Impact of the North Atlantic Oscillation on river runoff in the Belarus part of the Baltic Sea basin

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Received 6 November 2006; accepted in revised form 7 September 2007

Nordic Hydrology **Vol 38 No 4–5 pp 413–423** © IWA Publishing 2007

Abstract The dynamics of the North Atlantic Oscillation (NAO) and river runoff in the Belarus part of the Baltic Sea basin have been studied. Correlation coefficients between NAO indices and monthly, seasonal and annual discharges were calculated, changes in the runoff in the opposite stages of NAO and its intra-annual distribution were analysed, and runoff trends for different time series were investigated. The closest connection could be observed between NAO indices for December–March and the runoff of Belarusian rivers in the Baltic basin. The highest correlation coefficients were calculated for winter and spring months. The intra-annual runoff differs in opposite stages of the North Atlantic Oscillation. The most significant increase of monthly runoff was observed after 1961. There was a positive trend of runoff at the beginning of the year, but a negative one in the summer and autumn months.

Keywords Intra-annual distribution; Mann–Kendall test; North Atlantic Oscillation; River; runoff

Introduction

Seasonal changes in the discharge are a natural effect of the prevailing climatic conditions, but multi-year variations may suggest global environmental changes. Hence, the river discharge can act as a simple indicator. The issues often discussed in works on hydrology are long-term changes in hydroclimatic elements, their tendencies, trends and cyclicity (Peel *et al.* 2001; Pekarova *et al.* 2006), as well as stability of the hydrological regime (Krasovskaia 1996; Arnell 1999; Krasovskaia and Gottschalk 2002; Wrzesiński 2004, 2005). Their results are commonly employed in forecasting models defining properties of the hydrological regime under various scenarios of global climate change.

Deviations of climatic elements from average levels caused by, for example, changes in the atmospheric circulation modify the conditions in which the streamflow forms. The river regime is controlled by both precipitation and air temperature, whose magnitudes show a significant dependence on the intensity of zonal circulation. A simple indicator characterising the atmospheric circulation over the North Atlantic is the North Atlantic Oscillation Index (henceforth NAO). Its significance for the formation of the streamflow has been emphasised by, for example, Shorthouse and Arnell (1997), Popova and Shmakin (2003) and Rödel (2006). In winter, the discharges of north European rivers are positively correlated with the winter NAO index, and those of southern Europe are correlated negatively. While in northern Europe this relation can be accounted for by an increase in precipitation in a positive stage of the NAO and in southern Europe by its decrease, in central

doi: 10.2166/nh.2007.025

and western Europe the dependence of winter precipitation on the NAO is rather weak. A strong relation does exist, however, between the NAO indices and air temperatures. Temperature controls the magnitude of water loss through evaporation in summer and the development and disappearance of snow cover in winter. In central Europe during a warm winter (NAO +) snow cover dwindles, hence meltwater floods are rare and carry small discharge volumes. In a negative NAO stage, in turn, winters are severe with a thick snow cover, thus contributing to high and large-volume flood waves (Styszyńska and Tamulewicz 2004; Wrzesiński 2004, 2005).

Methods and materials

Data analysis, statistic downscaling and different statistical methods have been used. Indices (monthly, seasonal and annual) of the NAO for the period from 1900 to 2003 were used for an assessment of the atmospheric circulation impact on the river runoff in Belarus. Indices of the NAO are based on the difference of normalised sea level pressure (SLP) between Ponta Delgada, Azores and Stykkisholmur/Reykjavik, Iceland. In the study use was made of NAO values calculated according to Hurrell's (1995) method and obtained from http://www.cru.uea.ac.uk/cru/data/nao.htm.

Data from 15 hydrological observation stations, which belong to the Department of Hydrometeorology of the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus, were used in the analysis (see Figure 1). All of them came from rivers flowing into the Baltic Sea basin: the Zapadnaya Dvina (Daugava) and its tributaries – the Obol, Polota, Nacha, Berezovka and Drysa; and the Neman and its tributaries – the

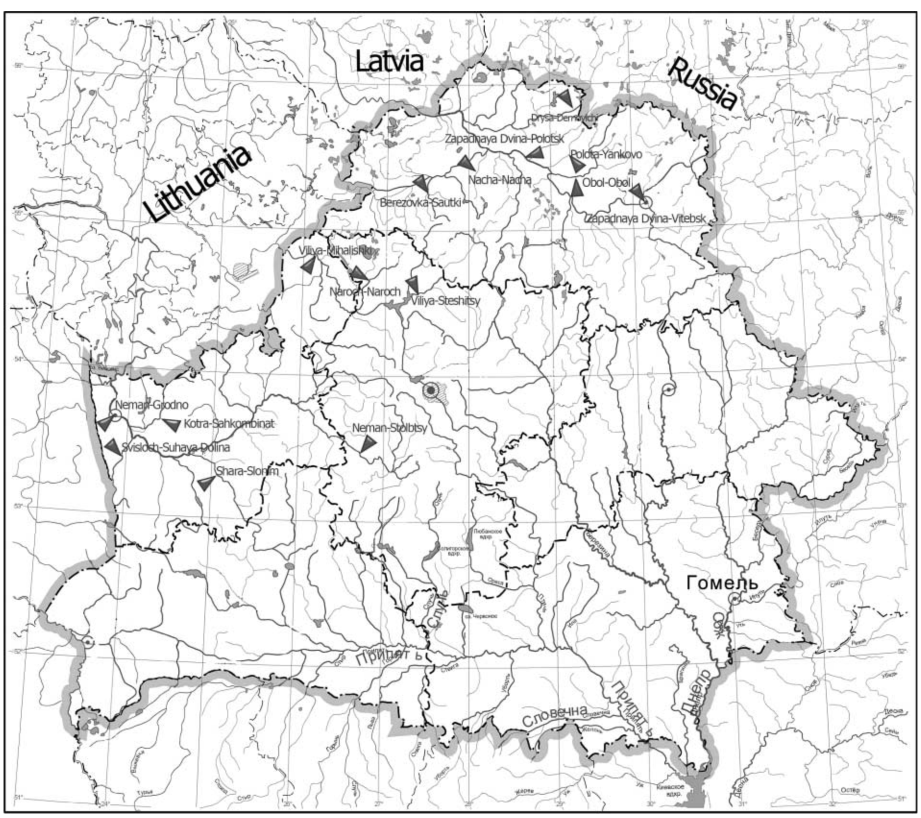

Figure 1 Diagram of location of hydrological stations

Viliya, Shchara, Svisloch, Kotra and Naroch. Use was made of monthly discharge figures for the period from 1900 to 2003.

General conditions in the area

The Republic of Belarus is situated in the west of the East European plain. The climate of the territory is determined by the situation in the temperate latitudes, the closeness to the Atlantic Ocean and the absence of natural borders in the path of air masses. The largest quantity of precipitation falls during the passage of Atlantic cyclones. It determines fluctuations in river runoff (Nekrasova *et al.* 2003). The fluctuation in the annual runoff during an observation period (104 years) reflects a dependence of runoff on the dynamics of the NAO (Figure 2). The highest index and longest period of a positive NAO stage was registered in 1989–1994 (6 years). Significant mean annual runoff prevailed throughout this period (except for 1992). Positive NAO indices were recorded in 1998–2000 (3 years) and they are correlated with high runoff in Belarus (Nekrasova 2004). At the beginning of this century (2001–2003) annual runoff was lower than average by 15–20%, and NAO indices were negative in 2001 and positive in 2002.

Results

Connection between the North Atlantic Oscillation and runoff

Pearson's linear correlation was used for assessment of the connection between the North Atlantic Oscillation and river runoff in Belarus. Correlation coefficients were calculated between:

(a) monthly NAO indices and monthly discharges,
(b) winter (December–February), spring (March–May), summer (June–August), autumn (September–November) NAO indices and discharges,
(c) annual NAO indices and monthly (January–December) discharges,
(d) NAO_{djfm} indices and monthly, seasonal and annual discharges.

The most significant coefficients of correlation between monthly NAO indices from January to December and monthly discharges from January to December were obtained for

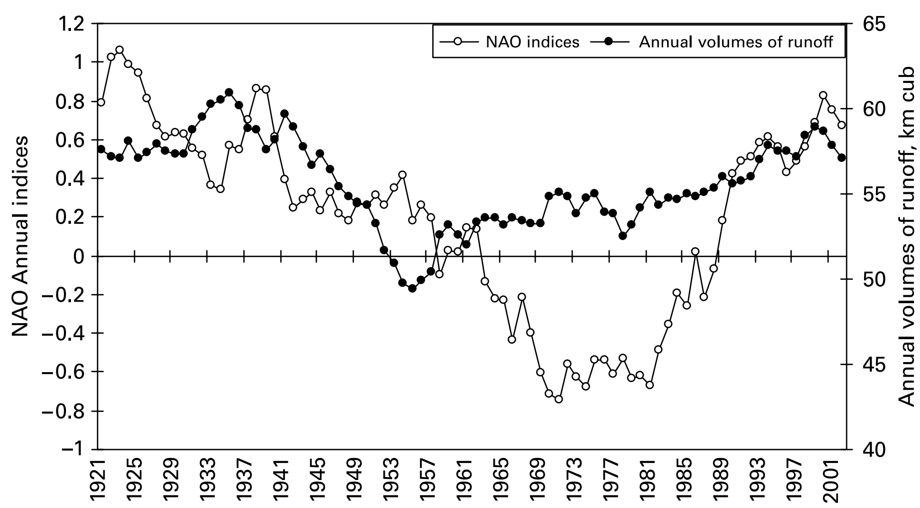

Figure 2 Changes in the annual indices of the North Atlantic Oscillation and runoff in Belarus expressed as a 20-year moving average

Table 1 Correlation coefficients between monthly NAO (from January to December) indices and monthly discharges (from January to December) (significant coefficients at the 0.05–0.001 level in bold)

River	Month											
	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Zapadnaya Dvina basin												
Z.Dvina-Vitebsk	**0.22**	**0.29**	**0.35**	−0.09	0.01	−0.19	**−0.22**	−0.01	−0.08	−0.05	0.00	−0.04
Z.Dvina-Polotsk	**0.21**	**0.31**	**0.37**	−0.11	0.02	−0.18	**−0.23**	0.04	−0.03	0.00	−0.08	−0.06
Obol-Obol	**0.23**	**0.27**	**0.41**	−0.05	0.03	−0.17	**−0.20**	0.02	−0.02	−0.02	−0.10	−0.07
Polota-Yankovo	**0.23**	**0.30**	**0.42**	−0.06	0.07	−0.17	**−0.20**	−0.08	−0.06	−0.06	0.00	0.02
Nacha-Nacha	**0.26**	**0.28**	**0.36**	−0.14	0.01	−0.18	−0.16	0.02	−0.09	−0.06	−0.08	-0.07
Berezovka-Sautki	**0.29**	**0.30**	**0.43**	−0.06	0.02	−0.12	−0.12	0.00	−0.11	−0.12	−0.08	−0.02
Dryssa-Dernovichi	**0.21**	**0.28**	**0.41**	−0.05	0.03	−0.15	**−0.20**	−0.01	−0.01	−0.05	0.02	−0.02
Neman basin												
Neman-Grodno	**0.31**	**0.32**	**0.37**	0.00	−0.07	−0.07	−0.03	0.08	−0.07	−0.17	0.06	0.18
Neman-Stolbtsy	**0.21**	**0.31**	**0.22**	−0.02	−0.08	0.04	−0.01	0.12	−0.08	−0.12	0.08	0.12
Neman-Mosty	**0.29**	**0.34**	**0.38**	−0.01	−0.07	−0.08	−0.02	0.09	−0.07	−0.17	0.06	0.18
Kotra-Sahkombinat	**0.29**	**0.29**	**0.32**	−0.02	−0.07	−0.01	−0.02	0.06	−0.08	−0.19	0.04	0.16
Svisloch-Suhaya Dolina	**0.35**	**0.34**	**0.23**	−0.02	−0.08	−0.04	−0.07	0.00	−0.14	−0.18	0.05	0.19
Viliya-Steshitsy	**0.30**	**0.38**	**0.40**	−0.05	0.01	−0.11	−0.03	0.15	−0.04	−0.12	0.01	0.09
Viliya-Mihalishki	**0.26**	**0.33**	**0.34**	−0.04	0.00	−0.07	−0.02	0.09	−0.03	−0.14	0.01	0.12
Naroch-Naroch	**0.27**	**0.37**	**0.44**	−0.06	−0.02	−0.14	−0.07	0.13	−0.05	−0.16	0.02	0.10

the first part of the year (January–March). They gradually increased from January to March (Table 1). They varied in January from 0.20 to 0.35, in February from 0.27 to 0.38 and in March from 0.22 to 0.44 (significant at the 0.0–0.001 level). Correlation coefficients were not significant in the remaining months of the year and were less than 0.2.

Correlation between winter, spring, summer and autumn NAO indices and discharges is significant in winter and spring for the rivers of the Zapadnaya Dvina and Neman basins (Table 2). The winter season is characterised by positive correlation coefficients – from 0.20 to 0.288 (sig. 0.05–0.001). In spring the correlation coefficients were negative and total from 0.20 to 0.32, but still significant (significant at the 0.05–0.001 level) for the Neman basin. Correlation coefficients were positive in summer and negative in autumn but they were not significant.

The correlation between annual NAO indices and monthly discharges (from January to December) is significant (significant at the 0.05–0.001 level) in the first half of the year (except the Neman–Stolbtsy) (Table 3). The coefficients are positive in January–March and total from 0.20 to 0.43. In April they become negative, and significant in the Neman basin with values from −0.32 to −0.39 (significant at the 0.001 level). The correlation is not significant in April for the rivers of the Zapadnaya Dvina basin, but significant in May and for some rivers in June with values from −0.20 to −0.31 (significant at the 0.05 level). It can be explained by different conditions of runoff formation for the Zapadnaya Dvina and Neman rivers.

The correlation coefficients between NAO_{djfm} indices and discharges are the most significant (Table 4). Correlation coefficients are positive in January–March and total from 0.30 to 0.52 (significant at the 0.001 level) for the rivers of the Zapadnaya Dvina basin, and from 0.20 to 0.44 (significant at the 0.05–0.001 level) for the rivers of the Neman basin. They are negative in April and May and vary from −0.20 to −0.43 for the rivers of Zapadnaya Dvina basin and from −0.20 to −0.50 for the rivers of the Neman basin (significant at the 0.05–0.001 level).

Table 2 Correlation coefficients between seasonal (winter: December–February, spring: March–May, summer: June–August, autumn: September–November) NAO indices and discharges (significant coefficients at the 0.05–0.001 level in bold)

	Seasons			
River	**Winter**	**Spring**	**Summer**	**Autumn**
Zapadnaya Dvina basin				
Z.Dvina-Vitebsk	**0.22**	−0.09	−0.17	−0.13
Z.Dvina-Polotsk	**0.22**	−0.10	−0.16	−0.18
Obol-Obol	**0.22**	−0.02	−0.14	−0.19
Polota-Yankovo	**0.24**	0.00	**−0.21**	−0.14
Nacha-Nacha	**0.20**	−0.14	−0.16	−0.18
Berezovka-Sautki	**0.25**	−0.13	−0.09	−0.16
Dryssa-Dernovichi	**0.23**	0.01	−0.15	−0.11
Neman basin				
Neman-Grodno	**0.26**	**−0.28**	0.06	−0.11
Neman − Stolbtsy	**0.22**	**−0.25**	0.04	−0.10
Neman-Mosty	**0.25**	**−0.26**	0.08	−0.11
Kotra-Sahkombinat	**0.24**	**−0.25**	0.11	−0.11
Svisloch-Suhaya Dolina	**0.28**	**−0.32**	0.02	−0.12
Viliya-Steshitsy	**0.28**	−0.18	0.06	−0.10
Viliya-Mihalishki	**0.20**	**−0.23**	0.05	−0.09
Naroch-Naroch	**0.27**	**−0.20**	0.04	−0.11

Table 3 Correlation coefficients between annual NAO indices and monthly discharges (from January to December) (significant coefficients at the 0.05–0.001 level in bold)

River	Month											
	Jan	**Feb**	**March**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Zapadnaya Dvina basin												
Z.Dvina-Vitebsk	**0.21**	**0.26**	**0.35**	−0.05	**−0.28**	−0.15	−0.03	−0.14	0.04	0.02	−0.08	−0.05
Z.Dvina-Polotsk	**0.21**	**0.25**	**0.35**	−0.09	**−0.29**	−0.16	−0.05	−0.12	−0.03	−0.05	−0.12	−0.17
Obol-Obol	**0.23**	**0.22**	**0.38**	−0.13	**−0.27**	**−0.20**	−0.13	−0.17	−0.05	−0.10	−0.14	−0.14
Polota-Yankovo	**0.25**	**0.26**	**0.43**	−0.02	**−0.27**	−0.13	−0.15	−0.16	0.02	−0.04	−0.09	−0.02
Nacha-Nacha	**0.25**	**0.22**	**0.36**	−0.17	**−0.31**	−0.10	−0.10	−0.11	−0.03	−0.09	−0.08	−0.02
Berezovka-Sautki	**0.29**	**0.16**	**0.34**	**−0.31**	**−0.29**	−0.05	−0.14	−0.12	0.02	−0.08	−0.07	0.10
Dryssa-Dernovichi	**0.24**	**0.27**	**0.40**	−0.03	**−0.28**	−0.15	−0.13	−0.16	0.00	−0.02	−0.06	−0.07
Neman basin												
Neman-Grodno	**0.20**	**0.24**	**0.31**	**−0.39**	**−0.32**	**−0.24**	−0.04	−0.01	0.00	−0.03	−0.02	0.10
Neman-Stolbtsy	0.10	**0.18**	**0.18**	**−0.35**	**−0.25**	−0.07	0.07	0.03	0.01	−0.04	−0.02	0.09
Neman-Mosty	**0.20**	**0.25**	**0.30**	**−0.39**	**−0.33**	**−0.25**	−0.04	−0.01	0.01	−0.03	−0.02	0.10
Kotra-Sahkombinat	**0.22**	**0.23**	**0.29**	**−0.32**	**−0.25**	**−0.21**	−0.03	−0.01	0.00	−0.03	0.02	0.07
Svisloch-Suhaya Dolina	**0.26**	0.16	0.12	**−0.38**	**−0.19**	−0.14	0.00	0.02	0.03	−0.03	0.01	0.08
Viliya-Steshitsy	**0.24**	**0.25**	**0.34**	**−0.33**	**−0.24**	−0.05	0.09	0.02	−0.03	−0.02	−0.03	0.14
Viliya-Mihalishki	0.14	**0.25**	**0.27**	**−0.32**	**−0.35**	**−0.26**	−0.02	−0.04	−0.08	−0.05	−0.07	0.04
Naroch-Naroch	**0.20**	**0.23**	**0.34**	**−0.33**	**−0.31**	−0.18	−0.04	−0.07	−0.08	−0.08	−0.04	0.10

Table 4 Correlation coefficients between NAO_{djfm} indices, monthly (from January to December) and annual discharges (significant coefficients at the 0.05–0.001 level in bold)

River	Month												Year
	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
Zapadnaya Dvina basin													
Z.Dvina-Vitebsk	**0.30**	**0.40**	**0.48**	−0.11	**−0.25**	−0.03	−0.03	0.02	0.19	0.19	0.11	−0.03	0.14
Z.Dvina-Polotsk	**0.31**	**0.39**	**0.49**	−0.18	**−0.28**	−0.06	−0.05	−0.01	0.13	0.12	0.09	−0.07	0.06
Obol-Obol	**0.31**	**0.34**	**0.52**	**−0.27**	**−0.26**	−0.10	−0.10	−0.02	0.11	0.09	0.07	−0.02	0.07
Polota-Yankovo	**0.31**	**0.39**	**0.52**	−0.12	**−0.25**	0.00	−0.08	0.01	0.16	0.17	0.09	0.01	0.17
Nacha-Nacha	**0.31**	**0.32**	**0.34**	**−0.32**	**−0.30**	−0.10	−0.10	0.00	0.11	0.15	0.14	0.04	0.03
Berezovka-Sautki	**0.37**	**0.30**	**0.28**	**−0.43**	**−0.27**	−0.06	−0.08	−0.01	0.18	0.14	0.11	0.13	0.04
Dryssa-Dernovichi	**0.31**	**0.41**	**0.53**	−0.09	**−0.27**	−0.05	−0.07	0.00	0.15	0.16	0.12	0.01	0.19
Neman basin													
Neman-Grodno	**0.25**	**0.42**	**0.31**	**−0.50**	**−0.31**	−0.15	0.10	0.06	0.06	0.12	0.06	0.05	−0.06
Neman-Stolbtsy	**0.19**	**0.38**	**0.15**	**−0.46**	**−0.24**	0.01	0.13	0.10	0.04	0.09	0.04	0.09	−0.09
Neman-Mosty	**0.24**	**0.44**	**0.31**	**−0.51**	**−0.32**	−0.16	0.09	0.06	0.05	0.11	0.05	0.03	−0.07
Kotra-Sahkombinat	**0.25**	**0.41**	**0.25**	**−0.39**	**−0.18**	−0.12	0.11	0.05	0.09	0.12	0.09	0.07	0.06
Svisloch-Suhaya Dolina	**0.28**	**0.36**	**0.03**	**−0.46**	−0.14	−0.06	0.18	0.08	0.17	0.12	0.10	0.06	−0.05
Viliya-Steshitsy	**0.29**	**0.44**	**0.31**	**−0.46**	**−0.28**	−0.03	0.11	0.05	−0.01	0.10	0.04	0.13	0.01
Viliya-Mihalishki	**0.22**	**0.42**	**0.24**	**−0.46**	**−0.35**	−0.20	0.04	−0.01	−0.03	0.07	0.01	−0.02	−0.15
Naroch-Naroch	**0.27**	**0.43**	**0.36**	**−0.46**	**−0.30**	−0.08	0.12	0.06	0.08	0.12	0.07	0.09	0.03

The high correlation in winter is explained by the fact that in winter the Icelandic Low becomes more significant and influences the weather to a larger extent. Thus, the formation of runoff strongly depends on meteorological processes and on atmospheric circulation.

As the obtained correlation coefficients indicate, the connection between North Atlantic Oscillation and runoff is weak but significant. The correlation is low because of the use of NAO indices and runoff during a long-standing period without taking into account the periods of zonal and meridional atmospheric circulation (Danilovich 2006; Danilovich and Chekan 2007). Further research should concentrate on the detailed analysis of the atmospheric circulation and its influence on runoff by finding correlations in particular epochs of atmospheric circulations.

Formation of runoff in the opposite stages of the North Atlantic Oscillation

The peculiarities of runoff formation in the opposite stages of the North Atlantic Oscillation were studied. We put all the years with positive indices of NAO_{djfm} in one group and all the years with negative indices in another, and calculated the average runoff in those groups. The calculations showed a significant difference in the monthly runoff figures in the years of positive and negative stages of the North Atlantic Oscillation for December–March.

The winters are usually frosty with significant snow cover in the negative stage of NAO_{djfm}, and therefore the amount of water feeding the rivers is small and winter runoff is below average. In the positive stage of NAO_{djfm} the winters are milder with frequent thaws and winter runoff is above the average.

Significant differences between the runoff figures in the years of positive and negative stages of NAO_{djfm} were observed in January–May. The differences were observed to increase gradually from month to month, and to reach a maximum in March. The differences are positive at the beginning of the year, which means a higher-than-average runoff in positive NAO_{djfm}. The differences become negative in April and May, which means that the spring runoff is higher in the negative stage of NAO_{djfm}. It should be noted that rivers with small basins have larger differences in the Zapadnaya Dvina basin, but not in the Neman basin because the climate is becoming more continental and the local peculiarities of runoff formation also count. The differences are not significant for the rest of the year except for the Zapadnaya Dvina, Polota, Obol and Dryssa rivers, where the runoff is observed to be higher than average in September–November in the years of a positive stage of NAO_{djfm} and runoff differences are positive and significant (significant at the 0.05–0.001 level).

In the years when the NAO_{djfm} index is negative, winter runoff (January–March) is below average, constituting from 58–85% of the average for the rivers of the Zapadnaya Dvina basin and from 79–93% of the average for those of the Neman basin (Table 5). The runoff increases from April on and varies from 109–126% of the average for the rivers of the Zapadnaya Dvina basin (the highest deviations being observed on small rivers) and from 129–139% of the average for those of the Neman basin. In May, runoff increases on the large rivers of the Zapadnaya Dvina basin to 122%, and on the small rivers the increase is lower than in April, varying from 116–119% of the average. For the rivers of the Neman basin, the increase of runoff is also lower, varying from 104–119%, but runoff is still higher than the average. In summer the runoff is observed to be about the average or slightly higher in the Zapadnaya Dvina basin, about 110%, and slightly lower, about 91%, in the Neman basin. In autumn the runoff record is below average, about 77%, for the rivers of the Zapadnaya Dvina basin and about 90% for the rivers of the Neman basin. The annual runoff fluctuates within the average on all the rivers.

In the years when the NAO_{djfm} index is positive, winter is mild, hence the water feeding the rivers is abundant, and the winter runoff (January–March) is observed to be above-average: from 110–123% of the average for the rivers of the Zapadnaya Dvina basin and

Table 5 Monthly runoff as percentages of long-term means in opposite stages of the North Atlantic Oscillation

River	Basin (km^2)	Stage of NAO	Jan	Feb	March	Apr	May	Year
Zapadnaya Dvina-Polotsk	41 700	NAO −	85	76	64	112	122	103
		NAO +	110	115	122	94	87	98
Obol-Obol	2520	NAO −	76	63	62	119	120	103
		NAO +	115	122	123	90	88	98
Nacha-Nacha	240	NAO −	73	63	74	126	119	102
		NAO +	117	123	116	86	89	100
Berezovka-Sautki	567	NAO −	58	57	80	135	119	102
		NAO +	126	126	113	81	89	99
Neman-Grodno	33 600	NAO −	92	84	80	133	118	103
		NAO +	105	110	112	82	90	98
Neman-Stolbtsy	3070	NAO −	94	82	89	139	116	105
		NAO +	104	111	106	78	91	98
Kotra-Sahkombinat	2000	NAO −	89	79	82	131	112	100
		NAO +	107	112	111	83	93	100
Viliya-Mihalishki	10 300	NAO −	93	85	83	133	117	105
		NAO +	104	109	111	82	91	98

from 104–112% for those of the Neman basin. The runoff decreases and varies from 77–94% of the average for the rivers of both basins in April and May. In the summer it is a little below the average and in the autumn a little higher, and for the whole of the year the runoff is about 100% of the average.

The intra-annual distribution of runoff differs in the years of opposite stages of the North Atlantic Oscillation (Figure 3). In the years of a negative stage of NAO_{djfm}, the runoff decreases in January–March and increases in April–May. In the years of a positive stage of NAO_{djfm}, the runoff increases in January–March and decreases in April–May. But the difference in the runoff percentages is significant in February–May only. It reaches maximum values in April, when runoff in the negative stage of NAO_{djfm} is higher by 4–17% than in the positive stage of NAO_{djfm} for the rivers of the Zapadnaya Dvina basin, and by 9–12% for those of the Neman basin (Figure 4). The intra-seasonal distribution shows more distinct significant differences: in winter from 2–8%, in spring from 6–13% and in autumn from 3–7% (significant at the 0.05–0.001 level).

Analysis of trends

The Mann–Kendall test was applied in an analysis of trends in the monthly, seasonal and annual runoff. The time series 1901–2000, 1921–2000, 1941–2000, 1961–2000 and 1971–2000 were compared.

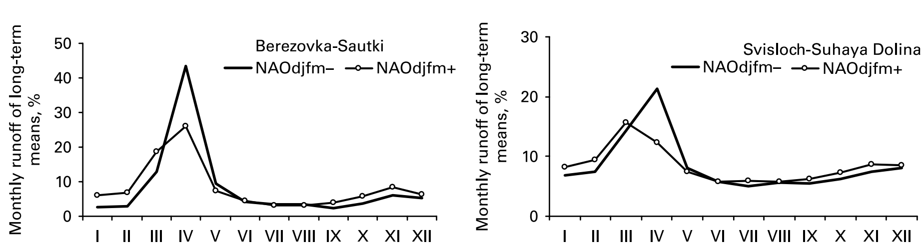

Figure 3 The intra-annual distribution of runoff in the years of opposite stages of the North Atlantic Oscillation

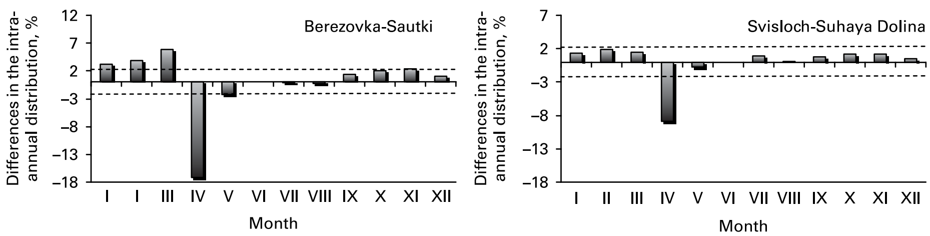

Figure 4 Differences in the intra-annual distribution of runoff in the years of opposite stages of the North Atlantic Oscillation

A significant increase in runoff was recorded in January, February and April, and May and August on the small rivers during 1901–2000 and 1921–2000 in the Zapadnaya Dvina basin. An increase in runoff was also observed in summer, autumn and the whole year in the Neman basin in the same time series. There was an increase in both basins in January–March and April–May on some tributaries of the Zapadnaya Dvina, and in June and July on the Neman tributaries. The test showed the increase in runoff since 1941 to be more significant than in the earlier time series.

The runoff was observed to increase in 1961–2000 in the Zapadnaya Dvina basin in January–March and June–December. A significant increase was observed in January–March and for some Neman tributaries in the winter and autumn months. The rise in runoff continued throughout the first third of the year in the Zapadnaya Dvina basin in 1971–2000. It should be noted that the test showed a positive trend in runoff in summer, autumn and the whole year. It did not show any significant changes in the Neman basin, but a significant positive trend was observed on the Viliya (near Steshitsy) and the Naroch in January and February, while a significant negative trend was recorded in July–August for the rest of the Neman tributaries.

Conclusions

The closest connection could be observed between North Atlantic Oscillation indices for December–March and the runoff of Belarusian rivers in the Baltic basin. The highest correlation coefficients were calculated for winter and spring months; the connection is direct in winter and inverse in spring. The connection between the NAO indices and the runoff differs between the Zapadnaya Dvina and Neman basins. The highest correlation coefficients are negative and recorded in spring, especially in April, in the Neman basin.

The runoff formation differs between years with $NAO_{djfm}+$ and NAO_{djfm}- indices. Runoff is below the average in the years with NAO_{djfm}- and above the average in spring. The runoff is above the average in the years with $NAO_{djfm}+$ and below the average in spring. The deviations of runoff from the average in the other months and the whole year are not significant. The deviations are more significant for the small rivers of the Zapadnaya Dvina basin. There is no such trend in the Neman basin.

A positive significant trend in runoff could be observed in the first third of the year in 1901–2000, 1921–2000, 1941–2000, 1961–2000 and 1971–2000. The highest significant increase in most months could be observed after 1961. There was a positive trend at the beginning of the year in 1971–2000, but a negative one in the summer and autumn months, and for the whole year.

References

Arnell, N.W. (1999). The effect of climate change on hydrological regimes in Europe: a continental perspective. *Global Environ. Change*, **9**(1), 5–23.

Danilovich, I. (2006). Impact of atmospheric circulation on river streamflow in Belarus. In: *Second Young Scientist Conference of UNS, Moscow*. p. 13.

Danilovich, I. and Chekan, R. (2007). Longstanding fluctuations of the river streamflow in Belarus part of Baltic Sea basin according to atmospheric circulation. In: *The 5th Study Conference on BALTEX, Kuressaare*. pp. 152–153.

Hurrell, J.W. (1995). Decadal trends in the North Atlantic Oscillation and relationship to regional temperature and precipitation. *Science*, **269**, 676–679.

Krasovskaia, I. (1996). Sensitivity of the stability of river flow regimes to small fluctuations in temperature. *Hydrol. Sci. J.*, **41**(2), 251–264.

Krasovskaia, I. and Gottshalk, L. (2002). River flow regimes in a changing climate. *Hydrol. Sci. J.*, **47**(4), 597–609.

Nekrasova, L. (2004). Influence of climate warming on hydrological regime of rivers in Belarus during 1988–2002. In: *XXIII Nordic Hydrological Conference.* Tartu University Press, Tartu, pp. 696-703.

Nekrasova, L., Chekan, G. and Danilovich, I. (2003). *Hydrometeorological conditions and runoff in 2002*. *State Water Cadastre, Minsk*, pp. 12–16.

Peel, M.C., McMahon, T.A., Finlayson, B.L. and Watson, F.G.R. (2001). Identification and explanation of continental differences in the variability of annual runoff. *J. Hydrol.*, **250**(1), 224–240.

Pekarova, P., Miklanek, P. and Pekar, J. (2006). Long-term trends and runoff fluctuations of European rivers. *IAHS Publ.*, **308**, 520–525.

Popova, V.V. and Shmakin, A.B. (2003). Influence of the North Atlantic Oscillation on multiyear hydrological and thermal regime of northern Eurasia. *I. Statistical analysis of observational data. Russian Meteorol. Hydrol.*, **5**, 47–56.

Rödel, R. (2006). Influence of the North Atlantic Oscillation on spatial and temporal patterns in Eurasian river flows. *IAHS Publ.*, **308**, 526–532.

Shorthouse, C.A. and Arnell, N.W. (1997). Spatial and temporal variability in European river flows and the North Atlantic Oscillation. *FRIEND '97: IAHS Publ.*, **246**, 77–85.

Styszyńska, A. and Tamulewicz, J. (2004). Warta river discharges in Poznan and atmospheric circulation in the North Atlantic region. *Quaest. Geograph.*, **23**, 63–81.

Wrzesiński, D. (2004). Flow regimes of rivers of northern and central Europe in various circulation periods of the North Atlantic Oscillation (NAO). In: *XXIII Nordic Hydrological Conference.* Tartu University Press, Tartu, pp. 670–679.

Wrzesiński, D. (2005). Changes of the hydrological regime of rivers of northern and central Europe in various circulation periods of the North Atlantic Oscillation. *Quaest. Geograph.*, **24**, 97–109.