Acta Agrophysica, 2010, 16(1), 79-91

EFFECT OF THE NORTH ATLANTIC OSCILLATION ON EXTREME AIR TEMPERATURES AT THE POLISH BALTIC COAST*

Czesław Koźmiński[1], Bożena Michalska[2]

[1]Department of Marine Climatology and Meteorology, Szczecin University
ul. Wąska 13, 71-415 Szczecin
[2]Department of Meteorology and Climatology, West Pomeranian University of Technology
ul. Papieża Pawła VI, 3, 71-434 Szczecin
e-mail: bozena.michalska@zut.edu.pl

A b s t r a c t. Data collected during the period of 1956-2005 at 8 meteorological stations of the Institute of Meteorology and Water Management (IMWM) situated along the Polish Baltic coast were used to provide a quantitative assessment of the North Atlantic Oscillation (NAO) effects on variability of the maximum and minimum air temperatures at the coast. The data were coupled with the NAO (Jones) index values reflecting the difference between normalized atmospheric pressure in Gibraltar (the Azores High) and in Reykjavik (the Icelandic Low). In December-March, NAO effects explain 53-68% of the variability of the maximum air temperature along the coast, the variability of the minimum temperature being accounted for in 43-63%. As a rule, the positive NAO phase (index values > 2.0) brings about an increase in the extreme daily temperature, the negative phase (< –2.0) resulting in a significant reduction of the temperature. A unit increase in the NAO index results in the highest increase of the minimum temperature, by 1.4-2.1°C, in February and January, and in the increase of the maximum temperature by 0.9-1.5°C in those months.

K e y w o r d s: extreme air temperature; NAO index; Polish Baltic coast

INTRODUCTION

The North Atlantic Oscillation (NAO) belongs to factors that substantially affect the thermal conditions in western and central Europe, particularly during the cold season (Chen and Hellstrom 1999, Girjatowicz 2008, Hurrell 1995, Kożuchowski and Marciniak 1988). At the positive values of NAO index (positive NAO phase) occurring at a high atmospheric pressure near the Azores and a low

*The study was supported by the research project PBZ-KBN-086/PO4/2003.

pressure of Iceland, polar-marine air masses move from the Atlantic towards the western and central Europe and shape the thermal conditions and precipitation in those areas (Jones *et al.* 1997, Marsz 1999, Wibig and Głowicki 2002). Advection of the Atlantic air masses results in warming in winter and in cooling down in summer. On the other hand, during the negative NAO phase, at a small pressure difference between the two baric centres mentioned above, the latitudinal atmospheric circulation is distorted and replaced by meridional (longitudinal) circulation (Beranova and Huth 2008, Rogers 1984, Marsz and Styszyńska 2001). In addition to the North Atlantic Oscillation, the air temperature at the Baltic coast is significantly affected also by the Baltic water temperature, the effect being visible as warming from September to early March and as cooling down in the second part of the year (Gidhagen 1987, Girjatowicz 2008).

This study was aimed at providing a quantitative assessment of relationships between the maximum and minimum air temperatures on the one hand, and the NAO index on the other, as well as at determining a trend in changes of those relationships in the period of 1956-2005.

MATERIALS AND METHODS

The study involved analysis of mean monthly temperatures as well as the absolute minimum and maximum monthly temperatures at 10 meteorological stations, situated at the Polish Baltic coast (Fig. 1) and operated by the Institute of Meteorology and Water Management (IMWM), during the period of 1956-2005. Regression analysis was applied to calculate correlations (r) and regression coefficients between monthly mean, maximum, and minimum temperatures in each month on the one hand, and the corresponding NAO index on the other. Linear trends in those temperatures over December-March versus monthly NAO index were determined, and the probability of index values >2.0 and <–2.0, causing a substantial increase and decrease, respectively, of the extreme air temperature, was calculated.

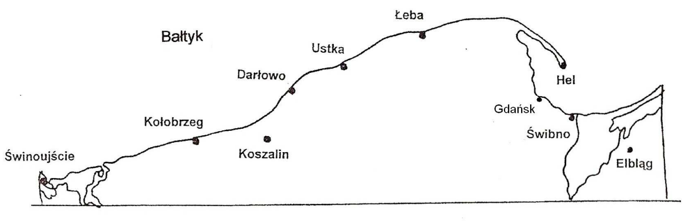

Fig. 1. Distribution of meteorological stations on the Polish Baltic coast

RESULTS AND DISCUSSION

In recent years (1991-2005), the highest and the lowest air temperatures along the Polish Baltic coast have been observed to increase, particularly from January to March and from June to August. As shown by the research published hitherto (Koźmiński and Michalska 2008 a,b), the maximum air temperature increase in the first half-year of the period of 1956-2005 ranged from 3.3^{o}C/50 years in January to 4.1^{o}C/50 years in April, the minimum temperature increasing by 2.3-6.7^{o}C/50 years in February and January, depending on the location of a station along the coast.

The long-term monthly mean NAO index values were found to range from –0.46 in September to 0.54 in February, the extreme values ranging from –4.70 in December 1996 to 5.26 in February 1997 (Tab. 1). The highest year-to-year variability of the NAO index was recorded from December (standard deviation of 1.96) to February (2.07), followed by August (1.82); the lowest variability was typical of May (1.43) to July (1.34). There were, however, continuous series of years with positive or negative NAO indices, e.g., during the winters of the 1990s (positive NAO phase) and autumns (negative phase).

Table 1. Statistics of the NAO index by month in 1956-2005

Month	Mean	Minimum	Maximum	Standard deviation	Trend
January	0.45	–4.09	4.82	1.98	0.148
February	0.54	–4.02	5.26	2.07	0.223
March	0.47	–3.78	3.68	1.66	0.114
April	–0.10	–3.34	2.59	1.56	–0.049
May	–0.10	–2.59	4.54	1.43	–0.203
June	–0.25	–4.05	2.99	1.47	–0.262
July	0.01	–2.99	3.70	1.34	–0.059
August	0.06	–3.67	3.97	1.82	–0.010
September	–0.46	–4.11	2.51	1.60	–0.236
October	–0.31	–4.13	2.79	1.66	–0.287
November	–0.03	–2.97	4.52	1.70	0.042
December	0.05	–4.70	3.42	1.96	0.070

The analysed period of 1956-2005 showed a positive, albeit non-significant trend of the NAO index, from November to March, the highest correlation coefficient (r) being observed in February (0.22). On the other hand, a negative trend was visible from April to October; that trend was significant at $\alpha_{0.05}$ only in October (–0.29), and was close to being significant in June (–0.26).

Changes in the North Atlantic Oscillation are important in shaping air temperatures at the southern Baltic coast (Marsz 1999 and Marhall *et al.* 2001). A highly significant relationship between the NAO index and the monthly mean air temperature was observed from October to March (except for November), the highest correlation coefficient (r) values being observed in January (from 0.71 in Łeba to 0.80 in Świnoujście, Tab. 2). In November, in the western part of the coast, there was a positive and significant effect of the NAO index on air temperature, the eastern part of the coast showing a positive non-significant effect. In the remaining months, NAO effects on the monthly mean air temperature were very weak, particularly in June and July. Similar relationships between the air temperature and NAO index were reported by Bukantis and Bartkeviciene (2005) for Lithuania and by Chen and Hellstrom (1999) for Sweden.

Table 2. Coefficients of correlation between the mean air temperature and the NAO index in 1956-2005

Station	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Świnoujście	0.80	0.73	0.57	0.09	0.22	0.11	0.04	0.13	0.26	0.54	0.33	0.53
Kołobrzeg	0.78	0.72	0.55	0.09	0.20	0.05	0.01	0.22	0.22	0.53	0.29	0.51
Koszalin	0.77	0.73	0.54	0.09	0.10	–0.01	–0.01	0.08	0.22	0.51	0.29	0.53
Darłowo*	0.77	0.73	0.53	0.04	0.10	0.11	0.03	0.24	0.28	0.55	0.29	0.49
Ustka	0.78	0.70	0.55	0.06	0.10	0.09	0.02	0.16	0.28	0.54	0.28	0.49
Łeba	0.71	0.70	0.53	0.07	0.12	0.04	0.04	0.15	0.28	0.54	0.25	0.48
Hel	0.77	0.72	0.51	0.05	0.09	0.03	0.03	0.07	0.25	0.59	0.23	0.47
Gdańsk	0.78	0.69	0.53	0.15	0.13	0.06	–0.02	0.06	0.17	0.56	0.23	0.52
Świbno*	0.79	0.75	0.54	0.06	0.10	–0.02	0.00	0.12	0.20	0.55	0.27	0.49
Elbląg	0.76	0.73	0.49	0.05	0.06	–0.02	–0.05	0.07	0.27	0.53	0.27	0.51

*1956-2000, $\alpha_{0.05} = 0.280$, $\alpha_{0.01} = 0.363$.

Comparison of the correlation coefficients contained in Tables 2 and 3 shows the NAO effects on the maximum air temperature at the coast to have been much weaker than the effects on the mean temperature, which could have resulted from the fact that the calculations involved only the highest daily temperature of a month. However, the winter months showed a positive, highly significant relationship between the maximum temperature and NAO index, particularly in January (from 0.67 in Ustka to 0.73 in Gdansk, Tab. 3). In April and November, there

Table 3. Coefficients of correlation between the maximum air temperature and the NAO index in 1956-2005

Station	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Dec-March
Świnoujście	0.68	0.68	0.41	–0.05	0.02	0.11	0.10	0.17	0.22	0.20	0.02	0.46	0.74
Kołobrzeg	0.69	0.66	0.48	–0.04	0.02	0.05	0.11	0.20	0.24	0.24	0.01	0.47	0.77
Koszalin	0.71	0.66	0.39	–0.12	0.06	0.12	0.03	0.18	0.27	0.14	–0.09	0.47	0.77
Darłowo*	0.66	0.69	0.47	–0.13	0.07	0.01	–0.04	0.04	0.27	0.09	–0.10	0.32	0.75
Ustka	0.67	0.62	0.55	–0.06	0.06	0.09	–0.04	0.11	0.19	0.11	–0.11	0.46	0.76
Łeba	0.69	0.66	0.48	–0.10	–0.04	0.09	0.00	0.11	0.22	0.13	–0.12	0.45	0.73
Hel	0.71	0.71	0.49	0.02	0.12	0.16	0.17	0.13	0.17	0.32	–0.20	0.41	0.79
Gdańsk	0.73	0.69	0.49	–0.09	0.06	0.16	0.11	0.10	0.17	0.35	–0.14	0.52	0.82
Świbno*	0.75	0.76	0.49	–0.10	0.04	0.09	0.11	0.20	0.16	0.09	–0.08	0.45	0.83
Elbląg	0.73	0.70	0.44	–0.20	0.06	0.03	–0.06	0.11	0.15	0.21	–0.13	0.43	0.81

*1956-2000, $\alpha_{0.05} = 0.280$, $\alpha_{0.01} = 0.363$.

Table 4. Coefficients of correlation between the minimum air temperature and the NAO index in 1956-2005

Station	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Dec-March
Świnoujście	0.64	0.64	0.29	–0.01	0.14	–0.05	–0.11	0.23	0.17	0.54	0.30	0.45	0.66
Kołobrzeg	0.60	0.62	0.28	–0.05	0.10	–0.01	–0.02	0.19	0.08	0.48	0.32	0.41	0.70
Koszalin	0.57	0.63	0.25	0.10	0.30	0.05	–0.06	0.01	0.01	0.49	0.24	0.43	0.70
Darłowo*	0.68	0.63	0.28	0.10	0.11	–0.19	–0.01	0.18	0.15	0.54	0.27	0.47	0.75
Ustka	0.65	0.65	0.30	–0.09	0.09	–0.06	–0.15	–0.11	0.18	0.55	0.31	0.41	0.74
Łeba	0.61	0.60	0.33	0.11	0.21	–0.10	–0.02	0.09	0.28	0.45	0.28	0.49	0.76
Hel	0.64	0.65	0.28	0.19	0.16	0.09	–0.05	0.15	0.10	0.25	0.30	0.34	0.67
Gdańsk	0.64	0.59	0.24	0.11	0.16	0.01	–0.14	–0.13	0.00	0.40	0.33	0.34	0.69
Świbno*	0.68	0.66	0.25	0.08	0.01	–0.20	0.00	0.00	–0.04	0.39	0.32	0.49	0.79
Elbląg	0.60	0.65	0.26	0.06	0.14	0.01	–0.01	–0.07	0.13	0.42	0.37	0.45	0.72

*1956-2000, $\alpha_{0.05} = 0.280$, $\alpha_{0.01} = 0.363$.

was a negative, albeit non-significant, correlation between the air temperature and NAO index (Tab. 3), which was paralleled by the NAO versus water temperature correlation determined by Girjatowicz (2008). The correlation coefficients for the period of January-March ranged, depending on the station, from 0.821 to 0.834.

As shown by Table 4 and Figure 2, the minimum air temperature was significantly and highly significantly correlated with the NAO index from October to February (to March in the western and central part of the coast), but the correlation coefficient values were lower (out of October and November) than those calculated for the correlations with the maximum air temperature (Tab. 3 and 4). In the warm half-year (April-September), values of the correlation coefficients were non-significant, and in June and July they were even negative (minimum air temperature) at most coastal stations.

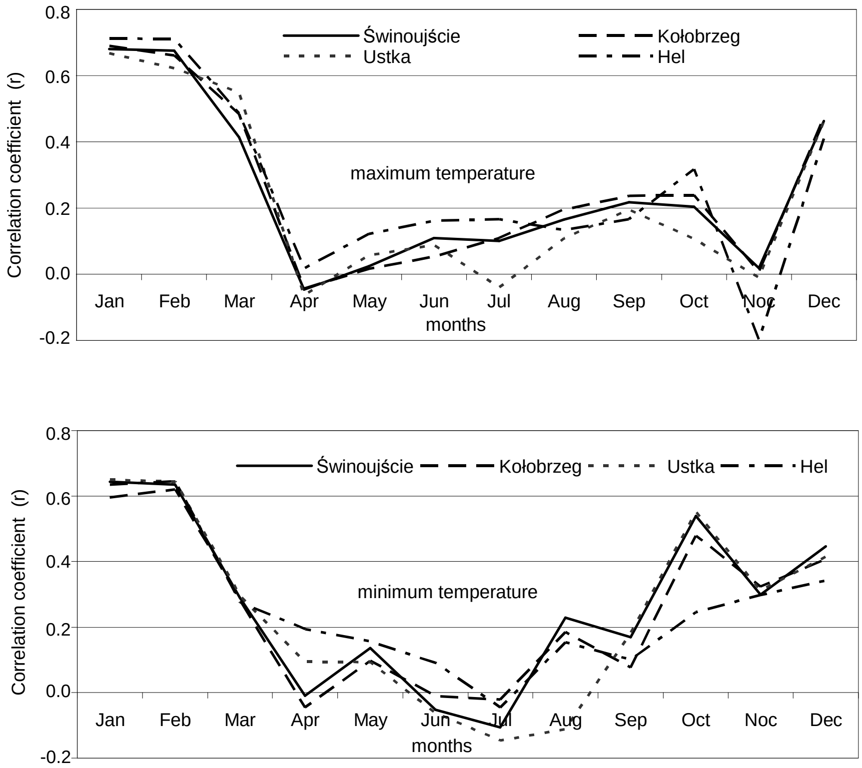

Fig. 2. Relationship of maximum and minimum air temperature with NAO Index according to months at selected stations on the Polish coast of the Baltic Sea. Years 1956-2005

As a rule, the positive and negative NAO phases (Fig. 3 and 4) bring about an increase and a decrease, respectively, of the maximum and minimum air temperature at the coast. At low NAO indices, the maximum temperatures may differ widely, as may the minimum temperatures. On the other hand, a strongly positive or a strongly negative NAO phase (NAO index >2.0 and <-2.0, respectively) results, as a rule, in a large increase or a large decrease of the extreme air temperature. For

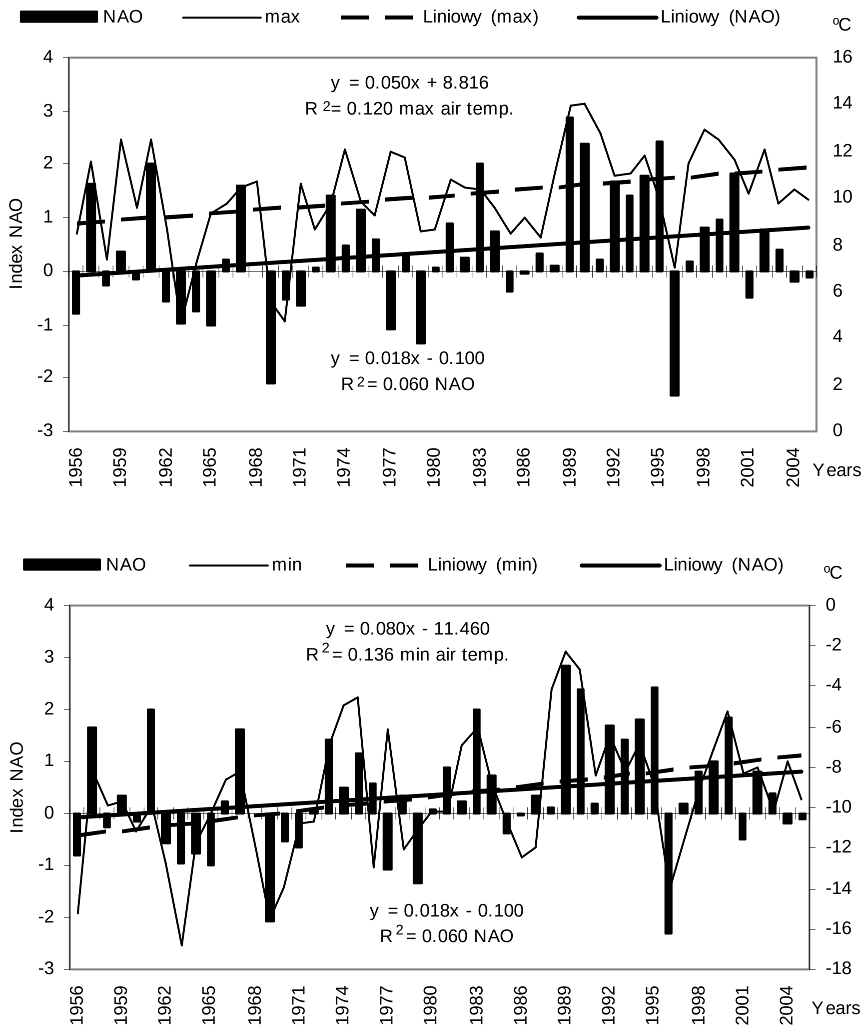

Fig. 3. Maximum and minimum air temperature (December-March) in Kołobrzeg against the NAO index values in 1956-2005; the trend lines are shown

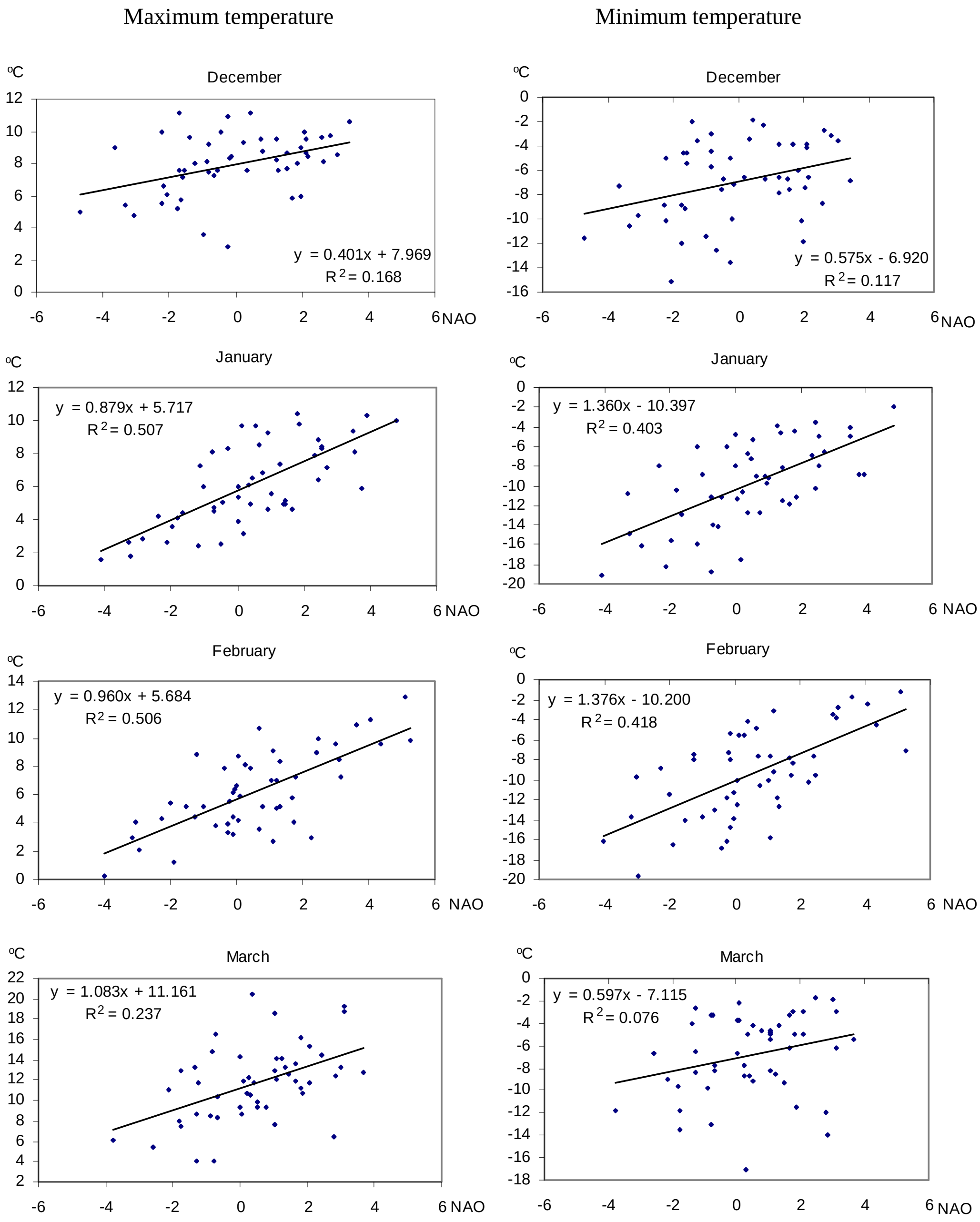

Fig. 4. Relationships of the maximum and minimum air temperature at Hel with the NAO Index. Years 1956-2005

example, in Kołobrzeg at the NAO index equal to -3.27 in January 1997, the minimum daily temperature was -14.8°C, while at the NAO index of 2.31 in January 2002, the maximum daily temperature was as high as 11.6°C. Therefore, Table 5 shows probabilities of NAO indices >2.0 and <-2.0 in individual months. The highest probability of the NAO index being >2.0 is typical of February (24.0%) and January (21.7%), the minimum probability occurring in June and September (6.3 and 6.2%, respectively). The probability of the NAO index <–2.0 is much lower (6.8-11.0%) from January to March, higher probabilities of such indices being typical of autumn (12.3-16.8%). In the warm half-year, the negative NAO phase prevails, as confirmed by both the mean values of the index (Tab. 1) and the higher probability of the index being <-2.0 rather than >2.0 (Tab. 5).

Table 5. Probability (%) of NAO index > +2.0 and < -2.0 by month in 1956-2005

NAO	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
> +2.0	21.7	24.0	17.8	8.9	7.1	6.3	6.9	14.3	6.2	8.2	11.6	16.0
< –2.0	10.8	11.0	6.8	11.2	9.2	11.7	6.7	12.9	16.8	15.4	12.3	14.8

In the cold half-year, a unit increase of the NAO index results, depending on the month, in varying increases of the extreme temperatures (Tab. 6). The highest increase of the maximum temperature occurs in February and March: from 0.9 in Świnoujście to 1.3°C in Gdańsk and Ustka, a slightly lower increase (from 0.3 to 1.1°C) being recorded in January and December. It was only in November that a unit increase in the NAO index may cause a reduction of the maximum temperature, the reduction being, however, not substantial (by 0.1 or 0.2°C). Similarly, Girjatowicz (2008) found a unit increase in the NAO index to cause water temperature increase by 0.6°C in Świnoujście, Mielno and Hel, and by 0.7°C at the remaining coastal stations. The temperature effect of the North Atlantic Oscillation is much more distinct in the minimum air temperature in the cold half-year: a unit increase in the NAO index in January ranges in the minimum temperature increase from 1.4 in Hel to 2.1°C in Gdańsk, the increase in February ranging from 1.4 in Hel to 1.8°C in Elbląg. In the remaining months of the cold half-year, except for December, the regression coefficients do not exceed 1.0°C. No effect of the North Atlantic Oscillation was found in the spatial variability of extreme temperature increase along the Polish Baltic coast (Tab. 6).

Table 6. Regression coefficients of the relationship between the maximum (a) and minimum (b) air temperature and the NAO index by month of the cold half-year in 1956-2005

Station		January	February	March	October	November	December
Świnoujście	a	1.0	1.2	0.9	0.3	0.0	0.6
	b	1.6	1.5	0.7	0.7	0.5	1.0
Kołobrzeg	a	1.0	1.2	1.1	0.4	0.0	0.6
	b	1.5	1.6	0.7	0.6	0.5	0.9
Koszalin	a	1.1	1.2	0.9	0.2	–0.1	0.7
	b	1.6	1.6	0.6	0.6	0.5	1.0
Darłowo*	a	0.9	1.2	1.1	0.2	–0.1	0.3
	b	1.9	1.7	0.7	0.8	0.6	1.0
Ustka	a	1.0	1.2	1.3	0.2	–0.1	0.6
	b	1.7	1.7	0.7	0.9	0.6	0.9
Łeba	a	0.9	1.1	1.1	0.2	–0.2	0.5
	b	1.7	1.6	0.9	0.5	0.5	1.0
Hel	a	0.9	1.0	1.1	0.4	–0.2	0.4
	b	1.4	1.4	0.6	0.3	0.4	0.6
Gdańsk	a	1.1	1.3	1.3	0.6	–0.2	0.7
	b	2.1	1.7	0.8	0.5	0.8	0.9
Świbno*	a	1.1	1.5	1.3	0.3	–0.1	0.6
	b	2.0	1.9	0.7	0.4	0.7	1.3
Elbląg	a	1.0	1.2	1.2	0.3	–0.2	0.6
	b	2.0	1.8	0.7	0.6	0.8	1.2

*1956-2000.

CONCLUSIONS

1. The strongest correlations between the air temperature and the North Atlantic Oscillation at the Polish coast occur in the cold half-year, particularly from December to March.

2. Variability of the maximum air temperature in winter (December-March) at the coast is in 53-68% explained by NAO effects, the effects of the minimum temperature accounting for 43-63% of the variability.

3. The maximum and minimum temperatures vary substantially at low values of the NAO index (from about –1.0 to about 1.0); on the other hand, the extreme daily temperature may significantly increase or significantly drop at the NAO index values exceeding 2.0 or below –2.0, respectively.

4. The positive NAO phase (NAO index values exceeding 2.0) occurs most often from December to March, with a maximum in February; it is much rarer from May to September. The negative NAO phase (<–2.0) probability distribution during the year is more even than that of the positive phase, and shows a slight increase in frequency in autumn.

5. The increase in the extreme daily temperatures recorded at the Polish coast since the early 1980s depends mainly on a strengthening of the positive phase of the atmospheric circulation (NAO).

6. In the cold half-year, a unit increase in the NAO index brings about the highest temperature increase in February and January: the minimum and maximum temperatures in those months increase by 1.4-2.1 and 0.9-1.5^{o}C, respectively.

REFERENCES

Beranova R., Huth R., 2008. Time variations of the effects of circulation variability modes on European temperature and precipitation in winter. International Journal of Climatology, 28, 139-158.

Bukantis A., Bartkeviciene G., 2005. Thermal effects of the North Atlantic Oscillation on the cold periods of the year in Lithuania. Climate Research, 28, 221-228.

Chen D., Hellstrom C., 1999. The influence of the North Atlantic Oscillation on the regional temperature variability in Sweden: spatial and temporal variations. Tellus Series A., 51, 505-516.

Gidhagen L., 1987. Coastal upwelling in the Baltic Sea – satellite and in situ. measurements of sea-surface temperatures indicating coastal upwelling. Estuarine. Coastal and Shelf Science, 24, 449-462.

Girjatowicz JP., 2008. The relationships of the North Atlantic Oscillation to water temperature along the southern Baltic Sea Coast. International Journal of Climatology, 28, 1071-1086.

Hurrell JW., 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science, 269, 676-679.

Jones PD., Jonsson T., Wheeler D., 1997. Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland. International Journal of Climatology, 17. 1433-1450.

Koźmiński C., Michalska B., 2008a. Variability of maximum daily air temperature in the zone of the Polish Baltic Sea coast. Acta Agrophysica, 12(2), 437-457.

Koźmiński C., Michalska B., 2008b. Variability of daily (24hrs) minimum air temperature in the zone of the Polish coast of the Baltic Sea (in Polish). Acta Agrophysica, 12(3), 713-736,.

Kożuchowski K., Marciniak K., 1988. Variability of mean monthly temperatures and semiannual precipitation totals In Europe In relation to hemispheric circulation patterns. Journal of Climatology, 8, 191-199.

Marhall J., Kushnir Y., Batisti D., Chang P., Czaja R., Dicson R., Hurrell J., McCartney M., Saravanan R., Visbeck M., 2001. North Atlantic climate variability: phenomena. impact and mechanisms. Journal of Climatology, 21, 1863-1898.

Marsz AA., 1999. The North Atlantic Oscillation and the thermal regime in the area of north-west Poland and the Polish coast of the Baltic Sea. Polish Geographical Review, 71(3), 225-243.

Marsz AA., Styszyńska A., 2001. The North Atlantic Oscillation and air temperature in Poland (in Polish). Marine Academ Press: Gdynia, 101.

Rogers JC., 1984. A comparison of the mean winter pressure distribution in the extremes of North Atlantic Oscillation and Southern Oscillation. In Studies in Climate. NCAR Technical Note. van Loon H (ed.).Colorado. CA: 208-241.
Wibig J., Głowicki B., 2002. Trends of minimum and maximum temperature in Poland. Climate Research, Vol. 20, 123-133.

ODDZIAŁYWANIE OSCYLACJI PÓŁNOCNOATLANTYCKIEJ NA EKSTREMALNE TEMPERATURY POWIETRZA W STREFIE POLSKIEGO WYBRZEŻA BAŁTYKU

Czesław Koźmiński[1], *Bożena Michalska*[2]

[1]Katedra Meteorologii I Klimatologii Morskiej, Uniwersytet Szczeciński
ul. Wąska 13, 71-415 Szczecin
[2]Zakład Meteorologii i Klimatologii, Zachodniopomorski Uniwersytet Technologiczny
ul. Papieża Pawła VI, 3, 71-434 Szczecin
e-mail: bozena.michalska@zut.edu.pl

Streszczenie. W celu ilościowej oceny wpływu Oscylacji Północnoatlantyckiej na zmienność maksymalnej i minimalnej temperatury powietrza wykorzystano dane z 10 stacji meteorologicznych IMGW rozmieszczonych wzdłuż polskiego wybrzeża Bałtyku za okres 1956-2005, a także indeks NAO (Jones), który odzwierciedla różnicę pomiędzy znormalizowanym ciśnieniem, atmosferycznym w Gibraltarze (Wyż Azorski), a Reykjavikiem (Niż Islandzki). W okresie grudzień-marzec zmienność temperatury powietrza na wybrzeżu można wyjaśnić oddziaływaniem Oscylacji od 53 do 68%, a minimalnej temperatury od 43 do 63%. Wystąpienie pozytywnej fazy NAO (wartości indeksy >2,0) z reguły powoduje wzrost dobowej temperatury ekstremalnej, a wystąpienie negatywnej fazy (–2,0) – znaczący spadek temperatury. Zwiększenie wartości indeksu NAO o jednostkę skutkuje największą zwyżką temperatury minimalnej od 1,4 do 2,1^{o}C w lutym i styczniu, a temperatury maksymalnej od 0,9 do 1,5^{o}C w tych samych miesiącach.

Słowa kluczowe: maksymalna, minimalna temperatura powietrza, indeks NAO, polskie wybrzeże Bałtyku