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# Effects of NAO on the climatic water budget at the Polish southern Baltic coast

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**Abstract.** Effects of the North Atlantic Oscillation (NAO) on the Standardized Precipitation-Evaporation Index (SPEI), a metric of the climate-dependent water budget, in the Polish part of the southern Baltic coastal areas were analysed. The analyses were based on monthly NAO index values calculated by P.D. Jones, T. Jonsson, and D. Wheeler for 1951-2010 and on monthly temperatures and sums of precipitation in Szczecin, Ustka, and Elbląg used to calculate SPEI. No strong effects of NAO on the water budget could be demonstrated. Intensified air mass advection from the west was found to slightly reduce SPEI in the Polish coastal zone. In winter (particularly in February), the reduction was caused by the temperature increase during air mass advection from the west, which increases evaporation. In summer (mainly in August), the effect was due to the decreased sum of precipitation, the reduction, however, not being significant. Therefore, NAO effects on the water budget are considered weak and irregular.

**Key words:**
NAO,
SPEI,
Polish coast,
correlation

## Introduction

The positive phase of the Northern Atlantic Oscillation (NAO), resulting from a steep pressure gradient in North Atlantic is accompanied by stronger-than-average westerlies, known to substantially affect the climate of Europe. The effect is primarily seen as an air temperature increase above the average values (Marshall et al. 1997; Kapala et al. 1998; Wang et al. 2005). In addition, NAO significantly affects precipitation in Europe, particularly in winter (Qian et al. 2000), although the effect throughout the continent vary (Lopez-Moreno and Vincente-Serano 2008; Folland et al. 2009; Vincente-Serano and Lopez-Moreno 2008; Hurrell and Deser 2010). The southern Baltic coastal zone of Poland, the focus of this paper, is located in a transition zone between northern and southern Europe, i.e., between areas differing in NAO effects on precipitation, and consequently on the water budget. It is then worthwhile to see if NAO affects the water budget in this part of Europe; finding out if such effects are observable is the aim of this work. The water budget metric used was the Standardised Precipitation-Evaporation Index (SPEI).

## Materials and methods

Monthly mean air temperatures and monthly sums of precipitation, as recorded in 1951-2010 at meteorological stations of Szczecin, Ustka, and Elbląg, were extracted from published climatological catalogues (Girjatowicz 2007; Girjatowicz et al. 2011) and annual reports of the Institute of Meteorology and Water Management (IMGW): „Bałtyk Południowy w 2002" [‘Southern Baltic in 2002'] to „Bałtyk Południowy w 2010 roku " [‘Southern Baltic in 2010'], (Miętus et al. 2003-2012) and „Warunki środowiskowe polskiej strefy południowego Bałtyku w 2001 roku" [‘Environmental conditions in the Polish zone of the southern Baltic in 2001' 2004]. The data were used to calculate the Standardised Precipitation-Evaporation Index (SPEI) for Szczecin, Ustka and Elbląg, representative of Polish coastal areas (Fig. 1).

The climatic water budget is understood as a difference between the sum of precipitation and the potential evaporation (Wibig 2012). The budget is expressed as the Standardised Precipitation- Evaporation Index (SPEI), i.e., a standardised difference between the precipitation and potential evaporation (Vincente-Serrano et al. 2010; Wibig 2012).

To determine monthly values of SPEI, potential evapotranspiration was calculated using the equation of Turec (1964, in Kossowska-Cezak and Bajkiewicz-Grabowska 2009):

$$PET=0.4\ t/(t+15)\ (K\downarrow + 50)$$

where: PET is a monthly potential evapotranspiration (mm); t is the monthly mean air temperature (°C); $K\downarrow$ is the monthly sum of total solar radiation (cal/cm$^{-2}$); 50 is the numerical coefficient for central Europe

$K\downarrow$ was estimated from data collected in central Poland by Miara et al. (1987, in: Kożuchowski 2011). There was no need for the equation to include relative humidity, as it was always higher than 50% in the coastal areas considered.

Following calculation of PET, mean monthly differences between sums of precipitation and potential evaporation were computed. Subsequently, the SPEI values were standardised for individual months, (Łabędzki and Bąk 2004).

In order to characterize values and variability of SPEI the following descriptive statistics were calculated: median, minimum, maximum, lower and upper quartiles as well as percentile 10% and 90%. The SPEI is a standardized value, therefore its mean value is equal to 0 and the standard deviation is 1. The existence of linear trends of monthly values of SPEI in the respective months in individual stations was verified, too. For this purpose linear regression coefficients were designated taking the time (consecutive years) as an independent variable. Determination coefficients, as a measure of matching of the trend line to the variable's values, were calculated, too. Theirs statistical significance were tested using Fisher-Snedecor test. Statistical significance was set at $\alpha = 0.05$.

Monthly values of the North Atlantic Oscillation (NAO) index as developed by Jones et al. (1997) were retrieved for 1951-2010 from the online database of the University of East Anglia (www.cru.uea.ac.uk/ftpdata/nao.dat). The NAO index was defined as a difference between the normalised values of atmospheric pressure in Gibraltar and the normalised pressure at stations in south-western Iceland, mainly in Reykjavik (Jones et al. 1997). The index was normalised using monthly means and standard deviations. On account of index normalisation (i.e., deviation from the mean values), a positive NAO phase resulting from steep pressure gradients (positive pressure gradient anomalies) is an evidence of intensive westerly advection, a negative phase reflecting weakened westerly advection usually allowing for advection from the east and intensified longitudinal circulation.

The correlation was used as a method of choice. Statistical significance was tested (Fisher-Snedecor test) for $\alpha = 0.05$. NAO index values in all months are normally distributed but the majority of monthly data of SPEI at individual stations does not have a normal distribution. Shapiro-Wilk test showed (at the significance level $\alpha = 0.05$), the most variables with normal distribution applies to monthly values in Szczecin (6) and the least in Ustka (only 2 – in March and December), in Elblag 4 variables fulfil this condition. Therefore, instead of the Pearson's correlation, Spearman's ranks correlation was used.

Mean values of SPEI for months with non-negative (positive in practice) and negative NAO indices were determined. Significance of differences between SPEI values at different NAO phases in the same months and at the same stations was assessed

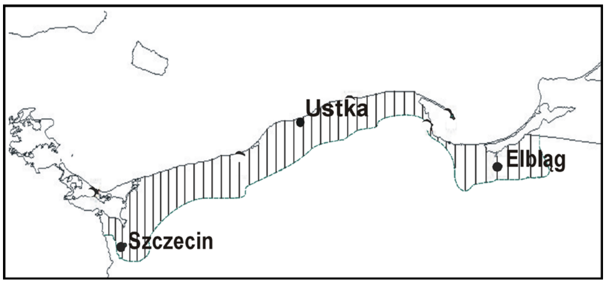


Fig. 1. Location of the weather stations on the Polish part of the Southern Baltic Seashores (the hatched area)

using Student's t test for independent samples at α = 0.05 - it was considered that there were significant differences between the mean values, when the level of significance is less than 0.05. It decided to use the Student's t test due to the fact that the probability distributions of SPEI in months with the positive and the negative NAO index in the majority of cases (44 out of 72 variables) satisfy the condition of similarity to a normal distribution with a significance level α = 0.05. In addition, this test is relatively resistant to break the assumption that the distribution of the results of a dependent variable in each of the analysed groups is close to normal distribution.

## Results

Median values, measures of variability as well as positional measures of SPEI at stations in certain months are presented in Table 1. Figure 2 shows the variability of monthly values of SPEI in Szczecin Ustka and Elbląg throughout the period 1951-2010.

Linear time trends of SPEI at individual stations in certain months were determined. Only a downward trend in Ustka in February was proved to be statistically significant at a level α = 0.05. The regression coefficient was equal in that case: -0.016 and the coefficient of determination was 0.077.

Coefficients of correlation between the NAO index and SPEI proved significant at α = 0.05 in February at all the three stations; other significant correlations were those in Elbląg in January and March, in Ustka in August and in Szczecin in September. All the significant correlation coefficients were negative (Table 2), indicating a decrease in SPEI with increasing NAO index.

The values of SPEI depends primarily on precipitation and temperature. In order to clarify to which of these two elements are more strongly affected by the NAO, correlation coefficients between NAO index and values of mean monthly temperature and monthly precipitation totals at individual stations were determined. The appointment of these compounds could explain why and how the NAO phenomenon effects on the water balance. Whether influence of NAO on the precipitation (water supply) or on temperature (evaporation) is more importance for variability of SPEI. Significant correlation coefficients of NAO index, temperature and precipitation totals are given in Table 3.

As shown by Table 3, NAO produced a stronger effect on the temperature than on precipitation; in addition, stronger effects were induced in winter, particularly in January.

Effects of NAO on the climatic water budget were analysed also by determining mean values of SPEI in months with positive and negative values of the NAO index (Fig. 3).

Differences between SPEI in NAO-positive and NAO-negative months, evidencing effects of western circulation intensity on the climatic water budget in the coastal areas of the southern Baltic were significant only in February in Szczecin and Elbląg as well as in August in Szczecin (Table 4).

## Discussion

The intensification of the NAO does not affect significantly the water balance of the southern Baltic coast manifesting itself, for example, by the values of rivers outflow (Wrzesiński and Paluszkiewicz 2011), in contrast to the influence on the rivers of Fennoscandia, Denmark and the nortwest part of the British Islas. During winters of high values of NAO index the maximum humidity transport axis across the Atlantic changes from the south-west to the north-west during winters with a high NAO index, which results in the movement of wet air towards Europe, this is relevant primarily in northern Europe, Scandinavia in particular (Hurrell 1995).

The positive NAO phase is characterised by exceptionally dry winters in the Mediterranean basin and southern Europe, and by wetter-than-normal

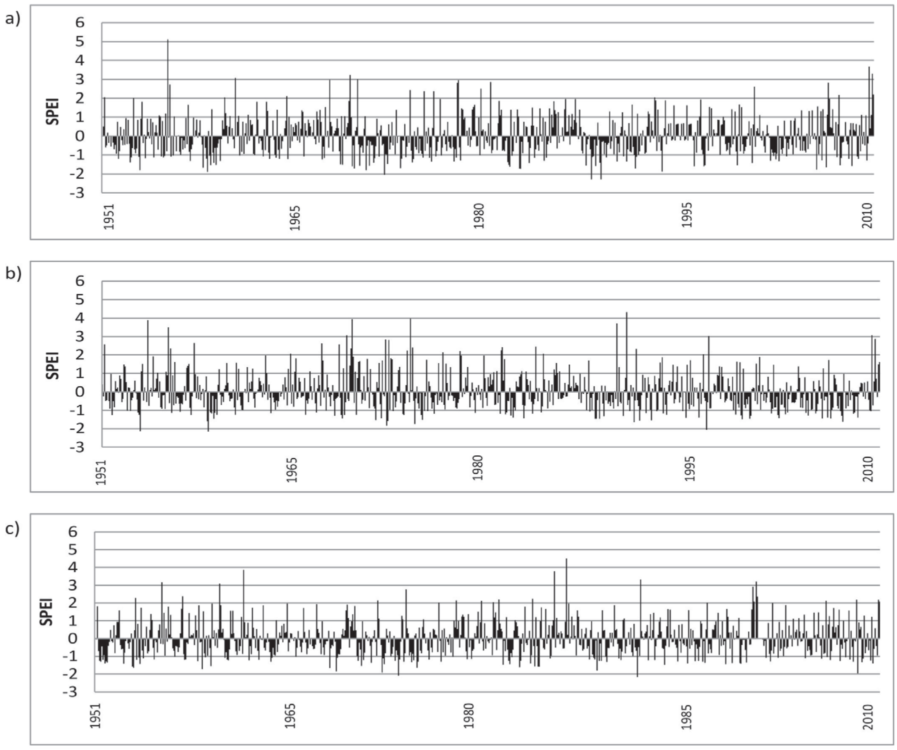


Fig. 2. Monthly values of SPEI in a) Szczecin, b) Ustka and c) Elbląg (1951-2010)

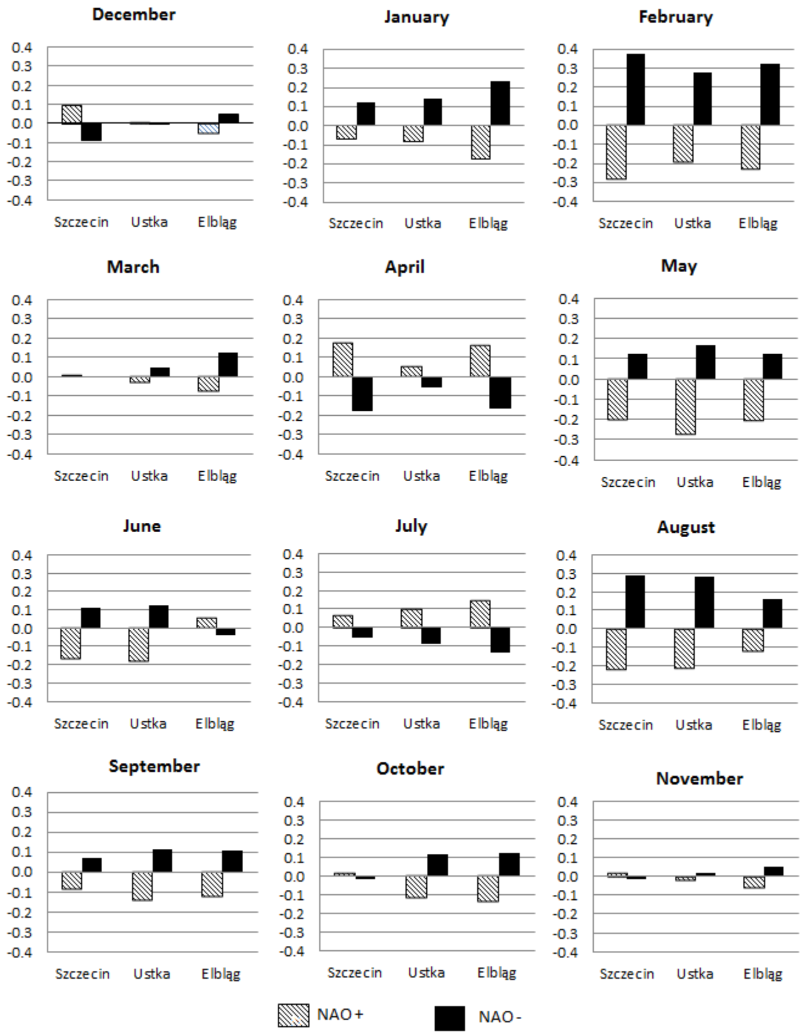


Fig. 3. Mean values of SPEI in months with positive (NAO +) and negative (NAO -) values of the NAO index (1951-2010)

Table 1. Descriptive statistics of SPEI (1951-2010

| month | median | minimum | maximum | lower quartile | upper quartile | percentile 10% | percentile 90% |
|---|---|---|---|---|---|---|---|
| **Szczecin** | | | | | | | |
| Jan | -0.03 | -2.29 | 2.37 | -0.80 | 0.74 | -1.21 | 1.41 |
| Feb | -0.06 | -1.40 | 5.11 | -0.71 | 0.43 | -1.05 | 0.93 |
| Mar | -0.07 | -1.89 | 2.86 | -0.79 | 0.63 | -1.27 | 1.39 |
| Apr | -0.22 | -1.66 | 3.23 | -0.74 | 0.77 | -1.09 | 1.13 |
| May | -0.21 | -1.58 | 3.07 | -0.73 | 0.75 | -1.21 | 1.25 |
| Jun | -0.15 | -1.73 | 2.83 | -0.70 | 0.49 | -1.19 | 1.30 |
| Jul | -0.02 | -1.89 | 2.11 | -0.95 | 0.78 | -1.40 | 1.39 |
| Aug | -0.13 | -1.72 | 3.68 | -0.68 | 0.59 | -1.13 | 1.20 |
| Sep | -0.07 | -1.62 | 2.98 | -0.73 | 0.56 | -1.06 | 1.08 |
| Oct | -0.03 | -2.29 | 2.37 | -0.80 | 0.74 | -1.21 | 1.41 |
| Nov | -0.19 | -1.68 | 3.30 | -0.69 | 0.55 | -1.08 | 1.32 |
| Dec | -0.24 | -2.04 | 2.43 | -0.70 | 0.74 | -1.11 | 1.42 |
| **Ustka** | | | | | | | |
| Jan | -0.18 | -1.66 | 2.07 | -0.66 | 0.68 | -1.31 | 1.58 |
| Feb | -0.12 | -1.75 | 3.49 | -0.49 | 0.30 | -1.24 | 1.23 |
| Mar | -0.32 | -2.17 | 2.57 | -0.67 | 0.74 | -1.15 | 1.34 |
| Apr | -0.04 | -1.40 | 3.94 | -0.63 | 0.29 | -1.10 | 1.07 |
| May | -0.31 | -1.55 | 3.08 | -0.71 | 0.78 | -0.99 | 1.57 |
| Jun | -0.19 | -1.56 | 4.32 | -0.65 | 0.30 | -0.94 | 1.19 |
| Jul | -0.21 | -1.46 | 3.90 | -0.64 | 0.54 | -1.18 | 1.27 |
| Aug | -0.19 | -2.06 | 2.86 | -0.78 | 0.54 | -1.12 | 1.49 |
| Sep | -0.19 | -1.53 | 3.70 | -0.70 | 0.61 | -1.21 | 1.30 |
| Oct | -0.21 | -1.26 | 3.98 | -0.76 | 0.36 | -0.98 | 1.37 |
| Nov | -0.22 | -1.25 | 3.06 | -0.80 | 0.46 | -1.08 | 1.34 |
| Dec | -0.09 | -2.15 | 2.63 | -0.63 | 0.48 | -1.18 | 1.58 |
| **Elbląg** | | | | | | | |
| Jan | -0.19 | -1.12 | 4.50 | -0.59 | 0.30 | -0.87 | 0.76 |
| Feb | -0.18 | -1.44 | 3.79 | -0.62 | 0.34 | -1.13 | 1.17 |
| Mar | -0.11 | -2.10 | 2.18 | -0.78 | 0.73 | -1.27 | 1.39 |
| Apr | -0.17 | -1.96 | 2.91 | -0.71 | 0.62 | -1.20 | 1.49 |
| May | -0.14 | -1.80 | 3.87 | -0.74 | 0.60 | -1.06 | 1.19 |
| Jun | -0.15 | -2.17 | 2.23 | -0.59 | 0.87 | -1.30 | 1.28 |
| Jul | -0.06 | -1.48 | 3.20 | -0.83 | 0.46 | -1.19 | 1.28 |
| Aug | -0.22 | -1.64 | 2.37 | -0.72 | 0.54 | -1.27 | 1.62 |
| Sep | -0.15 | -1.43 | 3.33 | -0.83 | 0.54 | -1.14 | 1.36 |
| Oct | -0.14 | -1.40 | 2.75 | -0.81 | 0.62 | -1.14 | 1.59 |
| Nov | -0.23 | -1.58 | 2.21 | -0.68 | 0.48 | -1.27 | 1.79 |
| Dec | -0.07 | -1.91 | 2.09 | -0.64 | 0.67 | -1.30 | 1.62 |

Table 2. Coefficients of Spearman's correlation between NAO index and SPEI (1951-2010)

| month | Szczecin | Ustka | Elbląg |
|---|---|---|---|
| Jan | -0.121 | -0.133 | **-0.299** |
| Feb | **-0.290** | **-0.338** | **-0.401** |
| Mar | -0.077 | -0.136 | **-0.268** |
| Apr | 0.226 | 0.015 | 0.154 |
| May | 0.021 | -0.019 | 0.051 |
| Jun | -0.160 | -0.186 | 0.031 |
| Jul | -0.122 | -0.017 | 0.090 |
| Aug | -0.244 | **-0.259** | -0.252 |
| Sep | **-0.327** | -0.127 | -0.177 |
| Oct | 0.084 | -0.107 | -0.112 |
| Nov | -0.014 | -0.107 | -0.162 |
| Dec | 0.147 | -0.001 | -0.022 |

Bold – statistically significant correlations

Table 3. Coefficients of correlation between NAO index and monthly mean temperature and sum of precipitation, significant at $\alpha=0.05$ (1951-2010)

| month | Temperature | | | Precipitation | | |
|---|---|---|---|---|---|---|
| | Szczecin | Ustka | Elbląg | Szczecin | Ustka | Elbląg |
| Jan | 0.792 | 0.777 | 0.761 | 0.385 | | |
| Feb | 0.680 | 0.644 | 0.670 | 0.291 | | |
| Mar | 0.680 | 0.595 | 0.536 | 0.274 | | |
| Jun | | | | -0.285 | | |
| Aug | | | | | -0.315 | -0.277 |
| Sep | 0.320 | | | | | |
| Oct | 0.440 | 0.444 | 0.470 | | | |
| Nov | 0.317 | | | | | |
| Dec | 0.624 | 0.583 | 0.574 | 0.340 | | |

Table 4. Significant differences between the mean values of the SPEI in the months of positive (NAO+) and negative (NAO-) values of the NAO index (1951-2010)

| month | average values of SPEI | | Student's test statistic | statistical significance level |
|---|---|---|---|---|
| | NAO + | NAO - | | |
| Szczecin - February | -0.271 | 0.379 | -2.573 | 0.013 |
| Elbląg - February | -0.231 | 0.323 | -2.160 | 0.035 |
| Szczecin - August | -0.223 | 0.291 | -2.004 | 0.049 |

winters in northern Europe and much of Scandinavia (Hurrell and van Loon 1997; Vincente-Serano and Lopez-Moreno 2008; Lopez-Moreno and Vincente-Serano 2008). During periods with high positive NAO indices, extremely high sums of precipitation and extremely low temperatures in northern Europe are more frequent than the average (Scaife et al. 2007). Southern Europe, Spain in particular, may be affected by droughts in the positive NAO years (Lopez-Moreno and Vincente-Serano 2006). Hurrell and Deser (2010) argue that drier conditions during positive NAO winters, resulting from changes in transport and distribution of atmospheric humidity convergence zones, occur also in most of central Europe. Wrzesiński (2005) proves that in rivers of Central Europe higher and longer-lasting rises and shorter low-flow periods occur in negative NAO stage than in positive one. High NAO indices are strongly related to water budgets of, e.g., Greenland and Canadian Arctic, so that during such winters evaporation exceeds precipitation (Hurrell and Deser 2010).

According to Lopez-Moreno and Vincente-Serano (2006), slightly higher values of the Standardised Precipitation Index (SPI) in August occur in southern Baltic coastal areas during years with positive winter NAO phase than during years with the negative phase. The differences, however, are not significant. NAO exerts a much stronger effect on air temperature than on the precipitation (Table 3), contributing to increase of the latter, and hence to increased evaporation. The correlation coefficients between the NAO index and the monthly mean temperature over 1864-1995 in Koszalin were as high as 0.614 and 0.622 for February and March, respectively (Marsz 1999), and were significant and positive also in January, April, May, and July.

The positive effects of air mass advection from the west on the winter air temperature and precipitation in Poland were mentioned by, i.a., Panfil and Dragańska (2004). Although their coefficients of correlations with precipitation oscillated usually around 0.2, the coefficients pertaining to correlation with temperature exceeded 0.7. Similar results were reported by Marsz and Styszyńska (2001) who analysed effects of NAO, as expressed by indices developed by Jones and Rogers (like in Panfil and Dragańska 2004), on the air temperature. Kaczmarek (2003) demonstrated that winters with extremely low values of the NAO index are followed by spring floods in Polish rivers. The strength of the relationship decreased westwards. Effects of low NAO indices on increased air humidity, as reflected by the increased SPEI in March, were evident in this study as well.

Negative coefficients of the NAO-SPEI correlation in June in Szczecin and in August in Ustka are most likely evidence of the positive NAO phase inducing a reduction in SPEI. Significance of the correlation coefficient is perhaps spurious. On the other hand, Mariotti and Arkin (2007) recorded lower-than-average sums of precipitation over the Baltic and the North Sea in summer during the positive NAO phase. Hurrell (1995) and Wibig (1999) found that, notwithstanding high winter precipitation during the positive NAO phase in north-western Europe, high NAO index values in warm seasons are correlated with reduced precipitation throughout Europe, except for Iceland and northern areas of the Scandinavian Peninsula. Studies on the Summer North Atlantic Oscillation (SNAO), a phenomenon related to NAO, showed the positive SNAO phase to be associated with warm, dry and relatively cloudless weather in north-western Europe in July and August (Folland et al. 2009). As shown by the analyses presented in this work, effects of SNAO on the weather in Europe extend to the southern Baltic coastal areas, although they are rather weak and irregular there.

## Conclusions

This study showed that NAO exerted no strong effect on the water budget in the southern Baltic coastal areas. Significant NAO-SPEI correlation coefficients occurred primarily in winter, particularly in February. This is a result of greater variation of NAO index values. In the warm part of the year, NAO is weakened, and its influence on parameters of the European climate is thus smaller.

Negative values of the NAO-SPEI correlation coefficients evidence that the air mass advection from the west onto the southern Baltic coastal areas contributes to the reduction of SPEI, i.e. to increased evaporation relative to the sum of precipitation. This is due to the effect of NAO being stronger with respect to the air temperature than to the sum of precipitation in winter.

Generally, intensified air mass advection from the west slightly reduces the climatic water budget (represented by SPEI) in Polish coastal areas. In winter (primarily in February), the effect is due to increased air temperature inducing increased evaporation. In summer (in August, according to Fig. 3), the reason lies in a reduced sum of precipitation which, however, is usually non-significant.

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