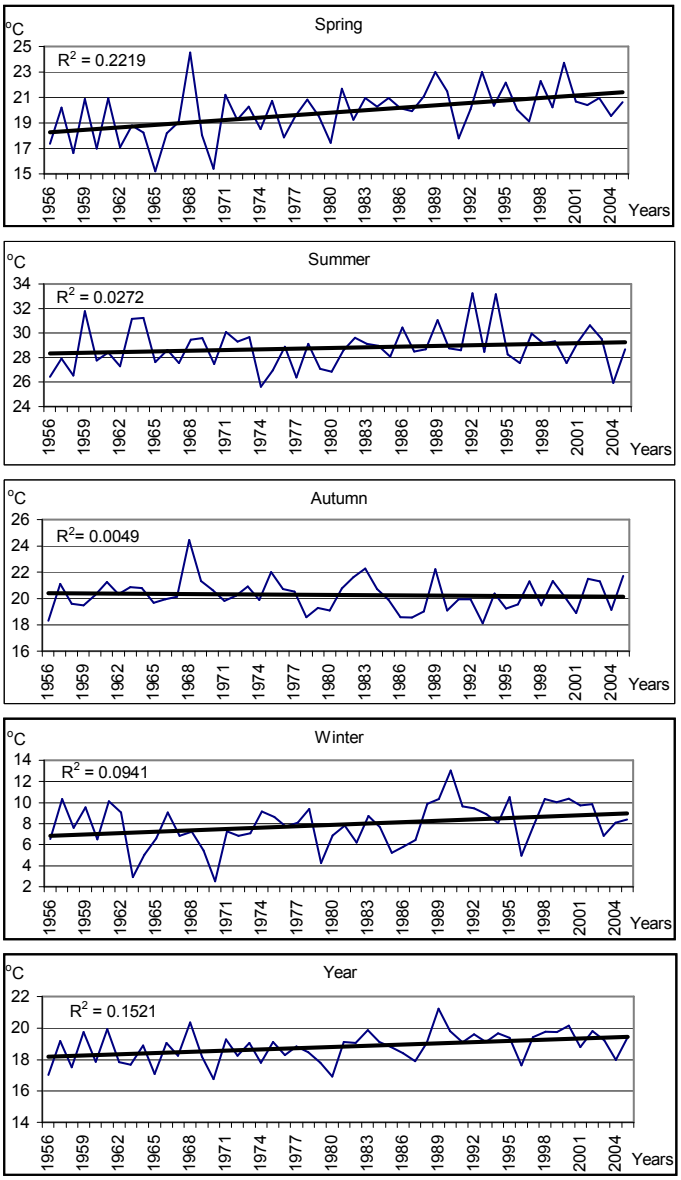


Fig. 2. Course of daily maximum air temperature and the trend according to seasons and year in 1956-2005. Averaged values from 9 stations on the coast

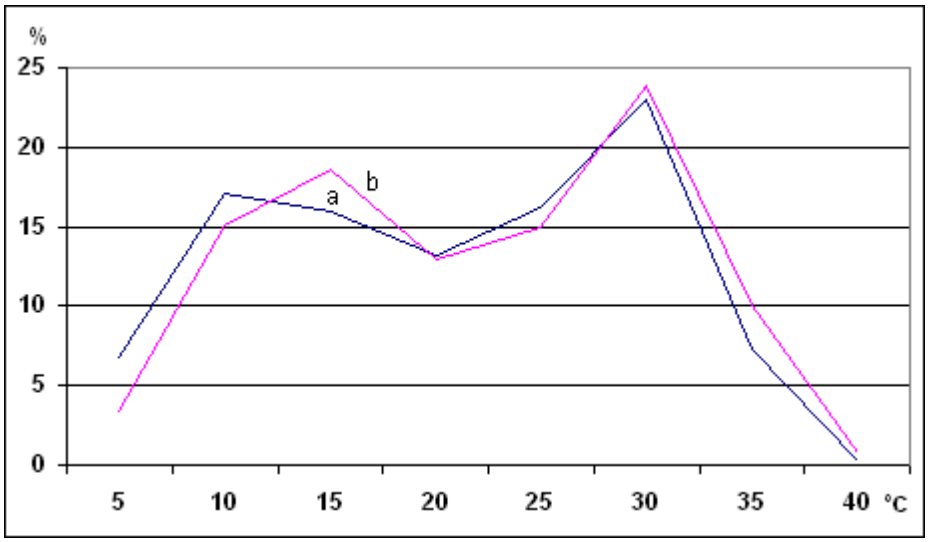


Fig. 3. Frequency of occurrence of daily maximum air temperature (stations in Świnoujście, Ustka, Elbląg) during a year according to accepted 5 step intervals in period 1956-1980 (a) and 1981-2005 (b)

maximum temperature during the two periods shows a clear displacement towards a higher temperature of the curve for the period of 1981-2005, particularly within the temperature of 10-15°C, as compared to 1956-1980. The average daily maximum air temperature calculated for the 3 mentioned above stations in 1956-1980 amounted to 18.6°C, whereas in 1981-2005 it was 1.0°C higher (19.6°C), at a lower standard deviation amounting to 8.89 and 8.74, respectively. Out of the 5 discussed 10-year periods during 1956-2005, the period of 1986-1995 was characterised by the highest maximum temperature in most of the months, and the period of 1966-1975 by the lowest. Whereas in autumn, to the contrary - the lowest values of the maximum temperature occurred in the 1986-1995 period of the analysed 50 years, and the highest in 1966-1975 (Tab. 4 and Fig. 4).

The time and spatial differentiation of the values of 5% quantiles (extremely low) and 95% ones (extremely high) of the daily maximum air temperature on the coast is illustrated in Table 5. The values of the 5% quantile vary during a year from 1.1°C in February at the station in Gdańsk to 25.5°C in Elbląg in June. The coldest month in respect of the occurrence of extremely low temperature is February, when the spatial differentiation on the coast amounts to 1.8°C, rising westwards from 1.1°C in Gdańsk to 2.9°C in Świnoujście. Whereas in summer, extremely low temperature (5% quantile) occurs, depending on the station, in July or August, taking on the values that range from 23.4°C in Hel to 25.2°C in Elbląg.

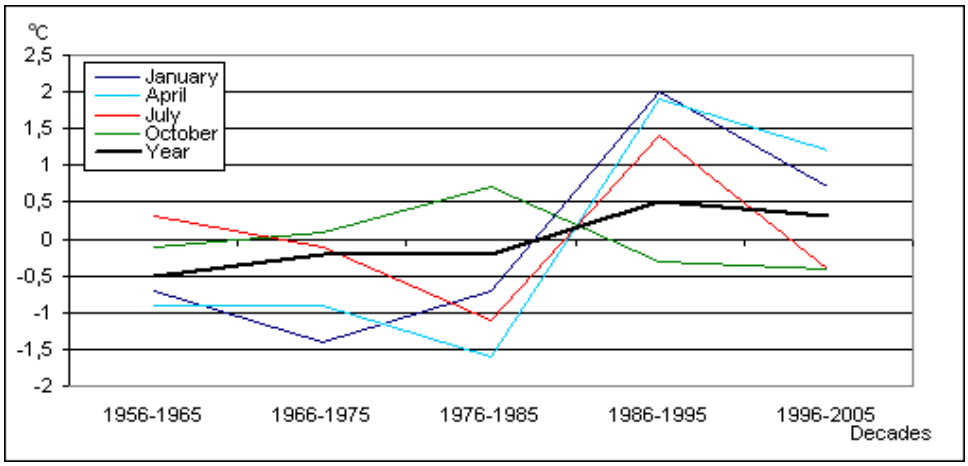


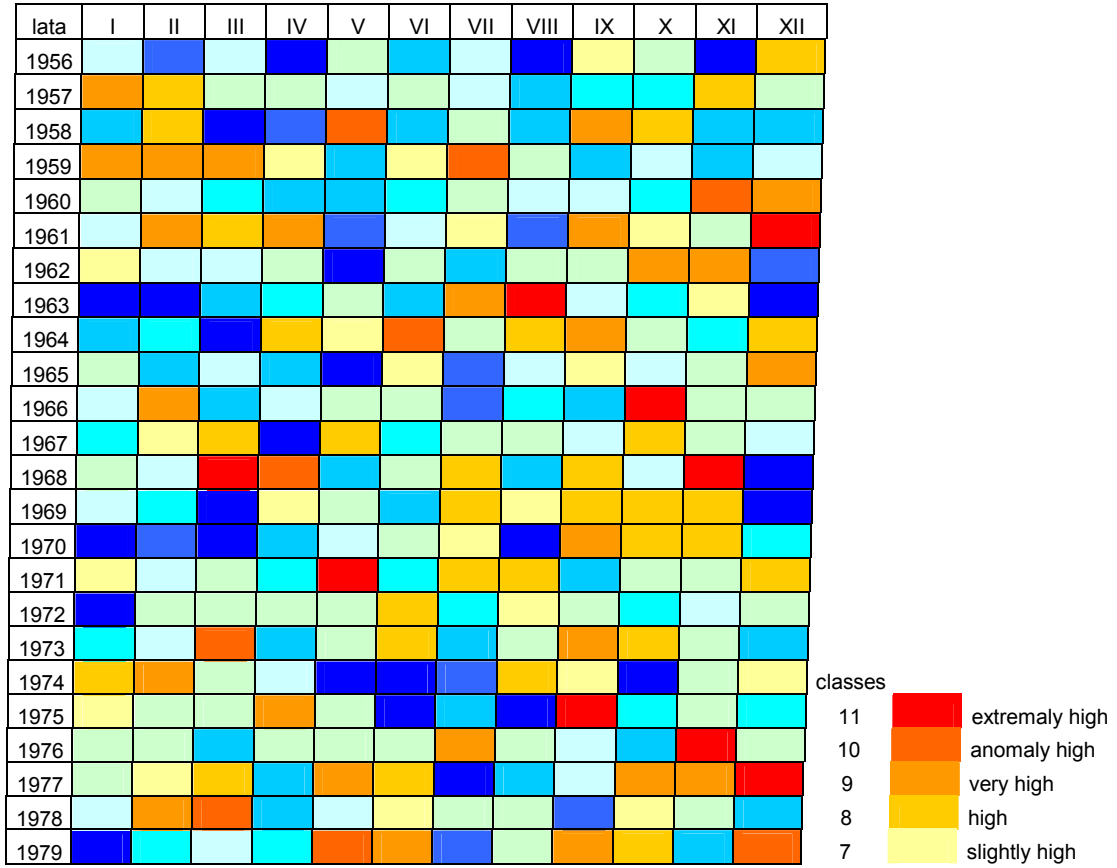
Fig. 4. Deviation of maximum air temperature (average from 8 stations) according to seasons of the year successive 10 years periods in comparison with average temperature (1956-2005)

During a year, the highest values of the 95% quantile occur in July, varying from 32.0° in Hel to 34.8° in Ustka, and even to 35.0°C in Koszalin. Slightly lower values can occur in August – from 30.5° in Hel to 34.8°C in Świnoujście, and at the same time they do not show any distinct spatial direction of changes in the values of daily maximum air temperature (Tab. 5).

In Figure 5, differentiation of the daily maximum air temperature is shown for the Kołobrzeg station in individual years of the 1956-2005 period according to the accepted 11 quantile intervals. The occurrence of months with higher values of maximum air temperature than the average is observed in winter and spring months, particularly from 1988 onwards. At the same time, the contrast of temperature between adjoining months and years increases. Noteworthy is the fact that in the 90s, in autumn, the maximum air temperature took on values remarkably lower than the multi-annual average, which was confirmed by negative values of correlation coefficients (r) of this temperature from September to November (Tab. 3).

In the characteristics of variability of the daily maximum air temperature, its dependence on the monthly average temperature was also taken into consideration. The values of coefficients of correlation between the mentioned temperatures of 1956-2005 included in Table 6 are highly significant, particularly from December to March, showing the closest relationship in January at the correlation coefficient ranging from 0.787 in Elbląg to 0.831 in Hel and 0.832 in Gdańsk (Fig. 6). A smaller relationship occurs in July – from 0.585 in Darłowo to 0.708 in

Kołobrzeg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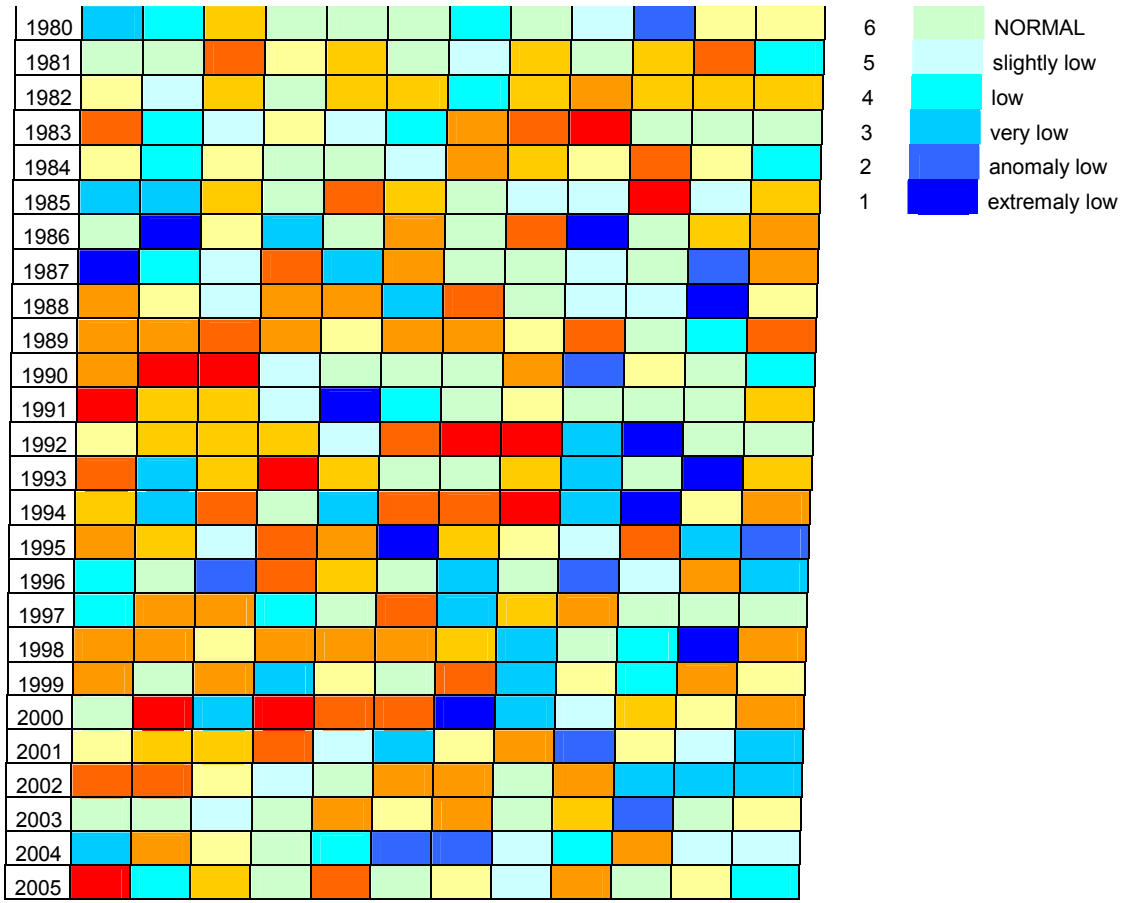

Fig. 5. Classification of daily maximum air temperature according to quantile intervals. Years 1956-2005

Table 5. Quantile values: 5 and 95% of daily maximum air temperature. Years 1956-2005

Station/Month	%	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Świnoujście	95	12.8	15.5	20.9	27.2	31.2	33.3	34.5	34.8	29.2	23.7	15.7	13.6	21.1
	5	3.0	2.9	8.7	14.4	20.4	24.1	23.9	24.2	20.0	15.5	9.1	5.4	17.5
Kołobrzeg	95	12.6	14.9	20.8	27.4	31.5	33.5	34.9	34.3	29.8	24.2	16.1	13.7	20.8
	5	2.8	2.7	8.2	13.6	20.7	22.9	24.1	23.7	19.2	15.6	9.1	4.9	17.6
Koszalin	95	12.5	14.9	21.1	26.9	31.1	33.1	35.0	34.3	29.9	24.4	15.8	13.6	20.9
	5	2.3	2.3	8.3	15.1	21.5	24.9	24.4	24.1	19.3	15.6	8.8	4.4	17.7
Ustka	95	12.1	14.8	20.4	27.6	31.5	33.5	34.8	34.1	30.1	24.6	16.0	12.9	20.7
	5	2.3	2.0	7.6	13.4	19.9	23.3	24.6	24.3	19.5	15.0	8.8	4.7	17.5
Łeba	95	10.8	13.5	19.3	27.1	31.0	32.8	34.3	33.2	29.7	24.0	15.8	11.9	20.4
	5	2.6	1.7	7.1	13.3	19.8	23.6	24.1	23.4	18.9	14.8	8.6	4.7	16.8
Hel	95	10.2	10.8	18.1	22.7	22.1	30.3	32.0	30.5	26.7	21.0	13.9	11.1	18.6
	5	2.0	1.6	4.9	12.5	18.5	21.5	23.4	23.9	19.1	14.4	8.7	4.9	15.6
Gdańsk	95	11.7	14.3	21.5	26.7	30.5	32.8	34.5	33.8	29.7	24.5	15.7	13.0	21.0
	5	1.9	1.1	7.1	14.5	20.9	24.2	24.7	25.2	19.9	15.3	8.5	4.2	17.0
Elbląg	95	11.1	13.5	21.3	27.0	30.7	32.1	34.4	33.7	29.3	24.1	15.5	12.3	20.6
	5	1.9	1.3	6.9	15.8	21.9	25.5	25.2	25.1	20.5	15.3	8.5	3.5	17.4

Table 6. Values of correlation coefficients (r) between monthly average and daily maximum air temperature. Years 1956-2005. Darłowo* 1956-2000

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Świnoujście	0.794	0.770	0.744	0.656	0.531	0.481	0.656	0.519	0.639	0.629	0.466	0.698	0.771
Kołobrzeg	0.827	0.781	0.750	0.674	0.535	0.501	0.613	0.388	0.657	0.599	0.489	0.669	0.636
Koszalin	0.825	0.780	0.768	0.659	0.655	0.545	0.680	0.549	0.637	0.583	0.437	0.715	0.793
Darłowo	0.828	0.785	0.687	0.675	0.557	0.495	0.585	0.446	0.643	0.463	0.433	0.621	0.720
Ustka	0.803	0.757	0.783	0.691	0.697	0.324	0.645	0.511	0.667	0.532	0.498	0.645	0.738
Łeba	0.820	0.792	0.733	0.640	0.644	0.553	0.664	0.498	0.606	0.540	0.511	0.672	0.733
Hel	0.831	0.836	0.740	0.645	0.627	0.487	0.673	0.532	0.605	0.594	0.534	0.701	0.764
Gdańsk	0.832	0.785	0.778	0.636	0.626	0.610	0.695	0.495	0.590	0.650	0.490	0.576	0.803
Elbląg	0.787	0.818	0.790	0.628	0.691	0.592	0.708	0.600	0.687	0.602	0.550	0.679	0.773

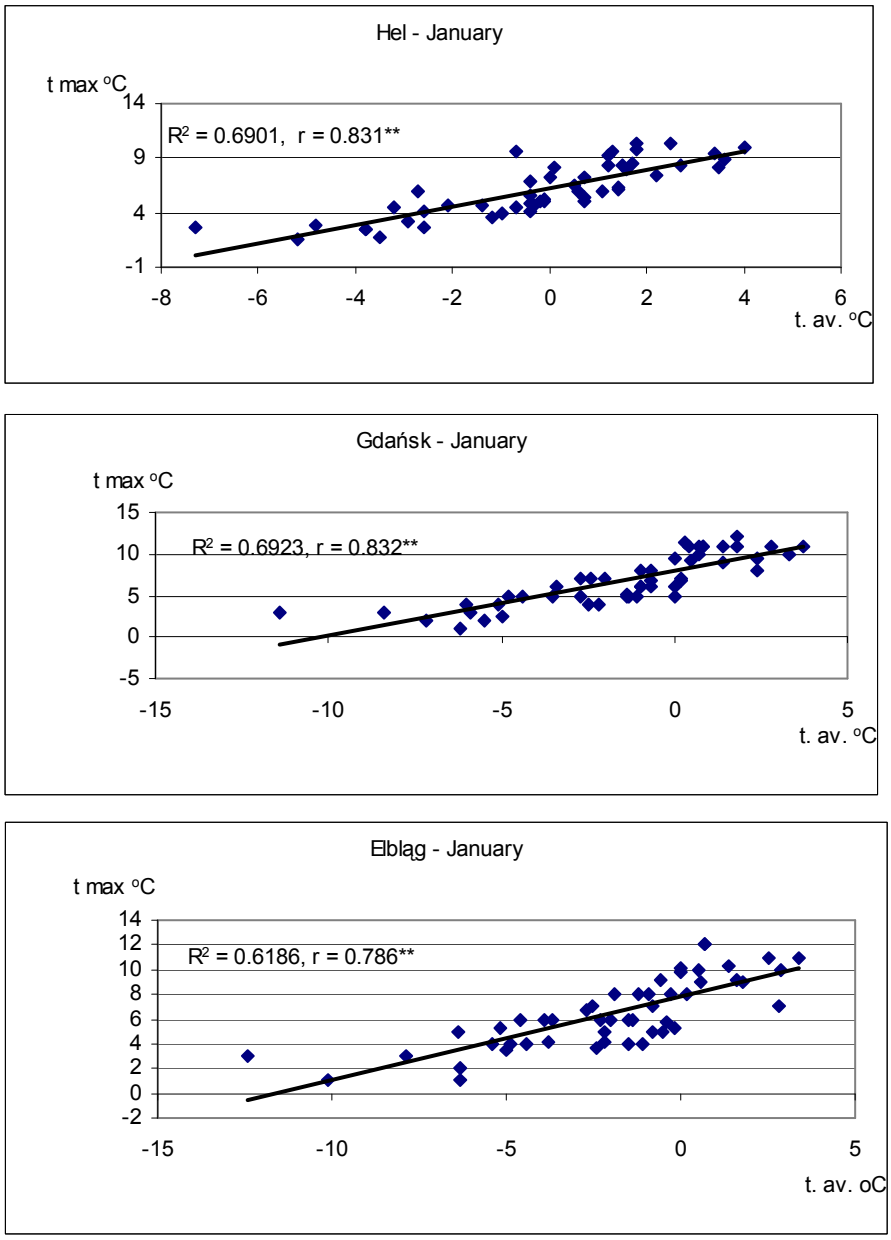

Fig. 6. Relationship between daily maximum air temperature and monthly average Years 1956-2005

Elbląg, and in April – from 0.628 in Elbląg to 0.691 in Ustka, and the smallest relationship is observed in November (from 0.433 to 0.550), June (0.324-0.610) and August (0.388-0.600).

In the light of the presented analysis, 3 zones differing in values of the maximum air temperature can be distinguished on the Polish coast of the Baltic Sea: I – a warm one, consisting of the western part of the coast from Świnoujście to Mielno, II – a moderately warm one, around the Bay of Gdańsk, and III – a cool one – including the central part of the coast from Mielno to Hel.

CONLUSIONS

1. In the Polish coastal zone of the Baltic Sea, the largest variability of the monthly average temperature of air is recorded from December to March, which is reflected in the occurrence of both very cool and very warm weather in winter.
2. The lowest monthly averages of air temperature occur in the western part of the coast in February, and in the north-eastern part in January.
3. During the period from March to November, the highest values of the daily maximum air temperature amounting to >20^{o}C can occur on the coast and from April to October they can be >25^{o}C, and from May to September >30^{o}C. In winter the lowest values of this temperature do not exceed –1.0^{o}C.
4. The largest variability of daily maximum air temperature is in March and in April and the lowest in November, a month of the strongest thermal contrasts between the Atlantic Ocean and the continent.
5. On the Polish coast of the Baltic Sea in spring daily maximum air temperatures are higher than in autumn, it is then contrary to the case of the monthly average air temperature.
6. In the first part of the year (apart from June) a distinct increase in the daily maximum temperature of the air occurred on the coast, statistically significant in January (3.3^{o}C/ 50 years) and in April (4.1^{o}C/ 50 years), and in autumn there was a slight decrease in the temperature, mainly in September.
7. During 1956-2005 an increase in the annual maximum air temperature was marked, larger by about 1.0^{o}C/50 years on the western part than on the eastern part of the coast. In the 5 analysed 10-year periods, the highest maximum temperature was characteristic of the 1986-1995 period, at concurrently the highest variability, month by month. The lowest values of this temperature occurred in the 10-year period of 1956-1965.
8. On the coast, the daily maximum air temperature becomes higher and higher and less variable and 3 zones of differentiated values of daily maximum air temperature can be distinguished.

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ZMIENNOŚĆ MAKSYMALNEJ DOBOWEJ TEMPERATURY POWIETRZA W STREFIE POLSKIEGO WYBRZEŻA BAŁTYKU

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S t r e s z c z e n i e . W pracy wykorzystano średnią miesięczną i maksymalną dobową temperaturę powietrza z 9 stacji meteorologicznych w strefie wybrzeża za okres 1956-2005. Określono zmienność i częstość występowania maksymalnej dobowej temperatury, trendy czasowe oraz zależność od średniej temperatury powietrza. Wykorzystując metodę kwantyli obliczono ekstremalnie niskie (kwantyl 5%) i ekstremalnie wysokie (kwantyl 95%) wartości maksymalnej dobowej temperatury powietrza, a dla 3 stacji (Świnoujście, Kołobrzeg, Hel) dokonano oceny warunków termicznych z roku na rok wg 11 przedziałów kwantylowych. W pierwszej połowie roku (poza czerwcem), wystąpił na wybrzeżu wyraźny wzrost maksymalnej dobowej temperatury powietrza, istotny statystycznie w styczniu (3,3^{o}C/ 50 lat) i w kwietniu (4,1^{o}C/ 50 lat) a jesienią niewielki spadek temperatury, głównie we wrześniu. Najniższe średnie miesięczne temperatury powietrza występuje w zachodniej części wybrzeża w lutym, a w północno-wschodniej w styczniu. W okresie od marca do listopada na wybrzeżu mogą występować najwyższe wartości maksymalnej dobowej temperatury powietrza >20^{o}C, od kwietnia do października >25^{o}C, a od maja do września >30^{o}C, a zimą najniższe wartości tej temperatury nie przekraczają –1,0^{o}C. Na wielkość maksymalnej dobowej temperatury powietrza w zimie (December – March) istotny wpływ ma cyrkulacja atmosferyczna z północnego Atlantyku (NAO) Na wybrzeżu, maksymalna dobowa temperatura powietrza staje się coraz wyższa i mniej zmienna. Na polskim wybrzeżu Bałtyku wydzielić można 3 strefy o zróżnicowanych wartościach maksymalnej dobowej temperatury powietrza.

S ł o w a k l u c z o w e : maksymalna temperatura, trendy liniowe, zmienność, strefy