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THE CHARACTERISTICS OF TEMPERATURE CHANGES IN KOSZALIN IN WINTER SEASON FROM 1850 TO 2010 AND THEIR RELATION TO NORTH ATLANTIC OSCILLATION

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Abstract

The article analyses the air temperature characteristics of the winter season in Koszalin from 1850 to 2010. The trends of changes have been determined. In addition, the frequency of thermal anomalies has been shown. The thermal classification of Lorenc has been adopted for this study. The relationship between the North Atlantic Oscillation and the air temperature in winter seasons has been estimated.

Key words: air temperature, changeability, North Atlantic Oscillation, Koszalin

INTRODUCTION

In recent years the problem of air temperature changes has been studied both with reference to time and space. The main aim of this research is to determinate the danger, which these changes might bring to the natural environment and humans. Between 1900 and 2004 the temperature on the surface of the Earth rose by about 0.4-0.8°C (IPCC Reports 2007). In Poland, in the second half of the 20th century, the average temperature rose by about 0.9°C. The predominant part of this warm-up took place during the 80's and 90's. Filipiak (2004) confirmed the occurrence of strong positive trend in annual air temperature rise during winter and spring at the Southern Baltic Sea coast in the second half of the 20th century. Kirschenstein and Baranowski (2008) obtained similar results in Słupsk. Between 1950 and 2007 the increase in the air temperatures amounted to about 1.3°C. Kirschenstein and Baranowski (2009a) also analysed the changes in air temperature in Koszalin between 1861 and 2007 and found out that in the period in question the increase in the air temperature amounted to about 1.5°C. While examining the temperature changes in Szczecin between 1950 and 2009, Kirschenstein (2011a) concluded that mean air temperature increase was 1.2°C in the period of 60 years.

The aim of this work is to analyse the variability of thermal conditions in Koszalin in the winter, considering the rate of changes determined with a coefficient of linear trend, and to investigate the relations between North Atlantic Oscillation (NOA) and the air temperature. In this study the Jones' index has been used, whose values were determined in 1825 and regularly published on National Weather Service website since then.

According to Boryczka and Stopa-Boryczka (2007) there is a great dependency of temperature field in the North Atlantic and in Europe especially during wintertime. The authors have found out that in 1825-2000 air temperature in Europe was usually positively correlated with the changes of NAO. Similarly, Panfil and Dragańska (2004), after analysing correlative relations between NAO and thermal as well as rain conditions in the north-eastern Poland, obtained statistically significant relations between NAO circulation and the temperature (especially from December to March). The phenomenon of air temperature dependency on North Atlantic Oscillation was also widely studied by Marsz and Styszyńska (Marsz 1999a, b, Marsz and Styszyńska 2002a, b). Also Niedźwiedź (2002) studied the correlation between NAO (according to Jones) and other oscillation indexes (W – zonal western circulation index, S – meridianal southerly circulation index, C – the cyclonicity index), which have a considerable influence on the variability of air temperature in Poland. Niedźwiedź (2002) arrived at the highest correlation between NAO and W index (0.69), above all studied for in the winter season.

The investigated record of air temperatures data in Koszalin based on monthly measuring data from 1850 to 2010. To verify the homogeneity of data series, the non-parametric Smirnov – Kolmogorov test was carried out. The conformity of a continuous series of temperature from 1850-1949 and 1950-2010 was studied. The test result obtained for air temperature showed $\lambda = 1.85$, and was lower than the critical value with the statistical significance of 0.001 ($\lambda_{0,001} = 1.96$), where λ is the 1.85. If $\lambda < \lambda_{0.001}$, it can be assumed that there is no basis to reject the series. Thus it can be stated that the series is probably homogenous.

Koszalin which was chosen to be analysed, is situated in the Southern Baltic Sea coast, about 10 km from the seaside. Such close location at the coasts makes Koszalin region different from other regions of the country. According to classification by Okołowicz (1978), Koszalin is a region being shaped by the influence of the Baltic Sea. In this area the air masses from the ocean, the sea, and the continent clash with each other. This results in a great variability of the weather conditions. The climate in this area has some features characteristic for the oceanic climate: temperature in winter is higher than in other areas in Poland, and on the contrary the temperature in summer is lower, autumn is warmer than spring, and there are high precipitation rates in winter and autumn. It is also important that the coast is exposed for cyclones, which move from North Atlantic towards north-eastern Europe.

In this study only a winter time has been chosen for particular investigations. This stems from the fact that winter season compose December of one year as well as January and February of the next year. This division of the seasons of the year varies from the traditional one in a sense that it is the December of the same calendar year that is taken into account, not the previous year. The author of this study was particularly interested in presenting the influence of NAO on the thermal characteristics of winter seasons in Koszalin as being shaped by changeable heat reserves stored in the waters of the North Atlantic in the warm season, which in turn shape the atmospheric oscillation and the course of air temperature change in the winter season being analysed.

To assess the frequency of thermal anomalies in winter seasons in Koszalin the scale of Lorenc (1998) was used (Table 1).

Table 1

The criteria adopted in the classification (Lorenc 1998)

Class No. and colour scale	Year evaluation	Values interval calculated according $T_{mpt.}$
1	EXTREMELY WARM	$T_{mat.} > T_{mpt.} +2.5SD$
2	ABNORMALLY WARM	$T_{mpt.} +2.0SD < T_{mat.} \leq T_{mpt.} +2.5SD$
3	VERY WARM	$T_{mpt.} +1.5SD < T_{mat.} \leq T_{mpt.} +2.0SD$
4	WARM	$T_{mpt.} +1.0SD < T_{mat.} \leq T_{mpt.} +1.5SD$
5	LIGHT WARM	$T_{mpt.} +0.5SD < T_{mat.} \leq T_{mpt.} +1.0SD$
6	NORMAL	$T_{mpt.} -0.5SD \leq T_{mat.} \leq T_{mpt.} +0.5SD$
7	LIGHT COLD	$T_{mpt.} -1.0SD \leq T_{mat.} < T_{mpt.} -0.5SD$
8	COLD	$T_{mpt.} -1.5SD \leq T_{mat.} < T_{mpt.} -1.0SD$
9	VERY COLD	$T_{mpt.} -2.0SD \leq T_{mat.} < T_{mpt.} -1.5SD$
10	ABNORMALLY COLD	$T_{mpt.} -2.5SD \leq T_{mat.} < T_{mpt.} -2.0SD$
11	EXTREMELY COLD	$T_{mat.} < T_{mpt.} -2.5SD$

($T_{mpt.}$ – mean perennial temperature; $T_{mat.}$ – mean annual temperature; SD – standard deviation)

Air temperature in winter season

The average annual air temperature in winter season in Koszalin amounts to -0.7ºC and in 1850-2010 it fluctuated between -6.6°C (1870/1871) and 3.7°C (1989/1990), (Fig. 1). The warmest month was December (0.1°C), while the coldest month was January (-1.4°C).

Both the highest mean monthly air temperature of 5.7°C (in 1989/1990 winter season), and the lowest temperature of -10.7°C (in 1928/1929 season) were noted in February. About 55.6% of studied years had their winter air temperature below zero. In terms of months, the coldest months were January (64.4%) and February (58.1%). While in December the mean air temperature was below zero only in 41.2% of years.

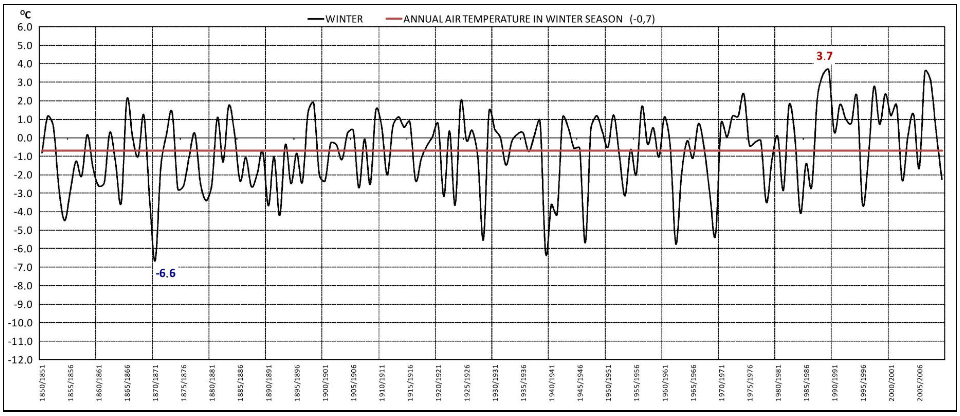

Fig. 1. Average air temperature in winter season in Koszalin (1850-2010)

The data for mean air temperatures was also correlated for decades (Fig. 2). It appears that until 1970, every decade experienced a subzero temperature in the winter season, whereas after 1970 a considerable warming was noted, especially in the last two decades. In the period that was under scrutiny in this study the coldest decade was 1870-1880 one, while the warmest was the 1990-2000 one.

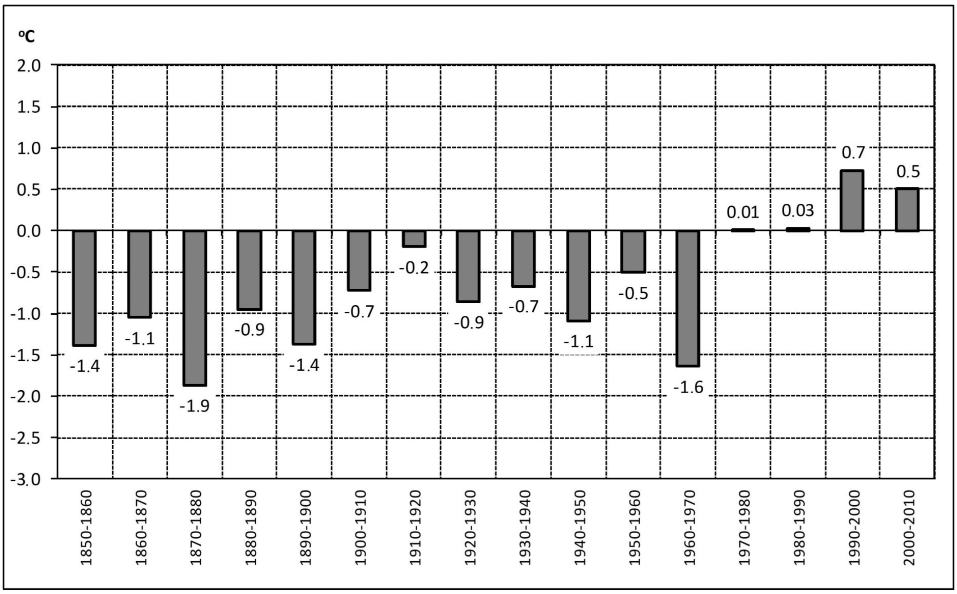

Fig. 2. Decade average air temperature in winter seasons in Koszalin (1851-2010)

In the warmest decade all the winter months experienced temperatures above zero (Fig. 3). Especially December draws our attention here, with seven decades where its temperature was above zero. The warmest one was in the last decade 2000-2010 (1.5°C) and the coldest one was in 1870-1880 (-2.1°C). January, being the coldest of all the months, was exceptionally cold in the following decades: 1890-1900 (-2.8°C), 1940-1950 (-2.7°C) and 1960-1970 (-2.3°C). February, on the other hand, experienced above zero temperature only in the last two decades, while it was the coldest in 1850-1860 decade (-2.3°C).

The analysis of air temperatures during separate months has showed that in 1850-2010 the temperature was characterized by the great variations. To check how great the variations of air temperature were, the values of trends have been calculated. They indicate that in Koszalin, in the long term of 1850-2010, the coefficient of linear trend for winter season equals to 0.0115ºC $year^{-1}$. The mean values obtained indicate that during the 160-year period in Koszalin an increase in air temperature by about 1.8°C was recorded. December was the month with the highest increase in the mean temperature. The rise was about 2.2°C in the 160-year period, whereas in January and February the increase was about 1.7°C. The estimated trends prove that Koszalin experience warming during the winter seasons, which in turn is a clear sign of increasing climate oceanicity.

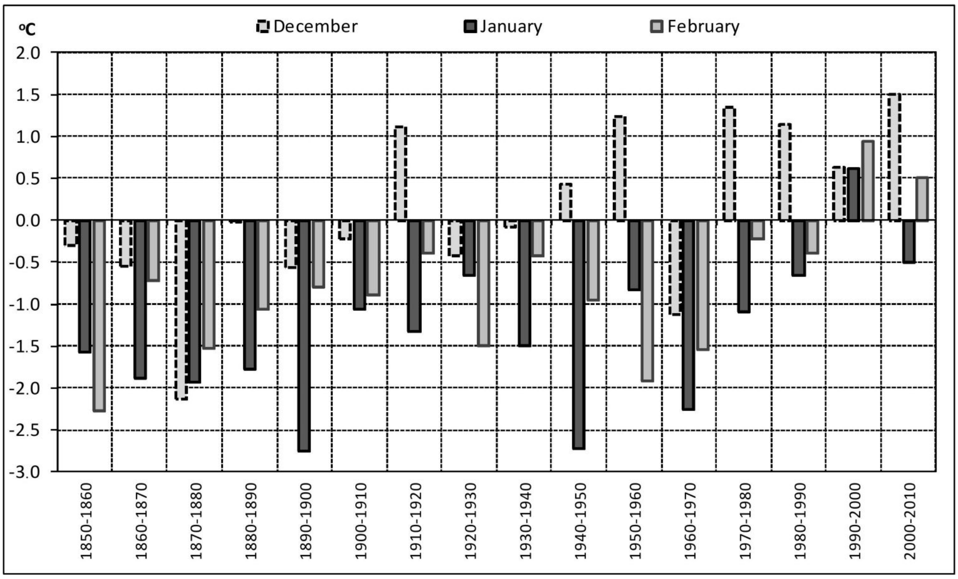

Fig. 3. Decade average air temperature in winter seasons in Koszalin (1851-2010)

The 1861-2007 data record analysed by Kirschenstein and Baranowski (2009a) also proved that Koszalin experience considerable air temperature growth in winter, autumn, and spring, with the lowest increase in the summer seasons. November and December were the months with the highest increase in temperature. More interestingly, the research of shorter periods after 1950 yielded that the increase in air temperature was considerably higher in Koszalin (Kirschenstein and Baranowski 2009b) and Szczecin (Kirschenstein 2011b) in winter and spring, whereas there was a considerable decrease during autumn (from September to November). It indicates considerable cooling of autumn, with a simultaneous warming of spring. These results have been also confirmed by Marsz (2005), who noticed that between 1971-2002 the warmer winters and springs dominated while autumns and the beginning of winter were getting colder. The author claims that the reason for warmer winter and the beginning of spring is the greater influence of zonal circulation over the southern part of the North Atlantic, where warmer oceanic waters have appeared.

North Atlantic Oscillation versus air temperature

The atmospheric circulation is one of the major factors affecting the regional thermal structure. The atmospheric circulation from over the Baltic Sea and over the Atlantic Ocean determines the variability air temperature and of precipitation in the north-western Poland. One of the research lines to assess the influence of atmospheric circulation on the weather conditions is correlation with the North Atlantic Oscillation (NAO) index. This is the difference of atmospheric pressure recorded on the sea level between two stations situated near the centres of the Icelandic Low and the Azores High. The NAO index has two phases, which bring different weather conditions. In winter during the positive NAO phase, there is a rise in pressure in the Azores High accompanied by drop in pressure in the Icelandic Low. Under the positive NOA the winters in Europe are warm and humid, since the air from the Atlantic Ocean moves from west towards east, to Europe and Poland. However, during the negative NAO phase the decrease in pressure gradient leads to the drop in latitudinal air advection, which leads to drop in temperature in Europe (winters are dry and frosty) (Kirschenstein 2011a).

In the years 1850-2010 in winter season the positive phase of NAO (accounted for 67.5% of years) was dominanted over the negative phase. Among the winter months the positive phase occured most often in January (70.0%), than in February (63.1%) and in December (55.6%) (National Weather Service 2011).

The correlations between air temperature in winter and monthly values of NAO index prove that both values show a high importance of correlation, (Fig. 4) with the overall correlation for winter of 0.61.

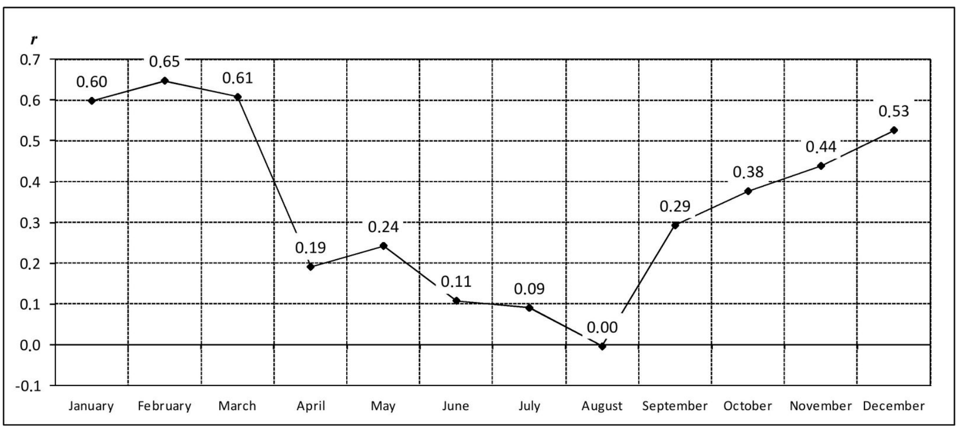

Fig. 4. Correlation coefficient (r) between air temperature and NAO index (1850-2010)

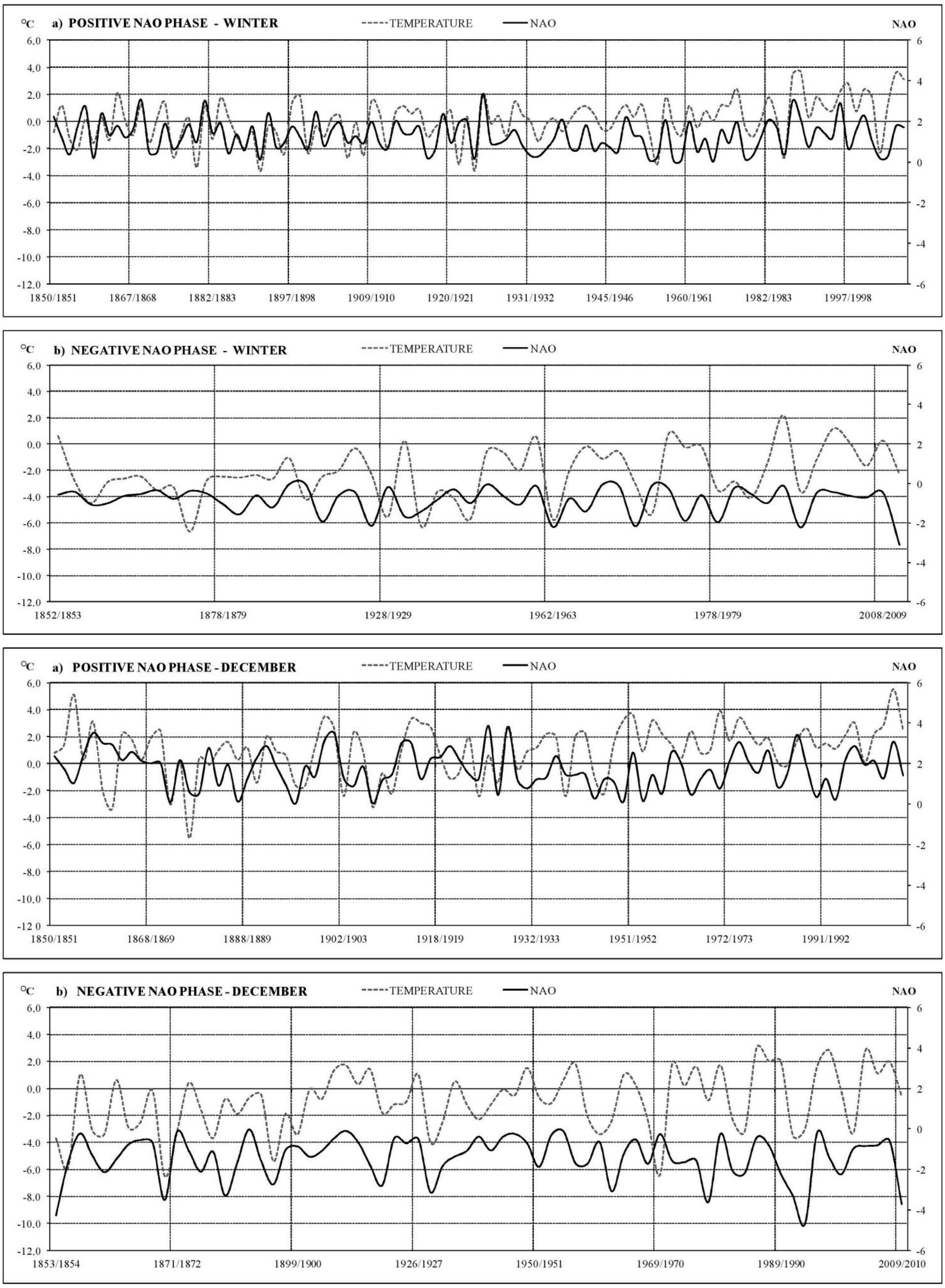

Fig. 5. Average air temperature in winter season and monthly temperature in December along with the NAO index, a – positive NAO phase, b – negative NAO phase (Koszalin, 1850-2010)

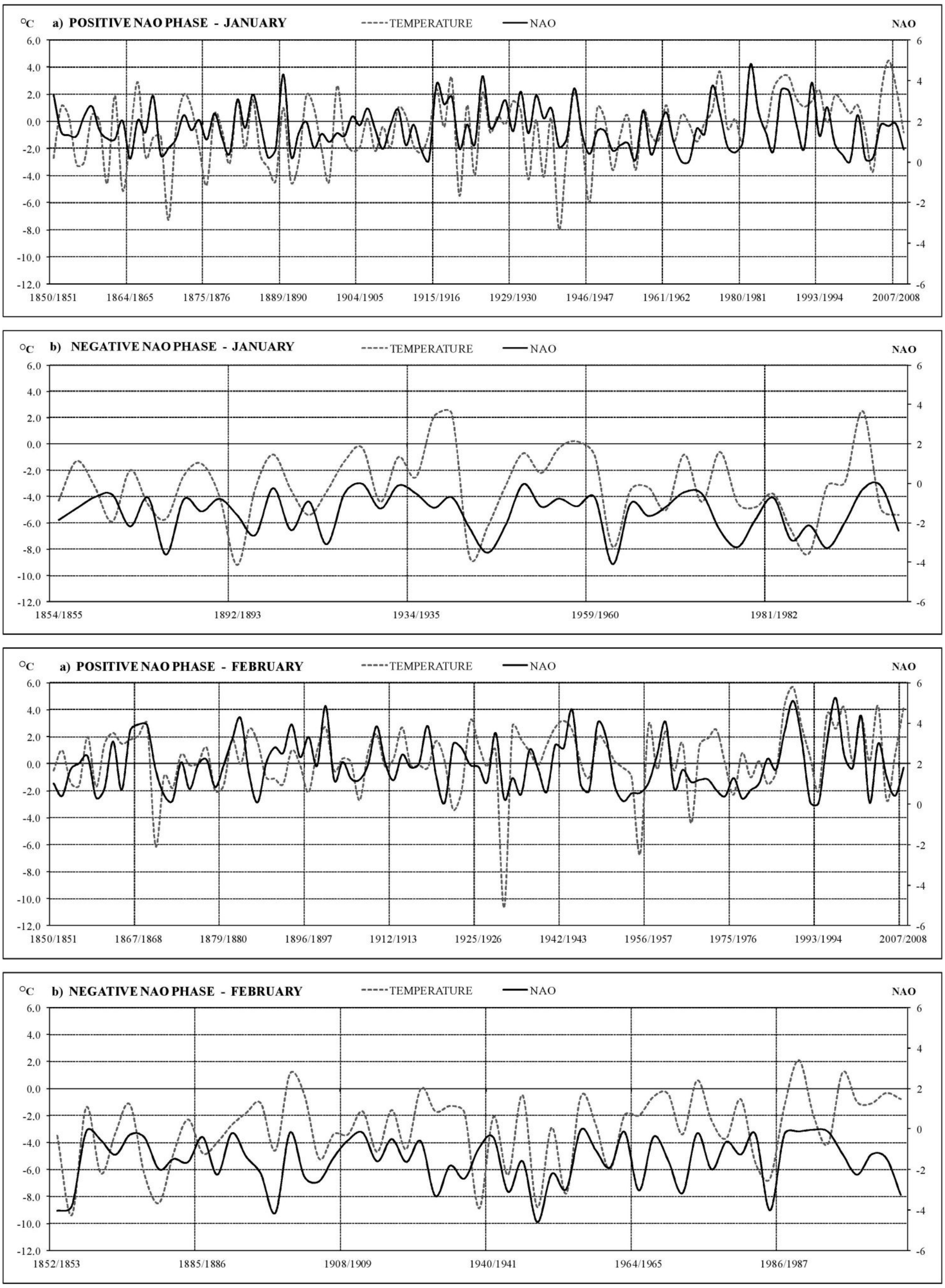

Fig. 6. Average monthly air temperature in January and February along with NAO index
a – positive NAO phase, b – negative NAO phase (Koszalin, 1850-2010)

In cold periods of the year, the highest the longitudinal pressure gradient between the Icelandic Low and the Azores High, the more heat stored in the waters of the North Atlantic finds its way into the air. As a result, winters are warmer with frequent thawing periods and short lasting ice cover. The dependence of the air temperature and the value of NAO index seems to be proven not only by the value of the index itself, but also by the graphs showing the average monthly air temperature and the NAO index in the long term of 1850-2010 (Figs 5, 6). From the graphs we can conclude that both elements are interrelated. In the studied months (Dec.-Feb.) we can observe a considerable phase conformity – the positive NAO phase is met with a rise in average monthly temperature, while the negative NAO phase is represented in the fall of temperature. In December the conformity of both phases equals to 70.6%, while in January the conformity is 60.6%, in February is 72.5%, whereas in winter season it is 66.9%. An exceptionally close relations are present while the NAO phase is negative, which in turn means fall in air temperature. In January the conformity of both parameters is 91.7%, in February – 91.5%, in December – 63.4%, whereas for the whole winter season the conformity amounts to 84.6%. In cases the phase is positive and when there is a rise in air temperature, the phase conformity is lower and amounts to 76.4% in December, 47.3% in January, 61.4% in February and 58.3% for the whole winter season.

The analysis also shows that the occurrence of the coldest and warmest months was closely related to the appropriate NAO phase. For example, under the maximum value of NAO index (5.3) the average air temperature was 2.6°C, whereas under the minimum value (-4.1) the temperature was -7.8°C. Similar dependence appeared in other months (Table 2). An exception here is the coldest February -10.7°C, which appeared in 1928/1929 season, the NAO index was positive and amounted to 0.27.

Table 2

The maximum and minimum values of NAO index and related air temperature mutual interdependence in Koszalin (1850-2010)

Minimum and maximum values	December	January	February	Winter
Maximum value of NAO index	3.9	4.8	5.3	3.4
Air temperature with maximum value of NAO index	0.6	4.2	2.6	2.0
Minimum value of NAO index	-4.7	-4.1	-4.6	-3.1
Air temperature with minimum value of NAO index	-3.0	-7.8	-8.8	-2.3
The coldest months in the long term period of the study	-6.5	-9.2	-10.7	-6.6
The value of NAO index in the coldest month	-3.5	-1.6	0.3	-0.4
The warmest month in the long term period of the study	5.5	4.5	5.7	3.7
The value of NAO index in the warmest months	3.1	1.8	5.1	2.1

The above analysis shows that atmospheric circulation marked with NAO index is closely correlated with the air temperature in winter season. This seems to result from high activity of pressure areas forming over the Atlantic. In the warmer part of a year this influence is decreased, especially in summer months.

In the warm season of the year the air that arrives from the Atlantic is colder and is characterized by a considerable changeability, which often brings colder periods. What is more, in this period the local conditions play a very important role. In case of southern Baltic littoral the Baltic Sea influences the air temperature, however differently for different seasons of the year. In cold periods of the year it causes the air to warm up, whereas in warmer the sea cools the air down. In that way it eases the contrasts between the seasons of the year. The complexity of different factors that play an important role in forming the air temperature distribution in Koszalin causes a considerable variability, both in the month to month run and the long term run.

Anomalies of air temperature

To assess the frequency of anomalies in the air temperature data distribution Lorenc's (1998) scale was adopted. Moreover, the scale was adopted to assess the frequency of monthly temperature records that were above or below the long term average. Hence we have normal periods where the average temperature is within the norm ($T_{mpt.}$ -0.5SD ≤ $T_{mat.}$ ≤$T_{mpt.}$ +0.5SD), warmer than usual (mean air temperature range within $T_{mpt.}$ +2.5SD < $T_{mat.}$ ≤ $T_{mpt.}$ +1.0SD as compared to mean perennial temperature) and colder than usual (mean air temperature range within $T_{mpt.}$ -1.0SD ≤ $T_{mat.}$ < $T_{mpt.}$ -2.5SD) as compared to mean perennial temperature.

Anomalies of air temperature in winter season

In the long term period of 1850-2010 the mean air temperature in the winter season was characterized by considerable variability as compared to perennial average. The researched data show that thermal anomalies were observed in all the winter seasons of the year (Fig. 7).

In the long term period which was studied here we did not encountered extremely warm winter seasons, but there were extremely cold ones in the winters of 1870/1871, 1939/1940, 1946/1947, 1962/1963 (Table 3, Fig. 7). Abnormally warm or very warm winters occurred rarely, as did the abnormally cold or very cold ones. On the other hand, there were a lot of normal winters (38.1%), light warm (19.4%) and light cold (13.1%). The general classification shows that abnormally warm winters were more frequent than abnormally cold ones (Table 3, Fig. 7).

With reference to months, between 1850-2010 December and January were most often abnormally warm, rarely they were normal and the least frequent were the abnormally cold ones. Whereas February was mostly normal, then abnormally warm (Table 3).

From the analysis of thermal classification of the months the following conclusions can be drawn (Table 3, Fig. 7):

– the winter months were mostly normal;
– very often they were light warm and warm or cold and light;
– in the period of 160 years extremely cold months occurred in December – 1855/1856, 1870/1871, 1969/1970, January – 1892/1893, 1939/1940 and February – 1854/1855, 1869/1870, 1928/1929, 1939/1940, 1946/1947;
– the winter months were never extremely warm but it happened they were abnormally warm (December – 1852/1853, 2006/2007, January – 2006/2007 and February – 1989/1990).

Table 3

Frequency (%) of periods with temperature above, within norm and abnormally warm and cold in Koszalin (1850-2010)

Thermal evaluation of the period	December	January	February	Winter
	Detail classification			
1. Extremely warm	0.0	0.0	0.0	0.0
2. Abnormally warm	1.3	0.6	0.6	1.9
3. Very warm	0.6	3.8	3.1	2.5
4. Warm	11.3	12.5	10.0	8.8
5. Light warm	22.5	18.1	17.5	19.4
6. Normal	**35.0**	**33.8**	**45.0**	**38.1**
7. Light cold	9.4	13.1	9.4	13.1
8. Cold	12.5	11.3	5.6	9.4
9. Very cold	4.4	3.1	3.8	3.1
10. Abnormally cold	1.3	2.5	1.9	1.3
11. Extremely cold	1.9	1.3	3.1	2.5
Thermal evaluation of the period	December	January	February	Winter
	General classification			
1. Warm	**35.6**	**35.0**	31.3	32.5
2. Normal	35.0	33.8	**45.0**	**38.1**
3. Cold	29.4	31.3	23.8	29.4

The thermal classification prepared for winter months and winter seasons proves that there is a considerable variability of the warm and cold periods, which follow one after another (we studied periods of at least 3 years). On the basis of the lists of data (Table 4, Fig. 7), the following characteristics can be drawn:

– there were some regular periods, lasting usually for 3-4 years, there were also some longer ones that lasted for 5 lat (February) and 7 years (winter);
– with reference to the very warm periods it also happened that they lasted

5 years (December, January, winter) or 7 years (January), whereas the longest very cold period lasted only for 5 years (January);

- among the abnormally cold periods we can enlist the following: 1853-1856, 1869-1871, 1878-1881, 1939-1942 and 1968-1970; in these periods we experienced 4 extremely cold winters, besides, February was extremely cold five times, December 3 times and January twice;
- after 1987 we could notice a very warm period, which lasted for 23 years with little exceptions, there were three very cold winters and five regular ones; in this time 3 abnormally warm winters took place; especially warm was the 2006/2007 one, during which we experienced abnormally warm December and January.

Table 4

The length of periods with temperature above, within norm and abnormally warm and cold in Koszalin (1850-2010)

Months and seasons	Periods	Length of the periods in years						
		3	4	5	6	7	3	4
December	Normal	3	2	-	-	-	3	2
	Excessively warm	5	-	1	-	-	5	-
	Excessively cold	3	1	-	-	-	3	1
January	Normal	5	1	-	-	-	5	1
	Excessively warm	-	-	1(1997- -2002)	-	1(1987- -1994)	-	-
	Excessively cold	2	-	1(1890- -1895)	-	-	2	-
February	Normal	7	-	1(1979- -1984)	-	-	7	-
	Excessively warm	1	1	-	-	-	1	1
	Excessively cold	2	-	-	-	-	2	-
Winter	Normal	2	1	-	-	1(1931- -1938)	2	1
	Excessively warm	2	2	1(1997- -2002)	-	-	2	2
	Excessively cold	3	-	-	-	-	3	-

To assess the degree to which the positive NAO phase correlates with the occurrences of abnormally warm months and winters, and the negative NAO phase correlates with abnormally cold ones, the thermal classes of months and winter seasons have been marked according to NAO indexes (Fig. 8). Results indicated that, when the NAO phase was positive, 90.4% winters were excessively warm.

	DECEMBER	JANUARY	FEBRUARY	WINTER		DECEMBER	JANUARY	FEBRUARY	WINTER		DECEMBER	JANUARY	FEBRUARY	WINTER		DECEMBER	JANUARY	FEBRUARY	WINTER
1850/1851	6	6	6	6	1890/1891	10	8	6	9	1930/1931	6	6	4	5	1970/1971	5	6	5	5
1851/1852	5	5	5	5	1891/1892	5	7	6	6	1931/1932	6	5	6	6	1971/1972	3	8	6	6
1852/1853	2	5	7	5	1892/1893	7	11	6	9	1932/1933	6	8	6	6	1972/1973	5	6	5	5
1853/1854	9	7	6	8	1893/1894	6	7	5	6	1933/1934	8	5	5	6	1973/1974	6	5	4	5
1854/1855	6	8	11	9	1894/1895	6	7	8	7	1934/1935	5	6	5	6	1974/1975	4	3	6	3
1855/1856	11	6	6	8	1895/1896	7	6	6	6	1935/1936	6	4	6	6	1975/1976	5	6	7	6
1856/1857	6	7	6	6	1896/1897	7	7	6	7	1936/1937	5	7	6	6	1976/1977	6	6	5	6
1857/1858	4	7	9	7	1897/1898	6	4	5	4	1937/1938	7	5	5	6	1977/1978	5	5	7	6
1858/1859	7	5	5	6	1898/1899	4	5	5	4	1938/1939	8	4	4	5	1978/1979	8	8	7	8
1859/1860	8	6	6	6	1899/1900	9	6	6	7	1939/1940	7	11	11	11	1979/1980	5	8	6	6
1860/1861	9	9	5	7	1900/1901	4	8	8	7	1940/1941	8	9	6	8	1980/1981	5	6	6	6
1861/1862	6	8	7	7	1901/1902	6	4	7	6	1941/1942	5	10	9	9	1981/1982	8	7	6	8
1862/1863	8	4	4	6	1902/1903	8	6	4	6	1942/1943	5	6	4	5	1982/1983	5	3	6	4
1863/1864	5	8	6	6	1903/1904	6	6	6	6	1943/1944	6	4	6	5	1983/1984	6	5	6	6
1864/1865	8	6	10	8	1904/1905	5	6	6	6	1944/1945	6	7	4	6	1984/1985	6	9	9	9
1865/1866	5	3	5	4	1905/1906	6	5	6	5	1945/1946	6	6	6	6	1985/1986	4	6	10	6
1866/1867	6	6	5	6	1906/1907	8	6	7	8	1946/1947	8	9	11	11	1986/1987	5	10	6	7
1867/1868	8	6	5	6	1907/1908	6	6	5	6	1947/1948	5	5	6	5	1987/1988	5	4	5	4
1868/1869	5	6	4	5	1908/1909	8	6	7	7	1948/1949	5	5	5	5	1988/1989	4	3	3	2
1869/1870	6	6	11	8	1909/1910	6	5	5	4	1949/1950	4	7	5	6	1989/1990	5	3	2	2
1870/1871	11	10	9	11	1910/1911	5	5	6	5	1950/1951	6	6	6	6	1990/1991	6	4	6	6
1871/1872	8	6	6	6	1911/1912	6	8	6	7	1951/1952	4	5	6	5	1991/1992	5	5	4	4
1872/1873	6	4	6	6	1912/1913	4	6	6	5	1952/1953	7	6	6	6	1992/1993	6	4	6	5
1873/1874	5	5	6	4	1913/1914	4	6	4	5	1953/1954	6	7	10	8	1993/1994	5	4	6	5
1874/1875	7	6	8	8	1914/1915	4	6	6	5	1954/1955	4	6	7	6	1994/1995	4	6	3	4
1875/1876	8	8	6	7	1915/1916	6	4	6	5	1955/1956	5	6	10	7	1995/1996	9	7	8	8
1876/1877	9	5	6	6	1916/1917	5	7	8	7	1956/1957	5	5	4	4	1996/1997	8	7	4	6
1877/1878	6	6	5	6	1917/1918	7	6	6	6	1957/1958	6	6	6	6	1997/1998	5	4	3	3
1878/1879	6	8	6	7	1918/1919	6	6	6	6	1958/1959	5	5	6	5	1998/1999	6	4	6	5
1879/1880	10	7	6	8	1919/1920	7	6	5	6	1959/1960	6	6	7	6	1999/2000	5	5	4	3
1880/1881	6	9	7	7	1920/1921	7	3	6	5	1960/1961	5	6	4	5	2000/2001	4	5	6	5
1881/1882	6	4	5	5	1921/1922	6	8	7	8	1961/1962	7	5	6	6	2001/2002	6	5	3	4
1882/1883	7	6	6	6	1922/1923	5	5	6	5	1962/1963	9	10	9	11	2002/2003	8	6	7	7
1883/1884	6	4	4	4	1923/1924	8	7	8	8	1963/1964	8	6	6	7	2003/2004	4	7	5	6
1884/1885	5	6	5	6	1924/1925	6	4	4	4	1964/1965	6	5	6	6	2004/2005	4	4	6	5
1885/1886	6	6	8	7	1925/1926	6	6	5	6	1965/1966	6	7	6	6	2005/2006	6	8	6	6
1886/1887	6	6	6	6	1926/1927	6	5	6	5	1966/1967	6	6	5	5	2006/2007	2	2	6	2
1887/1888	6	7	8	7	1927/1928	9	6	5	6	1967/1968	6	6	6	6	2007/2008	4	4	3	3
1888/1889	6	8	7	7	1928/1929	7	8	11	10	1968/1969	8	7	7	8	2008/2009	5	6	6	6
1889/1890	7	5	6	6	1929/1930	4	4	6	4	1969/1970	11	8	8	10	2009/2010	6	8	6	7

Scale:

1	EXTREMELY WARM	2	ABNORMALLY WARM	3	VERY WARM
4	WARM	5	LIGHT WARM	6	NORMAL
7	LIGHT COLD	8	COLD	9	VERY COLD
10	ABNORMALLY COLD	11	EXTREMELY COLD		

Fig. 7. Thermal classification in Koszalin (1850-2010)

	DECEMBER	JANUARY	FEBRUARY	WINTER		DECEMBER	JANUARY	FEBRUARY	WINTER		DECEMBER	JANUARY	FEBRUARY	WINTER		DECEMBER	JANUARY	FEBRUARY	WINTER
1850/1851	2.4	3.3	1.0	2.2	1890/1891	-2.8	0 3	2.8	0.1	1930/1931	1.2	-0.1	1.3	0.8	1970/1971	-1.6	-0.4	1.2	-0.3
1851/1852	1.7	1.5	0.4	1.2	1891/1892	2.9	-0.8	-2.2	0.0	1931/1932	0.8	3.5	-3.3	0.3	1971/1972	0.8	-0.5	-0.2	0.0
1852/1853	1.0	1.3	-4.0	-0.6	1892/1893	-1.1	-1.6	2.5	0.0	1932/1933	1.2	1.4	-1.8	0.3	1972/1973	2.1	1.4	1.2	1.6
1853/1854	-4.3	1.3	1.7	-0.4	1893/1894	1.9	1.4	4.0	2.4	1933/1934	-1.8	3.3	0.5	0.6	1973/1974	-1.7	3.8	0.7	0.9
1854/1855	2.4	-1.8	-3.8	-1.1	1894/1895	0.9	-2.6	-4.1	-1.9	1934/1935	1.3	-0.5	2.7	1.2	1974/1975	3.1	2.4	0.4	2.0
1855/1856	-1.7	-1.3	-0.1	-1.0	1895/1896	0.0	-0.2	2.3	0.7	1935/1936	-1.4	-1.2	-2.4	-1.7	1975/1976	-1.6	0.8	1.3	0.2
1856/1857	-0.2	-0.7	2.0	0.4	1896/1897	1.9	-2.4	3.3	0.9	1936/1937	2.4	2.2	1.7	2.1	1976/1977	-3.6	-2.4	0.3	-1.9
1857/1858	3.5	2.3	-0.5	1.7	1897/1898	1.4	2.0	1.9	1.7	1937/1938	-1.1	2.6	0.6	0.7	1977/1978	-0.3	0.5	-2.0	-0.6
1858/1859	3.0	2.7	2.4	2.7	1898/1899	3.1	0.7	-0.2	1.2	1938/1939	-0.4	-0.7	2.9	0.6	1978/1979	-2.1	-3.2	-0.6	-2.0
1859/1860	-1.3	1.5	0.3	0.2	1899/1900	-0.9	1.4	-2.4	-0.6	1939/1940	-1.1	-2.3	-0.9	-1.4	1979/1980	2.1	-1.8	0.7	0.3
1860/1861	-2.1	-0.6	0.8	-0.6	1900/1901	3.5	1.0	-2.6	0.6	1940/1941	1.5	-3.5	-0.4	-0.8	1980/1981	1.6	1.0	1.0	1.2
1861/1862	-1.5	1.2	-1.3	-0.5	1901/1902	-1.4	1.4	-1.4	-0.5	1941/1942	1.4	0.8	-3.1	-0.3	1981/1982	-2.2	-0.7	2.3	-0.2
1862/1863	2.9	1.1	3.1	2.4	1902/1903	1.3	1.3	4.9	2.5	1942/1943	1.5	1.2	2.8	1.8	1982/1983	2.6	4.8	-1.3	2.1
1863/1864	2.2	2.0	-0.3	1.3	1903/1904	-1.1	2.2	1.2	0.8	1943/1944	-0.4	3.6	-1.6	0.6	1983/1984	0.8	2.5	1.7	1.7
1864/1865	-0.8	0.2	-0.4	-0.3	1904/1905	0.9	1.8	2.1	1.6	1944/1945	0.3	-2.1	4.7	0.9	1984/1985	1.5	-2.9	-0.2	-0.5
1865/1866	2.6	2.1	0.7	1.8	1905/1906	1.9	2.6	1.3	1.9	1945/1946	-0.3	1.4	1.0	0.7	1985/1986	-0.4	1.5	-4.0	-1.0
1866/1867	2.1	-2.2	3.6	1.2	1906/1907	0.0	1.6	1.2	0.9	1946/1947	1.2	0.4	-4.6	-1.0	1986/1987	3.4	-2.1	-0.2	0.4
1867/1868	-0.6	1.5	4.0	1.6	1907/1908	1.2	0.6	2.0	1.3	1947/1948	-0.7	1.5	0.7	0.5	1987/1988	-0.8	0.5	-0.1	-0.1
1868/1869	2.0	3.3	3.9	3.1	1908/1909	1.5	1.8	-0.5	0.9	1948/1949	1.1	1.5	4.0	2.2	1988/1989	1.9	3.5	3.6	3.0
1869/1870	-0.7	0.3	-2.0	-0.8	1909/1910	-0.5	2.6	3.9	2.0	1949/1950	0.1	0.6	3.3	1.3	1989/1990	-2.2	3.5	5.1	2.1
1870/1871	-3.5	0.7	1.7	-0.4	1910/1911	-0.1	0.8	2.1	0.9	1950/1951	-1.9	0.8	0.9	0.0	1990/1991	0.3	1.9	0.0	0.7
1871/1872	-0.2	1.2	0.5	0.5	1911/1912	3.0	-0.9	-0.2	0.6	1951/1952	2.5	0.9	0.2	1.2	1991/1992	1.2	0.6	3.2	1.7
1872/1873	-1.1	2.3	0.2	0.5	1912/1913	3.0	1.8	1.2	2.0	1952/1953	-0.3	0.0	0.5	0.1	1992/1993	0.2	3.9	0.1	1.4
1873/1874	2.0	1.6	2.1	1.9	1913/1914	1.2	0.6	2.5	1.4	1953/1954	0.2	0.1	0.6	0.3	1993/1994	2.2	1.3	0.1	1.2
1874/1875	-2.1	2.1	-1.5	-0.5	1914/1915	2.2	0.1	1.8	1.4	1954/1955	1.4	-1.2	-2.2	-0 6	1994/1995	2.9	2.7	3.1	2.9
1875/1876	0.1	1.1	0.8	0.6	1915/1916	-0.7	3.8	2.0	1.7	1955/1956	0.5	-0.8	-3.0	-1.1	1995/1996	-3.3	-3.3	-0.1	-2.2
1876/1877	-1.1	2.4	2.0	1.1	1916/1917	-1.8	-3.1	-1.6	-2.2	1956/1957	2.6	2.5	1.1	2.1	1996/1997	-4.7	-2.0	5.3	-0.5
1877/1878	2.2	1.2	2.2	1.8	1917/1918	-2.8	-0.5	3.9	0.2	1957/1958	-0.1	0.4	0.0	0.1	1997/1998	-0.2	-0.3	2.4	0.7
1878/1879	-3.3	-0.7	0.9	-1.1	1918/1919	2.3	0.0	-0.5	0.6	1958/1959	-1.7	-1.2	2.5	-0.1	1998/1999	2.0	0.9	1.8	1.6
1879/1880	0.6	0.4	1.9	1.0	1919/1920	2.9	2.8	1.4	2.4	1959/1960	2.0	-0.7	-1.0	0.1	1999/2000	2.1	0.4	4.4	2.3
1880/1881	0.5	-3.6	-1.6	-1.6	1920/1921	-0.5	3.2	0.1	0.9	1960/1961	0.5	1.5	4.1	2.0	2000/2001	-1.4	0.0	0.1	-0.4
1881/1882	2.8	3.1	3.2	3.0	1921/1922	2.2	0.6	3.0	1.9	1961/1962	-1.7	2.4	0.8	0.5	2001/2002	-2.3	2.3	3.0	1.0
1882/1883	-1.7	1.7	4.3	1.4	1922/1923	1.5	1.8	2.8	2.0	1962/1963	-0.7	-4.1	-1.9	-2.2	2002/2003	-1.0	0.2	1.3	0.2
1883/1884	0.9	3.3	1.5	1.9	1923/1924	1.3	0.9	-1.6	0.2	1963/1964	-3.1	0.9	-0.1	-0.8	2003/2004	-0.9	0.2	-1.2	-0.6
1884/1885	1.9	-0.8	0.1	0.4	1924/1925	3.9	4.2	2.0	3.3	1964/1965	-1.2	0.0	-3.0	-1.4	2004/2005	1.3	1.8	-2.3	0.3
1885/1886	0.0	-1 4	-0.4	-0.6	1925/1926	-0.7	1.7	1.8	0.9	1965/1966	1.2	-1.0	-0.4	-0.1	2005/2006	-0.8	-0.1	-1.2	-0.7
1886/1887	0.1	1.9	2.0	1.4	1926/1927	-0.5	2.2	1.1	0.9	1966/1967	1.7	0.0	1.7	1.1	2006/2007	3.1	1.8	0.4	1.8
1887/1888	-1.6	0.2	-2.3	-1.2	1927/1928	-3.1	3.0	3.5	1.1	1967/1968	-0.5	1.7	-1.5	-0.1	2007/2008	1.4	1.9	1.8	1.7
1888/1889	1.3	0.7	-0.2	0.6	1928/1929	0.4	-1.3	0.3	-0.2	1968/1969	-1.7	-1.6	-3.2	-2.2	2008/2009	-0.6	0.6	-1.4	-0.5
1889/1890	2.3	4.3	-1.4	1.8	1929/1930	3.8	1.5	-0.6	1.6	1969/1970	-0.3	-1.2	1.1	-0.1	2009/2010	-3.7	-2.4	-3.3	-3.1

Scale:

1	EXTREMELY WARM	2	ABNORMALLY WARM	3	VERY WARM
4	WARM	5	LIGHT WARM	6	NORMAL
7	LIGHT COLD	8	COLD	9	VERY COLD
10	ABNORMALLY COLD	11	EXTREMELY COLD		

Fig. 8. Thermal classes of winter months and seasons marked according to NAO index (*red colour indicates the positive value, black and white negative value*) in Koszalin (1850-2010)

Especially, February was the most excessively warm (94.0%), next January (92.9%) and December (77.2%). When the NAO phase was negative, 68.1% of winters were excessively cold. Especially February, 79.0%, was excessively cold, next December (68.1%) and January (58.0%). It is worth to mention that normal spells, both with reference to winter (75.4%), and separate months were often present with the positive NAO phase (January – 72.2%, February – 65.3%, December – 53.4%).

CONCLUSIONS

The aim of this work is to analyse thermal conditions in Koszalin, considering the speed of changes determined with a coefficient of linear trend, and to investigate the relations between North Atlantic Oscillation and the air temperature. The winter courses of air temperature in Koszalin are characterized by a great variability. It is a result of atmosferic circulation originated over the North Atlantic.
The average air temperature in winter in Koszalin amounted to -0.7°C and between 1850-2010 fluctuated considerably from -6.6°C to 3.7°C. The warmest month was December, while the coldest was January. Warm winters occurred quite often (in total 44.4% of years, yield temperatures above zero).
The analysis of coefficients of linear trend showed that the averaged air temperature in winter season rose to 1.8°C during the studied period of 160 years. December was the month with the highest temperature increase (2.2°C), in January and February the temperature increase was smaller and amounted to 1.7°C. The above results seem to prove that we are experiencing a warming up of winters, which results from climate oceanicity.
NAO index undoubtedly correlates well with the air temperature from December to February. The temperature shows a great conformity of phases (the rise in average monthly temperature corresponds to the positive NAO phase, whereas the drop in average monthly temperature corresponds to the negative NAO phase). The conformity was especially evident with the negative NAO phase – for the whole winter season the value was 84.6% (90% in January and February). With the positive NAO phase conformity was 58.3% (the highest in December – 76.4%).
In the long term period more seasons were excessively warm as compared with that excessively cold. With reference to months, December and January were most often excessively warm, then within the norm, and finally excessively cold. Whereas February was usually within the norm, and then excessively warm.
There were no extremely warm seasons. However, there were three extremely cold ones. Similarly, there were no extremely warm months, but occasionally there were some extremely cold ones (most often February – five times).
The thermal assessment suggests that after 1987 a very warm period appeared and lasted for 23 years with little exceptions. There were three excessively cold winters and five winters within norm. In that time there were three abnormally warm winters, especially the 2006/2007 one, during which the December and January were abnormally warm.
A considerable conformity has been shown when assessing to what extent the positive NAO phase correlates with the occurrence of abnormally warm months and

winters, and the negative NAO phase correlates with those abnormally cold, especially with the positive NAO phase (as many as 90.4% of winters were excessively warm). With the negative NAO phase 68.1% of winters were excessively cold. It is worth to mention that normal periods, both in winter (75.4%), and in individual months, partially occurred while the NAO phase was positive.

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CHARAKTERYSTYKA ZMIAN TERMICZNYCH W SEZONIE ZIMOWYM W KOSZALINIE W LATACH 1850-2010 I ICH ZALEŻNOŚĆ OD OSCYLACJI PÓŁNOCNOATLANTYCKIEJ

Streszczenie

Celem pracy była analiza zmienności warunków termicznych w Koszalinie, z uwzględnieniem tempa zmian określonego za pomocą współczynnika trendu liniowego oraz zbadanie zależności temperatury powietrza od indeksu Oscylacji Północnoatlantyckiej NAO. Na podstawie przeprowadzonych badań stwierdzono, że temperatury powietrza w sezonie zimowym w Koszalinie charakteryzowały się dużą zmiennością. Wynika ona ze zmiennego oddziaływania cyrkulacji znad Oceanu Atlantyckiego, Morza Bałtyckiego i obszaru kontynentalnego oraz uwarunkowań lokalnych. Z przeprowadzonych badań wyciągnięto następujące wnioski:

– Średnia temperatura powietrza w sezonie zimowym w Koszalinie wynosiła -0,7°C i w okresie 1850-2010 ulegała wahaniom od -6,6°C do 3,7°C. Najcieplejszym miesią-

cem był grudzień, najchłodniejszym styczeń. Często występowały ciepłe zimy (łącznie w 44,4% lat średnie temperatury zimą były dodatnie).

– Analiza współczynników trendu liniowego wykazała, że średnia temperatura powietrza w sezonie zimowym wzrosła o 1,8°C w rozważanym 160-leciu. Miesiącem o najwyższym wzroście temperatury był grudzień (2,2°C), w styczniu i lutym wzrost temperatury był mniejszy i wyniósł 1,7°C. Otrzymane wyniki potwierdzają postępujące ocieplanie się zimy, które stanowi przejaw narastającego oceanizmu klimatycznego.
– Z analizy związków między zmianami Oscylacji Północnoatlantyckiej NAO a temperaturą powietrza wynika, że niewątpliwie w okresie od grudnia do lutego cyrkulacja atmosferyczna określona wskaźnikiem NAO bardzo dobrze koreluje z temperaturą powietrza. Temperatura powietrza wykazuje bardzo dużą zgodność fazową (pozytywnej fazie NAO odpowiada wzrost średniej miesięcznej temperatury, negatywnej fazie NAO odpowiada spadek średniej miesięcznej temperatury). Szczególnie duża zgodność występowała przy ujemnej fazie NAO – dla całego sezonu zimowego wartość ta wynosiła 84,6% (w styczniu i lutym powyżej 90%). Przy pozytywnej fazie NAO – 58,3% (najwyższa była w grudniu – 76,4%).
– W badanym wieloleciu więcej było sezonów zimowych nadmiernie ciepłych niż nadmiernie chłodnych. W przypadku miesięcy – grudzień i styczeń były najczęściej nadmiernie ciepłe, następnie – w normie i najrzadziej – nadmiernie chłodne. Luty natomiast najczęściej był w normie, a następnie – nadmiernie ciepły.
– Nie wystąpiły sezony zimowe ekstremalnie ciepłe, ale trzy razy pojawiły się ekstremalnie chłodne. Podobnie, nie wystąpiły miesiące ekstremalnie ciepłe, ale sporadycznie pojawiały się ekstremalnie chłodne (najczęściej luty – pięć razy).
– Z oceny termicznej wynika, że po roku 1987 zaznaczył się bardzo ciepły okres, trwający przez 23 lata z małymi wyjątkami – pojawiły się 3 zimy nadmiernie chłodne i 5 zim w normie; w tym czasie 3 zimy były anomalnie ciepłe; szczególnie ciepła była zima 2006/2007, podczas której anomalnie ciepły były grudzień i styczeń.
– Przy ocenie, w jakim stopniu pozytywnej fazie NAO odpowiada występowanie miesięcy oraz zim anomalnie ciepłych, natomiast negatywnej fazie NAO – anomalnie chłodnych, stwierdzono bardzo dużą zgodność, szczególnie przy występowaniu pozytywnej fazy NAO (aż 90,4% zim było nadmiernie ciepłych). Przy występowaniu negatywnej fazy NAO stwierdzono 68,1% zim nadmiernie chłodnych. Okresy normalne, zarówno w przypadku zimy (75,4%), jak i w poszczególnych miesiącach częściej występowały przy pozytywnej fazie NAO.