DOI:10.28974/idojaras.2020.1.5

IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 124, No. 1, January – March, 2020, pp. 97–111

Winter air temperature in Warsaw depending on the NAO index and the regional circulation

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(Manuscript received in final form March 8, 2019)

Abstract— The paper discusses the circulation and thermal conditions over Poland and their dependence on the sign and values of the North Atlantic Oscillation (NAO) index (hereinafter NAO+ and NAO-). The input data used in the research consisted of average monthly values of air temperature in Warsaw, NAO index values, and a calendar of atmospheric circulation types according to *Lityński* (1969). The study comprised the three winter months (December, January,February) from the period 1951–2015. The dependence between the circulatory and thermal conditions was investigated on the basis of 10 months representing each of the winter months with the highest NAO+ and NAO- values and 10 months with the greatest positive and negative temperature deviations from the long-term average (Δt+, Δt-), based on the assumption, that they should largely be the same months. In general, the analysis confirmed these assumptions, but it also showed that there are deviations from previously known regularities as regards the effect of the positive or negative phases of the NAO on the thermal conditions in Poland.

Key-words: atmospheric circulation, NAO, air temperature, Warsaw

1. Introduction

The temperate zone is characterized by the high variability of atmospheric circulation, which translates into significant variations in weather conditions. This follows from the fact that the zone is under the influence of the formation, evolution, and movement from west to east of families of dynamic cyclones separated by high-pressure ridges. This results from the global system of atmospheric circulation, which – in this zone – takes place within the Ferrel cell, i.e., between subtropical anticyclones and moderate-latitude cyclones. In the Northern Atlantic, the Icelandic Low and the Azores High are such centers of atmospheric activity. The values of atmospheric pressure between these two systems demonstrate a negative correlation (*Marsz,* 2002), which means that when pressure within the Icelandic Low drops, it increases in the Azores High and vice versa. However, as *Marsz* (2002) explains, the interrelations between these two pressure centers are not stable. It may so happen that only one of them can be strong or weak.

The relationships between the Azores High and the Icelandic Low have been known for over 100 years (*Hurrell*, 1995; *Wibig,* 2000), and in the 1920s the phenomenon was named the North Atlantic Oscillation or NAO.

The development of the NAO index as a quantitative characteristics of westerly circulation (or lack thereof) over the eastern part of the Atlantic at the latitude of Europe created new research opportunities. These include, inter alia, an opportunity for investigating the relationship between the air temperature in Poland in individual winter months and the sign and value of the index. However, since temperatures in Poland are determined directly by the circulation over its territory, studying the link between air temperature and the NAO should include an intermediate stage, i.e., an analysis of atmospheric circulation over Poland. This follows from the fact that smaller areas may observe meso-circulation processes, which are determined by regional geographic factors and differ from those occurring on the macroscale. This was clearly shown by *Niedźwiedź* (2002), who determined the statistical relationship between the zonal circulation index over Poland and the NAO index. The correlation coefficients obtained by Niedźwiedź were significant only from December to April, with the highest dependence in February ($r = 0.66$).

Thus, this study focuses on answering the question on how a specific NAO phase and its intensity influence air temperatures at a distance of nearly 2000 kilometers from the Atlantic coast. As the sea air masses travel the distance, not only do they undergo significant transformation, but they may also change their primary trajectory as a result of pressure systems forming over Europe. Therefore, in central Europe, as well as in other parts of it (*Castro-Diez et al.* 2002; *Kossowska-Cezak* and *Twardosz,* 2018), the relationship between the air temperature in winter and the positive or negative NAO phase may be, but does not need to be, strong or even unambiguous, even though numerous studies (as well as non-scientific observations) indicate the existence of such a relationship. For example, it has been found that warm or cold winters in Europe correspond to a specific phase of the NAO (*Saunders* and *Lea*, 2006; *Hirschi* and *Sinha*, 2007; *Hirschi,* 2008; *Cattiaux et al*., 2010; *Wang et al*., 2010; *Buchan et al.*, 2014).

2. Data and methods

This study is based on a 65-year-long series (1951–2015) of the NAO index defined as the difference the between normalized sea level pressure over Gibraltar and the normalized sea level pressure over Southwest Iceland (*Jones et al.*, 1997). The values were taken from the website of the *Climate Research Unit* (http://www.cru.uea.ac.uk/cru/data/nao.htm). The second set of data consists of average monthly values of air temperature in Warsaw and a calendar of circulation types according to *Lityński* (1969), as developed by *Pianko-Kluczyńska* (2007). The calendar includes 27 types of circulation, including nine cyclonic types, nine "0" (transitional) types, and nine anticyclonic types from 8 directions, as well as a ninth, advectionless type. The study covers the three coolest months of the year, i.e., from December to February. Based on previous research, we know that the North Atlantic Oscillation has the strongest effect on temperatures in winter, when westerly movement of air masses clearly predominates (*Hurrell*, 1995; *Marsz,* 2002). This is attributable to the greatest thermal contrasts between air masses in the extratropical areas of the Northern Hemisphere during the year.

The dependence between the air temperature in Warsaw in the 3 winter months of the 65-year period and the NAO index value demonstrates that the majority of the values of both characteristics clearly diverge from the dependence line and the 95% confidence interval (*Fig. 1*). Therefore, studying the circulatory and thermal conditions over Poland relative to the sign and value of the NAO index (hereinafter NAO+ and NAO-) is not based on the full 65-year series of average values for the 3 months (December-February), but on values from selected months. Thus, 10 months from the 65-year period with the highest positive and negative NAO values (hereinafter: high NAO+ and high NAO-) and 10 months with the highest positive and negative (Δt) deviations from the multiannual average (hereinafter: high Δt+ and high Δt-) were selected for analysis. If there was a close relationship between the monthly NAO and Δt values, then the months identified independently according to each criterion (NAO or Δt) would be the same, while in the absence of such a relationship, the months would be completely different. As is demonstrated by the summary in *Table 1*, in the months with high NAO+ or high Δt+, the sign of the other characteristics was opposite (Δt-, NAO-) in only one month, while in the months with high NAO- or high Δt- there were more similar cases, namely 8. This confirms that, as expected, the consistency between the signs of NAO and temperature Δt is greater for positive values than for negative ones. This should be attributed to the different numbers of atmospheric pressure field types during specific phases of the NAO over the North Atlantic and Europe. According to *Styszyńska* (2002), the positive phase of the NAO involves one or two pressure field types, while during the negative phase, the number of the possible field types can be very different.

At this point it should be observed that despite their apparent similarity (+ or -), the compared values of the average monthly NAO and the deviations of the monthly average temperature from the long term average (Δt) are two completely different kinds of value. The NAO index informs us about a current pressure system distribution over the Northern Atlantic Ocean. On average, and most frequently, the two dominant pressure systems are the Azores High and the Icelandic Low, and the resulting pressure gradient runs from south to north, while the NAO is positive. Shifts in the exact location of these pressure systems and their pressure values are reflected in constant changes in the NAO value and, periodically, also in its sign. In this way, NAO provides objective information about the status of the atmospheric pressure distribution. The deviation of the air temperature in a given month from the long-term average, on the other hand, is a relative metric, where the sum of deviations over a relevant multi-year period arrives at nil.

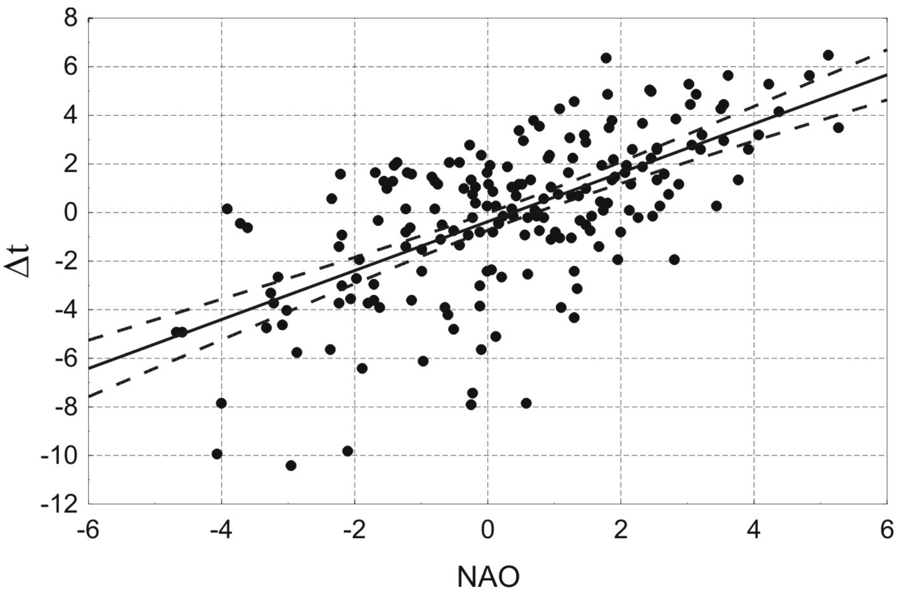

Fig. 1. Relationship between the deviation of average temperature (Δt) in the winter months in Warsaw from the NAO index and the 95% confidence interval of the regression line, (1951–2015). The correlation coefficient is $r = 0.600$ significant at the level of significance α=0.05.

Table 1. Number of months with high NAO +/- and/or high Δt +/- (1951–2015)

		Dec	**Jan**	**Feb**	**Dec –Feb**
	Δt+	6	5	5	16
NAO+	(Δt+)	4	5	4	13
	(Δt-)	–	–	1	1
	NAO+	6	5	5	16
Δt+	(NAO+)	4	5	5	14
	(NAO-)	–	–	–	–
	Δt-	7	7	4	18
NAO-	(Δt-)	2	2	4	8
	(Δt+)	1	1	2	4
	NAO-	7	7	4	18
Δt-	(NAO-)	3	2	3	8
	(NAO+)	–	1	3	4

Explanation: NAO +/- – months with a positive/negative NAO index; Δt +/- – months with a positive/negative deviation of temperatures from the multiannual average; symbol without parentheses – "high" value, i.e., one of the 10 highest values in the 65-year period; symbol in parentheses – value lower than the tenth highest in the 65-year period.

3. Atmospheric circulation over Poland in selected months with a high monthly average value of the NAO and/or Δt

The frequency of circulation types over Poland according to *Lityński* (1969) was calculated for all the months when a high value occurred (i.e., which saw one of the 10 highest positive and negative NAO and/or Δt values). Following this, the average frequency of days with circulation from individual directions and with cyclonic, "0" (transitional), and anticyclonic circulation across the categories of months distinguished according to the sign and size of NAO and Δt were calculated. When compiling the months selected on account of a high NAO and/or Δt value, the NAO index was adopted as the primary characteristic (*Table 2*). The average number of days with circulation from each direction and of different nature is given in integral values for a 31-day month.

Table 2. The average number of days in a month with circulation from the individual directions and of different nature (according to Lityński (1969)) during different categories with high NAO+/- and/or high Δt+/-. The highest values are marked with bold type, C is for cyclonic types, 0 is for types "0" (transitional types), A is for anticyclonic types

Month category	No. of months	N	NE	E	SE	S	SW	W	NW	0	C	0	A
NAO+/Δt+	16	2	–	–	1	2	**9**	**8**	**8**	1	10	9	12
NAO+/(Δt+)	13	4	2	1	1	3	**6**	**6**	**6**	3	9	7	15
(NAO+)/Δt+	14	2	1	2	2	**5**	**7**	**4**	**6**	2	14	9	8
(NAO+)/Δt-	4	4	3	**6**	**7**	3	2	2	3	2	11	8	12
NAO-/Δt-	18	3	**6**	**7**	**6**	3	1	1	1	3	10	8	13
NAO-/(Δt-)	8	4	4	4	**8**	4	2	1	2	2	13	10	8
(NAO-)/Δt-	8	3	4	**6**	**6**	5	1	1	1	4	7	8	16
NAO-/(Δt+)	4	3	1	4	**6**	**6**	3	3	2	3	16	8	7

Explanation as in *Table 1*. The single month in the NAO+/Δt- category is disregarded.

3.1. Months with a positive value of the NAO index

In all the months from December to February in which the positive phase of the NAO occurred and the mean temperature in Warsaw was higher than the long-term average, there was a clear predominance of days with circulation from the western sector and a small number of days with circulation from the eastern sector.

In the months with high NAO+ and Δt+ (16 months) values, there was an average of 25 days with circulation from the SW-NW sector, and a mere 1 day from the NE-SE sector; advectionless situations also appeared, but they were very rare. The share of cyclonic, "0" (transitional), and anticyclonic types was fairly balanced, with a slight advantage of the last type (*Table 2*). In this category of months, several months stood out. The second highest NAO+ value (5.11) and one of the two highest Δt+ values (6.5 °C, which is equivalent to 1.8 standard deviations) occurred in February 1990 (28 days), when SW-NW circulation occurred on 24 days. At the time, the greatest deviation of air temperature considered to be anomalous, i.e., exceeding 2 standard deviations ($t \geq t_{av.}+2\sigma$) covered vast areas of Europe from Scandinavia and northern western part of Russia, through southern western part of Europe to the islands of the western Mediterranean Sea (*Fig. 2*). In Kajaani and Arkhangelsk, the temperature anomaly was Δt=10.5 °C, and even in Bordeaux, it exceeded 5 °C. The same group also included the previous month January 1990 (NAO = 3.5, Δt = 4.5 °C). As a result of having two such warm months in succession (and a fairly warm December), the winter of 1989/90 was one of the mildest in Europe in the mid-20th century (*Kossowska-Cezak* and *Twardosz*, 2017). In January 1983, which saw the highest January NAO+ (4.82) and Δt+ (5.8 °C), there were 19 days with SW-NW circulation. February 1995 (NAO=3.13, Δt = 5.0 °C) had 27 days with circulation from this sector (out of 28). December 2015 saw both the highest December NAO+ (4.22) and Δt + (5.4 °C); there were 23 days with SW-NW circulation and 3 days with circulation from the south.

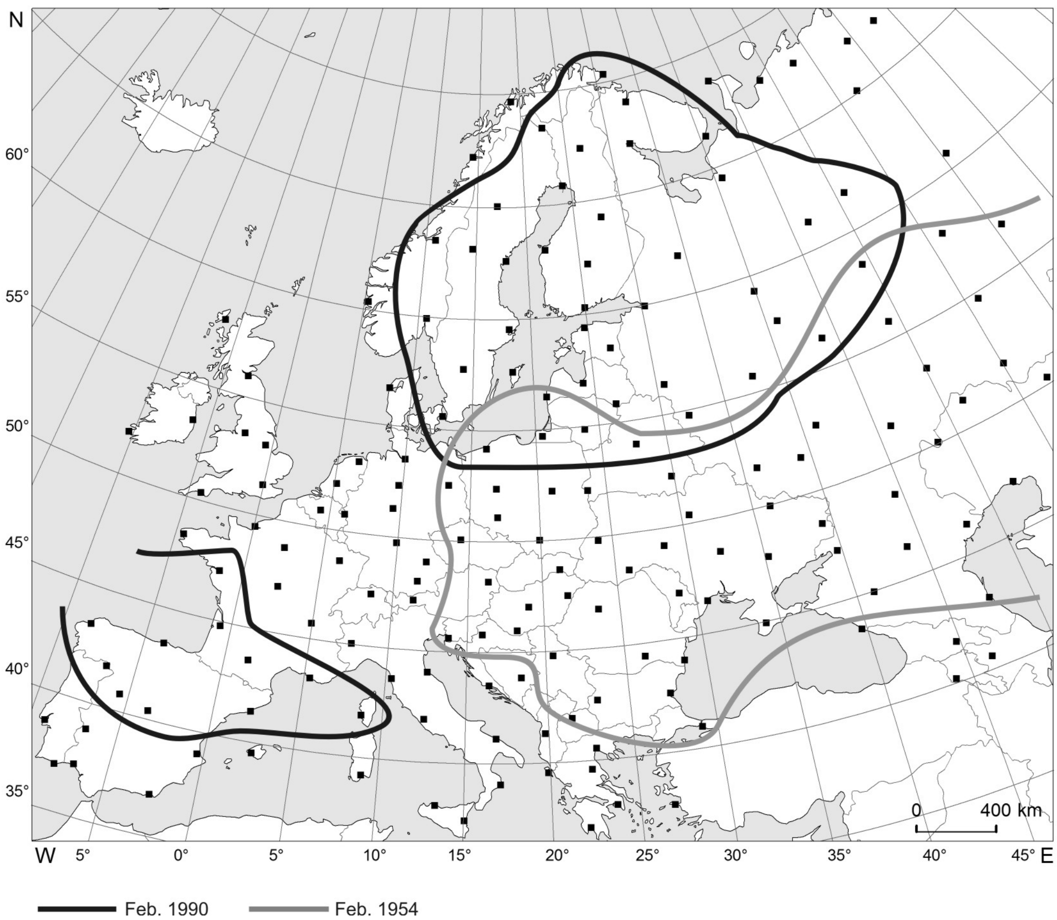

Fig. 2. Ranges of the positive (Δt+) and negative (Δt-) thermal anomalies during the positive NAO phase: February 1990 – NAO+/Δt+; February 1954 – (NAO+)/Δt- (explanations as for *Table 1*, the ranges are based on the publication by *Kossowska-Cezak* and *Twardosz,* 2017)

Months with high NAO+ do not always see high Δt+. In months with lower temperature deviation from the multiannual mean [NAO+/(Δt+), 13 months, *Table 1*], the average number of days with SW-NW circulation was 18 (*Table 2*), and from the opposite sector it was 4, i.e., NE-SE with a slightly higher share of days with northerly (N – 4 days) and/or southerly circulation (S – 3 days). For example, January 1974 (NAO=3.75, Δt=1.4 °C) had 12 days with SW-NW circulation, 11 days with S and 5 days with SE circulation, while in February 1961 (NAO=4.06, Δt=3.3 °C), SW-NW circulation occurred on 14 days, while N circulation on 6 days. This category of months also included February 1997, with the highest value of NAO+=5.26 (Δt = 3.5 °C) in the 65-year period. There were 23 days with SW-NW circulation, 4 days with circulation from the northeastern sector, and 15 days with anticyclonic circulation.

However, a high positive temperature deviation from the long-term average may occur in months with a relatively low NAO+ value [(NAO+)/Δt+, 14 months, *Table 1*]. This group included months with a wide range of NAO+ values from the "high" categories to the near-zero ones, and thus to the variation in the share of circulation directions in individual months. However, on average, days with SW-NW circulation predominated (17 days, *Table 2*), with 5 days on average with circulation from the opposite sector. This group included January 2007, with one of the two highest winter Δt+ = 6.5 °C, (1.9 standard deviations; NAO = 1.76). That month saw 27 days with SW-NW circulation and only one day with circulation from the NE-S sector; at the same time, it was the only month with a complete absence of anticyclonic circulation. At the time, a positive temperature anomaly extended to the southern and central parts of Europe and the southeastern part of European Russia (*Kossowska-Cezak* and *Twardosz*, 2017). Also, February 1998 was a month in the (NAO+)/Δt+ category (NAO = 2.44, Δt = 5.0 °C) recording 19 days with SW-NW circulation and no days with circulation from the NE-SE sector, but there were 3 days each with N and S circulation and anticyclonic circulation prevailed (15 days). This group also included January 1965 (NAO = 0.01, Δt = 3.5 °C) and February 1974 (NAO = 0.68, Δt = 3.9 °C), in which the number of days with SW-NW was 10 and 12, respectively, and the number of days with NE-SE circulation was 11 and 10, respectively; cyclonic circulation prevailed in both months – 15 and 13 days, respectively.

During spells with the positive NAO phase, there were occasional months when the average temperature in Warsaw was lower than the long-term average (4 months during the 65 years, *Table 1*). These months included February 2011, which represents the category (NAO = 2.79, Δt = -2.0 °C). The low temperature in that month was determined by the prevailing share of SE circulation (11 days), which was mostly anticyclonic in nature (14 days).

Months with a greater negative deviation of mean temperature from the multiannual average, but with a low positive value of the NAO index, i.e., the (NAO+)/Δt- category months were more frequent (4 months). In those months, the NAO value ranged from 0.01 to 1.28. Circulation from the NE-SE sector was predominant (16 days on average – *Table 2*), and that from the SW-NW sector was the least frequent (7 days). The months of this category included the anomalously cold February 1954 (NAO = 0.57, Δt = -7.8ºC). That month saw circulation from the E-S sector for 27 days, and anticyclonic circulation for 26 days. At the time, the negative temperature anomaly was present across vast areas of Europe from the southern Baltic countries to the shores of the Caspian Sea (*Fig. 2*); in Astrakhan, the temperature anomaly (Δt-) was -14.0 ºC (*Kossowska-Cezak* and *Twardosz,* 2017).

3.2. Months with a negative value of the NAO index

During negative NAO phases from December to February, Warsaw usually saw a monthly average temperature below the long-term mean. In those months, the prevailing circulation in Poland was that from the NE-SE direction, but its predominance was not as strong as for the SW-NW circulation in the NAO+ months, with advectionless situations being more frequent.

On average, in the months with a high NAO- and, at the same time, high Δt- (18 months, *Table 2*), there were on average 19 days with circulation from the NE-SE and only 3 days with circulation from the opposite sector (*Table 2*). Two examples of such months were December 1996, which experienced the greatest December NAO- in the 65-year period (-4.70, Δt = -4.7 ºC), and December 2010 with the second highest NAO- (NAO = -4.61, Δt = -4.7 ºC). During the latter month, the negative temperature anomaly stretched across the entire northwestern part of Europe (*Fig. 3*). In those months, NE-SE circulation was recorded on 13 and 15 days, respectively, with SW-NW circulation occurring only 5 and 7 times; furthermore, in December 1996, there were 6 days with advectionless situations. January 1963, which had the highest NAO- (-4.09), observed both the highest January Δt- and the second highest negative winter temperature anomaly (Δt = -9.8 ºC). That month stood out for the dominance of circulation from the N-E sector (27 days, including 13 days with NE) and the complete absence of circulation from the SW-NW sector; anticyclonic circulation prevailed (21 days). In that month, the negative temperature anomaly extended in Europe from the British Isles and France to western Russia and Ukraine (*Fig. 3*). At the eastern ends of the anomaly, Δt exceeded -10 ºC. The month that followed – February 1963 – was of the same category (NAO = -1.90, Δt = -6.3 ºC), with a prevalence of the NE-SE circulation (25 days) and, likewise, an absence of the SW-NW circulation. At the time, the negative thermal anomaly covered western Europe and the

Greenland Sea and Barents Sea islands, where Δt exceeded -10 °C (*Kossowska-Cezak* and *Twardosz,* 2017). The entire winter of 1962/63 was anomalously cold. The greatest negative thermal anomaly in Warsaw in the 65-year period (Δt = -10.4°C) was also recorded during a month in this category, namely in February 1956 (NAO = -2.96). In that month, NE-SE circulation was recorded on 26 days, and that from W and NW on 2 days; there were 15 days with anticyclonic circulation. February 1956 was highly exceptional, because it was the only month in the 65-year period when the negative temperature anomaly covered more than half of the continent, from the Pyrenean Peninsula to the Urals (except Scandinavia and northern Russia, *Fig. 3*). The greatest anomaly occurred in central Europe (Δt = -11 – -12 °C) (*Kossowska-Cezak* and *Twardosz*, 2017). It should be noted that at least half of the months in this category were classified as anomalously cold ($t \leq t_{av.} - 2\sigma$).

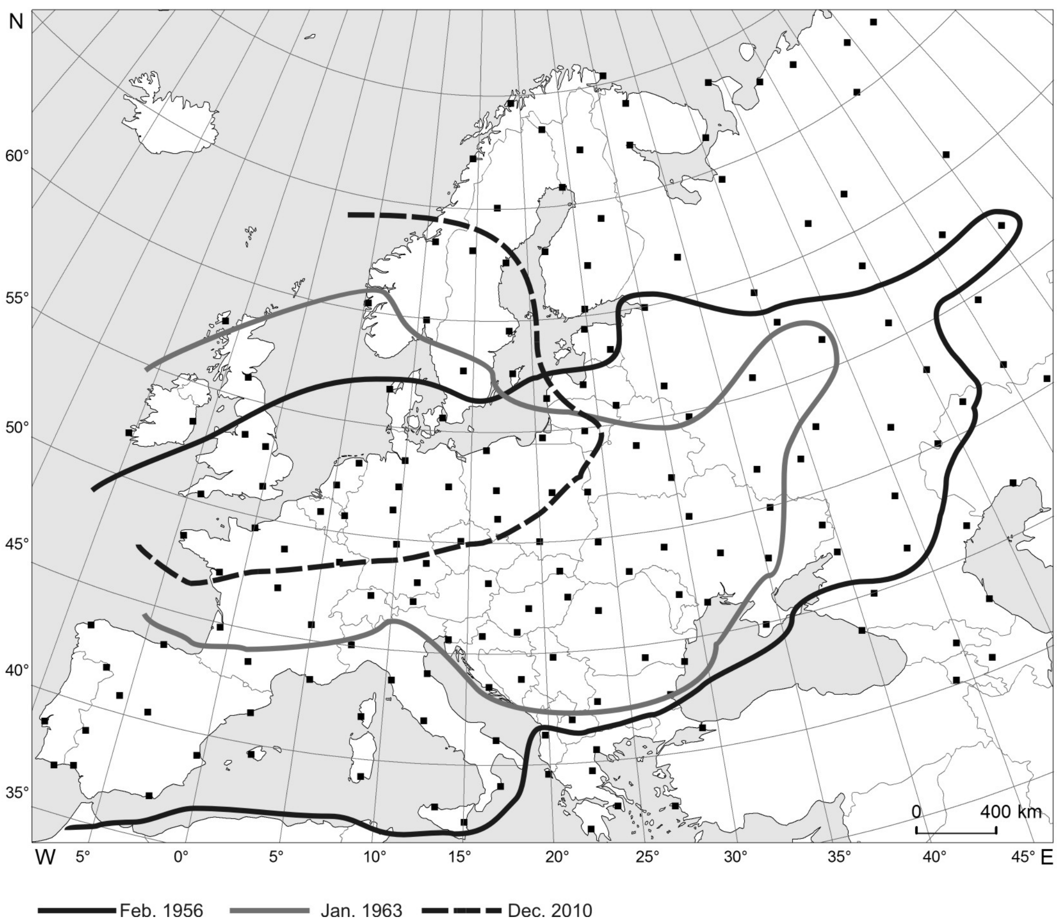

Fig. 3. Ranges of the negative thermal anomaly during the negative NAO phase – NAO-/Δt- (explanations as for *Table 1*, the ranges are based on the publication by *Kossowska-Cezak* and *Twardosz*, 2017)

Not every month with high NAO- see high negative deviations of temperature from the long-term average. In the months of the NAO-/(Δt-) category (8 days, *Table 1*), the disproportion between the number of days with the NE-SE and SW-NW circulations is lower; an average of 16 and 5 days respectively (*Table 2*). Such months included, inter alia, February 1969 (NAO = -3.16, Δt = -2.6 °C), which saw 23 days with E-S circulation, including 18 days with SE, and only 2 days altogether with SW and W, as well as December 1976 (NAO = -3.63, Δt = -0.5 °C), in which there were only 12 days with NE-SE circulation and 12 days with circulation from the S-SW section.

By contrast, significant deviation of monthly average temperatures from the long-term average can occur in months with a low NAO- value [category (NAO-)/Δt-; 8 months, *Table 1*]. In those months, there were on average 16 days with NE-SE circulation and 3 days with SW-NW circulation; advectionless and anticyclonic situations were relatively frequent (*Table 2*). This category includes inter alia January 1972 (NAO = -0.52, Δt = -4.8 °C), January 2006 (NAO = -0.10, Δt = -4.8 °C), and February 1985 (NAO = -0.24, Δt = -7.4 °C). All those months were dominated by days with circulation from the ES or NE-SE sectors (at least 20 days), and saw very few days or no days at all with SW-NW circulation (January 1972). One noteworthy fact is the characteristic, vast area of the negative temperature anomaly ($t \leq t_{av.}$-2σ) in February 1985, from Scandinavia to the Balkans and the Black Sea (*Fig. 4*).

In periods with negative NAO phase, there are also single months with an average temperature above the long-term mean (4 in total), but in none of those months did both these characteristics in question reach "high" levels. The 4 months saw high NAO- accompanied by slight Δt+ (0.2 – 1.9 °C). The months saw a slight advantage of the number of days with NE-SE circulation (11 days) over SW-NW (8 days), but with a significant share of days with S circulation (6 days, *Table 2*). Thus, this group of months should rather be described as marked with a prevalence of circulation from the southern sector (SE-SW – an average of 15 days) over northerly circulation (NW-NE – 6 days – *Table 2*), even though in individual months, atmospheric circulation over Poland varied. For example, in January 1977 (NAO = -2.36, Δt = 0.7 °C), circulation from the SE-SW sector occurred on 25 days (including 14 days with southern circulation) and NW-NE circulation on only 3 days, while in December 1989 (NAO = -2.23, Δt = 1.8 °C), such circulation occurred on 11 and 10 days, respectively. A compact area with a positive temperature anomaly in the latter month was seen in the southwestern part of Europe (*Fig. 4*).

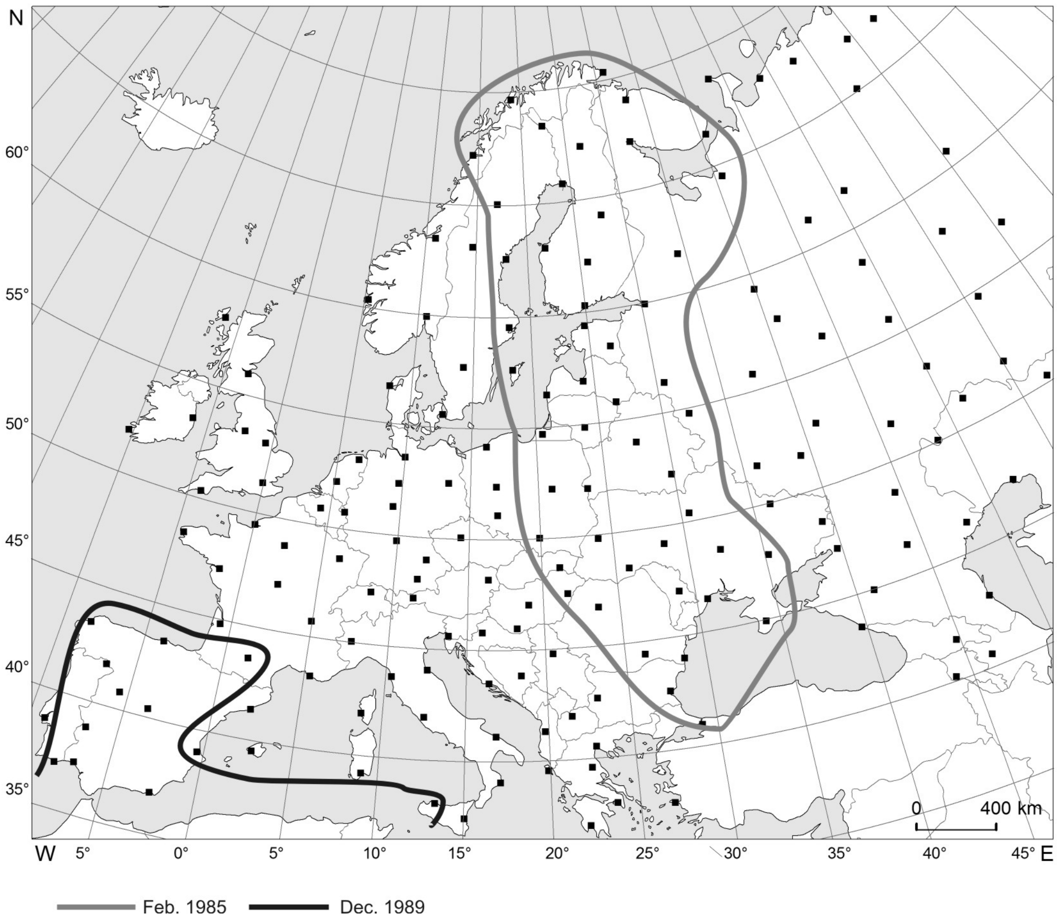

Fig. 4. Ranges of the positive and negative thermal anomalies during the negative NAO phase: December 1989 – NAO-/Δt+; February 1985 – (NAO-) /Δt- (explanations as for *Table 1*, the ranges are based on the publication by *Kossowska-Cezak* and *Twardosz* 2017).

4. Conclusions

Research into the relationship between the monthly thermal conditions in Warsaw and the monthly value of the NAO index in the winter months of 1951–2015 has led to several observations.

With a high positive value of the NAO index (at least 2.5), which is indicative of a strong westerly flow, central Europe is dominated by circulation from the western sector (SW-NW), with a negligible share or absence of circulation from the opposite sector. As a result of the advection of sea air masses in winter, temperatures over Poland are several degrees higher than the multiannual average (even by 5–6 ^{o}C and more). In general, the greater the number of days with westerly circulation, the higher the temperature.

An equally high positive temperature deviation can also occur with a low NAO+ index values if the prevalence of western circulation over Poland is similar to that in months with high NAO+ (e.g., January 2007). Based on this, it can be concluded that values of the NAO index calculated on the basis of atmospheric pressure measured at specific points (which is necessary for comparison purposes) does not always reflect the actual intensity of westerly air mass transport controlled by the actual difference in pressure between the Azores High and the Icelandic Low.

When regional pressure systems form over Europe, thereby modifying the direction of advection of air masses reaching the central part of Europe, circulation from easterly directions and consequently temperatures below the long-term average may predominate in Poland despite the positive NAO phase (February 1954). This follows from the fact that average monthly temperatures clearly higher or lower than the long-term average show a better correspondence to the directions of advection over Poland than to the intensity of westerly air mass transport as expressed by the NAO index, even though the thermal characteristics of air masses are not only determined by the direction of their inflow.

As might be expected, months in the negative NAO phase see a more diverse circulation than those in the positive phase. Circulation from the western sector rarely occurs over Poland (on individual days) or does not occur at all, with easterly circulation gaining the advantage, which is, however, not so strong as that of circulation from the western sector in the positive phase. Cases of strong concentration of advection directions into a single sector for the whole month are rare and mainly observed in February (e.g., in February 1929, the coldest one in the 20th century ($t \leq t_{av.}-2\sigma$), when NE-SE circulation occurred on 24 days, NAO index = 0.27; *Kossowska-Cezak*, 1997).

The advection of air from the east and/or the north in those months translated into a negative temperature anomaly in central Europe at the time. In months with a lower predominance of circulation from the N-E-SE sector, the deviation of temperature below the long-term average tends to be lower, while in months with a lower NAO- index, the predominance of N-E-SE circulation may be significant, as a result of which air temperatures may be well below the long-term average (e.g., January 1972: NAO = -0.52, Δt = -4.8 ^{o}C; SE –15 days, S – 10 days, anticyclonic circulation – 20 days).

It should be noted here that, as a rule, months in the negative phase of the NAO distinguished by particularly low temperatures have a high share of circulation within an anticyclone, which is an indirect indication of the effect of cloudiness on thermal conditions in winter (night cooling through radiation during long cloudless nights).

In the negative NAO phase, temperatures above the long-term average may occur in Poland, which occurs when there is increased circulation from the southern sector. However, the temperature deviation does not reach such values as in warm months during the positive phase of the NAO with westerly advection.

The analysis conducted in the present study confirms well-known regularities related to the impact of a strongly marked positive or negative NAO phases on the thermal conditions during Polish winters. However, it also reveals certain deviations from these regularities, which should be attributed to regional pressure systems over Europe, which control the advection within the territory of Poland and directly affect the thermal conditions here. At the same time, it must borne in mind that the direction of advection is not the sole determinant of the thermal characteristics of an incoming air mass.

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