THE NORTH ATLANTIC OSCILLATION IMPACT ON THE THERMAL REGIME IN LITHUANIA

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Introduction

The North Atlantic Oscillation (NAO) is the dominant mode of winter climate variability in the North Atlantic region ranging from central North America to Europe and much into Northern Asia (Hurrell & van Loon 1997). The positive NAO index phase reveals a stronger than usual subtropical high pressure center and a deeper than normal Icelandic low over the North Atlantic. The increased pressure difference results in more and stronger winter storms crossing the Atlantic Ocean on a more northerly track. This results in warm and wet winters in Europe and in cold and dry winters in northern Canada, Greenland and Mediterranean. The negative NAO index shows a weak subtropical high and a weak Icelandic low. Subsequently the reduced pressure gradient results in fewer and weaker winter storms crossing on a more west-east pathway. The moist air enters into the Mediterranean and cold air - to northern Europe (Trigo et al. 2002)

The storm track exhibits variations from winter to winter in its strength and position, but a particularly recurrent variation is for the storm track to be either strong with a north-eastward orientation taking depressions into NW Europe (a high NAO winter) or weaker with an east-west orientation taking depressions into Mediterranean Europe (a low NAO winter).

Since the Atlantic storms that travel into Europe control our rainfall, there is a strong influence on European precipitation patterns (Fowler & Kilsby 2002, Hurrell et al. 2002). The contribution of change in NAO to the current global and hemispheric mean winter temperature trend is of particular interest (Grey et al. 2000). According to Hurrell (1996), both NAO and the El Niño/Southern Oscillation (ENSO) have a linear relation with this climatic trend, but the NAO impact on terrestrial temperatures in the Northern Hemisphere is greater than that of ENSO.

NAO phases may influence human economic activities, agricultural crops (duration of the vegetation period, thermal moisture indices), sea navigation, fisheries, the ecological state of regions, and the functioning of terrestrial and aquatic ecosystems. (Marshall et al. 2001).

The entire European region is in the impact zone of the western flow from the Atlantic Ocean, where the precipitation, temperature and the runoff regime, as well as sea water level variations and ice formation conditions, are for the most part preconditioned by the NAO. Therefore our focus on the climatic effects in Lithuania that result from the NAO impact on thermal effects is explained by NAO forcing during the cold season of the year.

1. Data and methods

The mean daily and monthly air temperatures from 9 meteorological stations (MS) used in this study. Air temperature anomalies, Δt (°C), were calculated on the basis of the climatology for 1961 to 1990. Even the datasets differ in duration: the longest is of Vilnius MS (1865 to 2000), whereas the other MSs had data from 1948 to 2000, all datasets are homogeneous (Bukantis et al. 1998).

The one of the NAO indices used in this study was selected as the difference of normalised sea level pressure (SLP) between Ponta Delgada (Azores) and Stykkisholmur/Reykjavik (Iceland) and was obtained from the NCAR Climate Analysis Centre (Hurrell 1995). Index is calculated for period between 1865 and 2000. It was called as NAO-1 index. Another index is represented as the normalised SLP difference between Gibraltar and Stykkisholmur/Reykjavik and was obtained from the Climate Research Unit, University of East Anglia (Jones et al. 1997). That index also was calculated for period

1865-2000 and called as NAO-2 index. The third NAO index was taken from Climate Prediction Center as the dominant mode for the Northern Hemisphere. Its calculation procedure and large scale impacts on temperature and precipitation is freely available from the NOAA NWS CPC website - http://www.cpc.ncep.noaa.gov/products/. This index in current study was called as NAO-3. This index calculation involves much shorter period – 1950-2000. If the first two indices are station based and reflect only SLP latitudinal anomaly differences, the third one derived using principal component analysis from the 700 hPa monthly geopotential height data and has significant seasonal variation of the Centers of Action. The NAO indices (I) were classified as extremely low or high when they satisfied the condition - $| I | > \pm 1.5\sigma$, where σ is the standard deviation of the dataset for I.

The study also includes SLP field and 500 hPa height field data taken from the Reanalysis-1 database at Climate Diagnostics Centre (CDC) (Kalnay et al. 1996). These data cover cold periods (November to March) from1948 to 2000 in the Atlantic-European sector at 25 N - 90 N and 70 W to 70 E. The data resolution is a regular grid of 2.5 × 2.5° latitude and longitude.

All extreme circulation periods in the North Atlantic described by NAO indices were divided into blocking and/ or damping processes under the negative NAO phase and enhanced westerly flow under the positive NAO phase. All averaged weather patterns were classified according their temperature effects and references to the: (1) position and intensity of the Centers of Action (Icelandic and Azores), as well as the location of troughs and ridges in the SLP field; (2) geographical location, sign and amplitude of SLP anomalies; (3) location of upper troughs and ridges at 500 hPa and dominant flow over southeastern Baltic; (4) position of the centres of geopotential height anomalies, and sign and amplitude of 500 hPa height deviations and the change in their gradients over Lithuania.

The Wilcoxon or Mann-Whitney nonparametric U-criteria was used for statistical analysis of the correlations between temperatures at various meteorological stations and NAO indices.

2. NAO forcing on the regional thermal regime

It is already well known that surface temperature in Lithuania is strongly influenced by the flow strength from the Atlantic Ocean and the distance from the sea (Bukantis 1994). The same results are evident also using various datasets including the Reanalysis-1 850 hPa level temperature and land surface temperature (Willmott and Robeson, 1995) database (Stankunavicius and Bartkeviciene, 2003).

Linear correlation coefficients between NAO indices and monthly mean air temperature at Vilnius show that the statistically significant NAO impact on surface temperature is possible from September to March, and that of the NAO-1 and NAO-3 indices extend to July and August as well. This is predetermined by high meridional gradients in SLP and geopotential height during the cold period and late summer (Stankunavicius 2001). The strongest correlation of NAO indices with the surface temperature extends from January to March, when anomalies of SLP and geopotential height are greatest, and the NAO-2 index contribution is the largest. In spring and summer, when the weak-gradient pressure fields and a weak zonal flow prevail, the radiative factors also become very important.

A similar dependence of temperature fluctuation on the NAO has been reported from neighboring countries: changes in wind speed, temperature and seasons length in Estonia (Aasa et al, 2004; Suursaar et al, 2006), the changed winter temperatures and the ice regime in Latvian rivers (Klavins et al, 2004), the mean minimum and maximum temperatures are correlated with the NAO index (except during summer); the strongest correlation is between NAO and mean maximum temperature in winter in Poland (Wibig & Glowicki 2002).

The positive linear correlation between mean winter (January to March) Vilnius temperature for 1865 to 2000 and NAO-1was not significant at the 95% confidence level according to Student's t-test. Negative temperature deviations from the long-term winter mean were dominant in the second half of the 19th century and the middle of the 20th century, whereas positive deviations prevailed in the early 20th century and since 1980. These temperature fluctuations well coincide with those of NAO-1. The lowest mean seasonal temperature recorded in 1940 (–11.0°C) and 1942 (–11.5°C), when the indices were highly negative. The season of 1990 (+2.0°C), which had the highest temperature, coincides with a maximal value of NAO-1, NAO-2 and NAO-3.

3. Extreme NAO indices and temperature variation in Lithuania

Negative NAO phase usually corresponds to negative temperature anomalies, and positive NAO phase - to positive temperature anomalies. With extremely high values of NAO indices (I > 1.5), temperature anomaly is positive in 84 to 88% of cases across Lithuania; with an extremely low NAO index (I < –1.5), anomaly is negative in 77 to 86% of the winter months. The strongest link between air temperature in Lithuania and extreme NAO-1, NAO-2 and NAO-3 indices occurs in December to February. The differences between monthly air temperature anomalies during opposite phases of all NAO indices are statistically significant (Mann-Whitney-Wilcoxon test, 99% level). Consequently, extreme values of the all three indices represents Lithuanian thermal regime quite well for December to March. And only extreme NAO-3 index is able properly reflect regional temperature behavior for summer months (particularly for July-September).

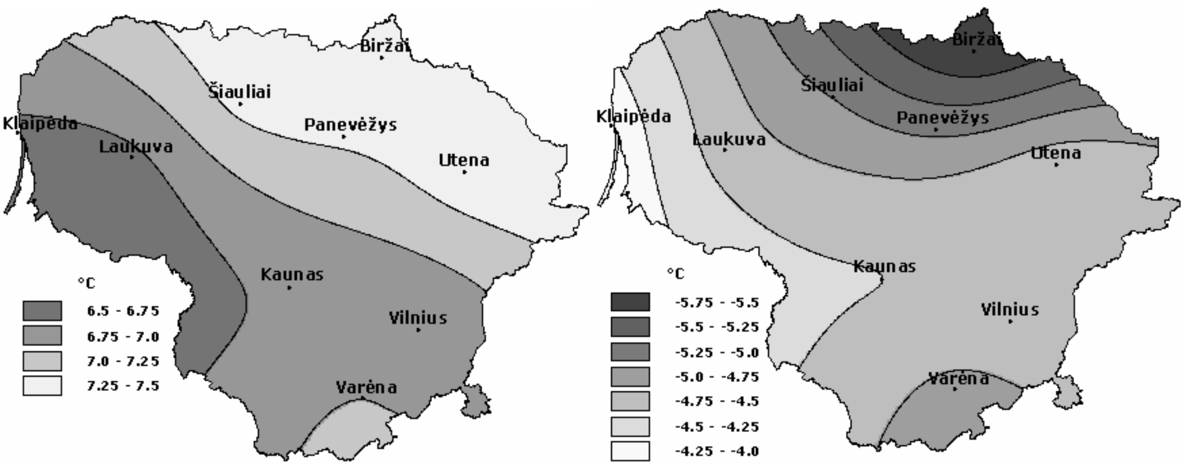

Fig. 1. Air temperature anomaly (° C) in Lithuania: 1989 February (left) and 1962 March (right). Anomalies estimated as deviations from climatology (1961-1990). Explanations see in the text.

For example, February 1989 was characterized by an anomalously intensive zonal flow over Europe, temperature anomaly values across Lithuania were between +6 °C and +7 °C, while the gradient of temperature anomalies was directed from northeast to southwest, and the values of NAO-1, NAO-2 and NAO-3 were 4.1, 3.6 and 2.0 respectively. Lowest values of NAO-3 are because of despite its standardization it is also normalized. Conversely March 1962 witnessed the opposite: the westerly flow was blocked in the entire Atlantic-European sector, and a cold upper trough developed over north and central Europe. NAO-1, NAO-2 and NAO-3 values were extremely low (–5.3, –3.8, -2.5 respectively), resulting in strong negative temperature anomalies in Lithuania (from –4 to –6°C), but the direction of the temperature gradient has nearly climatic shape extending from southwest to the north (fig. 1).

Such a good consistency between extreme values of analyzed indices and temperature is dominant but not always.

There are numerous short term (2-7 days) cases when the NAO phase does not reflect regional surface temperature fluctuations properly but only few months when the monthly anomaly sign was an opposite to the coherent NAO phase. In the November 1993 the zonal circulation prevailed between the NAO centers of action over the North Atlantic, the values of the NAO-1, NAO-2 and NAO-3 were positive (3.7, 0.8 and 2.6 respectively), and a warm upper blocking anticyclone developed over Scandinavia. Due to the radiative cooling that was forced by clear sky conditions, negative temperature anomaly values prevailed (–5.6 to –6.1°C). Another atypical situation developed in January 1977, when extremely low values of NAO-1, NAO-2 and NAO-3 (–2.7, –2.4 and -1.0 respectively), led to positive temperature anomaly, whereas its spatial differences did not exceed 1°C across Lithuania (not shown). The extremely negative values of NAO indices of that month were determined by large-scale Rossby waves over the Atlantic-European sector: the upper ridges were over the central North Atlantic and east Europe, the upper trough was over west Europe, and the dominating southern and southwestern air flow was over Lithuania. From the other hand all large scale structures during those months were not very persistent and at least there were two weakly scale time periods with the intensive cyclone and frontal activity over Southern Baltic (Stankunavicius & Bartkeviciene 2003).

4. Damped and enhanced NAO effect on the regional temperatures

All cases with unusual NAO forcing were classified into two groups (A and B): damped NAO effect – positive NAO index values and the negative temperature anomaly, and enhanced NAO effect – negative NAO (like blocking over Northeastern Atlantic) and positive temperature anomaly. An analysis includes only such monthly fields when the sign of all three indices coincides. Group A accounts 4.5 % of all winter months during 1950-2000 period and B – 3 %.

The group A was also divided to the two different types A1 and A2. Type A1 includes all cases when the Centers of Action both in SLP field and 500 hPa level are close to their climatic position and the prevailing zonal flow from the west to the Baltic region is blocked by an intensification of the Siberian anticyclone, which then occupies nearly the entire European region. The upper ridge appears over Eastern Europe (this is untypical for the positive NAO phase), and drives the Atlantic origin air towards the northeast. The weather in Lithuania is developed under positive SLP anomaly forced by Scandinavian and Siberian anticyclones. Type A2 collates all cases of the extended Azores High ridge into the Southern Scandinavia and the Atlantic air masses are directed to the Arctic. In Lithuania prevails positive SLP anomaly however upper level trough over Northwestern Russia forces polar air advection into the Baltic region from the northwest.

Enhanced NAO effect also is represented by 2 types (B1 and B2). Both types seem not to be the prominent patterns in midwinter months (especially in January February) but become more frequent in November and March. SLP field over the North Atlantic is characteristic for the negative NAO phase in B1 cases however typical blocked zonal circulation over North Atlantic follows divergent southwesterly flow over Baltic. SLP as well as geopotential heights tend to be lower than normal. The atmospheric circulation of type B2 differs from typical negative NAO phase: Icelandic Low is shifted to the Norwegian Sea and Azores High to the west. The axes of the upper trough and ridge are located more to the west, and Lithuanian territory then lies on the eastern periphery of the upper trough, with zonal flow over Baltic. Negative anomalies of SLP are greater than those of Type B1. The Atlantic cyclones following upper frontal zone cause positive deviations in air temperature and precipitation.

All described relations between circulation over North Atlantic and regional temperatures seem to be valid under more persistent circulation. From the other hand even few intramonthly abrupt changes in circulation do not guarantee coincidence with analyzed cases.

5. Conclusions

Air temperatures in Lithuania during the cold period of the year are strongly related to NAO variations. A positive NAO phase usually leads to high temperatures, whereas a negative NAO phase is reflected by low temperatures. During the last 3 decades, winters have become warmer, as a result of more frequently positive NAO indices. The highest NAO indices of the cold period have been recorded in the late 1980s and early 1990s. In the mid-20th century, when negative NAO indices dominated, cold winters increased in frequency in east and central Europe, including in Lithuania. The correlation between the NAO and air temperature fluctuations from April through June is not statistically significant.

Recently widely used NAO indices do not always represent the proper impact of the atmospheric circulation on surface temperature in Lithuania during winter. Untypical situations make up about 8% of the cases, when the NAO phase is opposite to the temperature anomaly sign. Cold anomalies in Lithuania simultaneously with the positive NAO phase are caused by the extended westward Siberian anticyclone, which develops under Scandinavian upper ridge or anticyclone and leads to the advection of continental air masses into the Baltic region.

Winter thermal anomalies during the negative NAO phase are caused by southwesterly or westerly flow over the Baltic region. The Siberian anticyclone is weak and does not block the zonal flow from the Atlantic. The weather in Lithuania is then mostly determined by Atlantic and southern cyclones. Other atmospheric circulation indices, i. e. teleconnection indices are able to explain some fraction of data variance which is classified as untypical for particular NAO phase. Unfortunately even such indices like Scandinavian (SCAND), East Atlantic (EA) or East Atlantic-Western Russia are much less persistent as NAO.

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