Character of ice regime in Latvian rivers

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Abstract

Different aspects of the ice regime of rivers in Latvia were studied. For all rivers in Latvia the ice cover periods have been shorter during the last decades. However, the long records of collected ice data for the Daugava River (started from 1529) indicate that oscillation around mean values is normal. Climate during the cold season, and thus also the ice regime, is very much influenced by oscillation patterns of the North Atlantic.

Key words: ice regime of rivers, long-term changes, NAO indexes

Introduction

There is a need to apply a multitude of different factors to the evaluation of climate change and the patterns of processes in the environment. Records of ice freeze-up and break-up times in rivers allow for assessment of long-term and seasonal variability of the climate, especially in regard to climate change [Livingstone 1997; Magnuson *et al.* 2000). There are three major reasons why ice regime studies are important: (a) since calendar dates of freezing and thawing of lakes and rivers have been recorded in many rivers (also in Latvia) well before scientific observations in Latvia began, the data covers a longer period than that of other hydrological factors; (b) the ice regime influence the hydrological regime during the period of maximal discharge of accumulated atmospheric precipitation; (c) ice conditions are sensitive and reliable indicators of climate.

Winter ice regimes have been observed to be related to the North Atlantic Oscillation (NAO) pattern [Hurell 1995; Osborn *et al.* 1999] of large-scale anomalies in the North Atlantic atmospheric circulation. Moreover, the Southern Oscillation has been proven to also be able to influence the ice regime of lakes and rivers in the Northern Hemisphere [Robertson et al.2000]. The so-called positive phases of NAO (associated with strong westerly winds and increased flow of warm and moist air to Western Europe) cause warmer and later winters, and early springs [Hurrell 1995; Paeth et al. 1999; Chen and Hellström 1999]. The air temperature regime and the occurrence of warm rainfall, influenced by airflows from the North Atlantic (indicated by NAO), significantly affect the ice regime [Loewe and Koslowski 1998], and hence also the river discharge pattern [Hurrell and van Loon 1997]. Furthermore, global warming processes may constitute another major factor influencing the ice regime [Ruosteenoja 1986; Singh *et al.* 2000]. Break-up dates for the last two centuries on rivers in the Northern Hemisphere provide consistent evidence of later freezing and earlier break-up [Magnuson *et al.* 2000]. Since easily identifiable parameters describing ice break-up have been recorded for a long period of time [Beltaos 1997; Benson *et al.* 2000; Likens 2000; Arai 2000] several studies have analyzed ice regime trends for inland waters. These studies have clearly shown long-term climate changes, as well as the dependence of natural processes and the ice regimes of surface waters in Northern Europe on the NAO [Yoo and D'Odorico 2002]. The ice regime of the Baltic Sea has been previously analyzed using a historical time series of ice break-up at the port of Riga [Jevrejeva 2001] in order to reconstruct climatic history [Tarand and Nordli 2001].

It is the aim of this study to analyse the different aspects of the ice regime in Latvia, in order to put the recent shortening of the ice cover into a long-term perspective.

Sources and methods

The first time series of ice break-up data for the River Daugava was published by P. Stakle (1931), which also has been used for this study. Data on temperature records for the period 1795 to 2002 was obtained from the Meteorological Station at the University of Latvia in Riga. Before analyses the standard homogeneity test was applied on the data set [Lizuma and Briede 2003].

During the study period, the sampling and observation methods followed standard approaches and historical observations were re-evaluated to adjust them for existing time-counting principles [Stakle 1931]. No replacements of the data were made and only original data were used in this study.

To investigate the links to wide-scale climatic forcing, we used the extended NAO index [Luterbacker *et al.* 2002].

The multivariate Mann-Kendall [Hirsch *et al.* 1982; Hirsch and Slack 1984] test for monotone trends in time series of data grouped by sites, plots, and seasons was chosen for determination of trends, as it is a relatively robust method concerning missing data yet avoid the strict requirements regarding data heteroscedasticity. The Mann-Kendall test was applied separately to each variable at each site, at a significance level of $p<0.5$. A trend was considered as statistically significant at the 5 % level if the test statistic was greater than 2 or less than -2.

Results and discussion

The climate, hydrological processes, and ice regime of inland waters of Latvia occur in the context of its physico-geographic characteristics: a relatively flat surface topography (57 % of Latvia's territory located below 100 m above sea level) and dominance of Quaternary glacial and ancient sea sediments (parent soil materials consist of moraine loam and sands). The climate is humid (the mean precipitation ranges from 600 to 850 mm per year) and comparatively cold and the area supports a dense net of rivers (the mean density of the river network is 588 m per 1 km^2).

The long-term variability of the seasonal air temperature is shown in Figure 1. The seasonal air temperatures, according to records from the Meteorological Station at the University of Latvia in Riga, have changed substantially during the last 200 years (1795-2002). The air temperatures in winter have increased by 1.9 ºC, in spring by 1.3 ºC and in autumn by 0.7 ºC. The mean annual temperature has increased by 1.0 ºC. In comparison with the long-term mean (1961-1990), the lowest mean temperature occurred during the period from 1830 to 1930, measured for annual and seasonal temperatures (autumn, spring, and summer). Winter season temperatures have been increasing gradually since the 19th century. During the 1830-1930 period the long-term minimum was not reached.

Notable increases of winter and spring air temperatures have been observed since the 1970's.

There exist direct links between temperature and ice regime on rivers. The time series of ice break-up dates for the Daugava River at Daugavpils (Table 1) indicates a mean date of April 3. In comparison with the other rivers studied, the break-up time can differ by more than one month, depending on the distance from the Baltic Sea and Gulf of Riga, as well as on river catchment's characteristics.

A decreasing linear trend indicates that ice break-up dates are coming earlier (Table 1). The calculated regression equation estimated that the time of ice cover during the 20th century (observation periods of 77-60 years, depending on river station) was shifting to an earlier time by 2.8 to 5.1 days every 10 years.

In general, the shift in the ice break-up in rivers towards earlier dates, indicating an earlier start of flooding, can explain the increase of winter runoff of rivers in Latvia. This is thought to be associated with climatic variability, as indicated by temperature charts. However, differences are evident for the rivers studied and the changes have not been consistent for different time periods. For example, a shift of ice break-up to an earlier time has not been a typical feature for the entire period of observations for the Daugava (Figure 2). The downward trend was expressed more during the last 150 years, and especially during the last 30 years. No downward trend was detected for the initial period, which includes the Little Ice Age. Lengths of periods are not equal and mild winters can be followed by hard winters. However, the periodicity cannot be considered as a fixed cycle and it is more likely a quasi-periodic process.

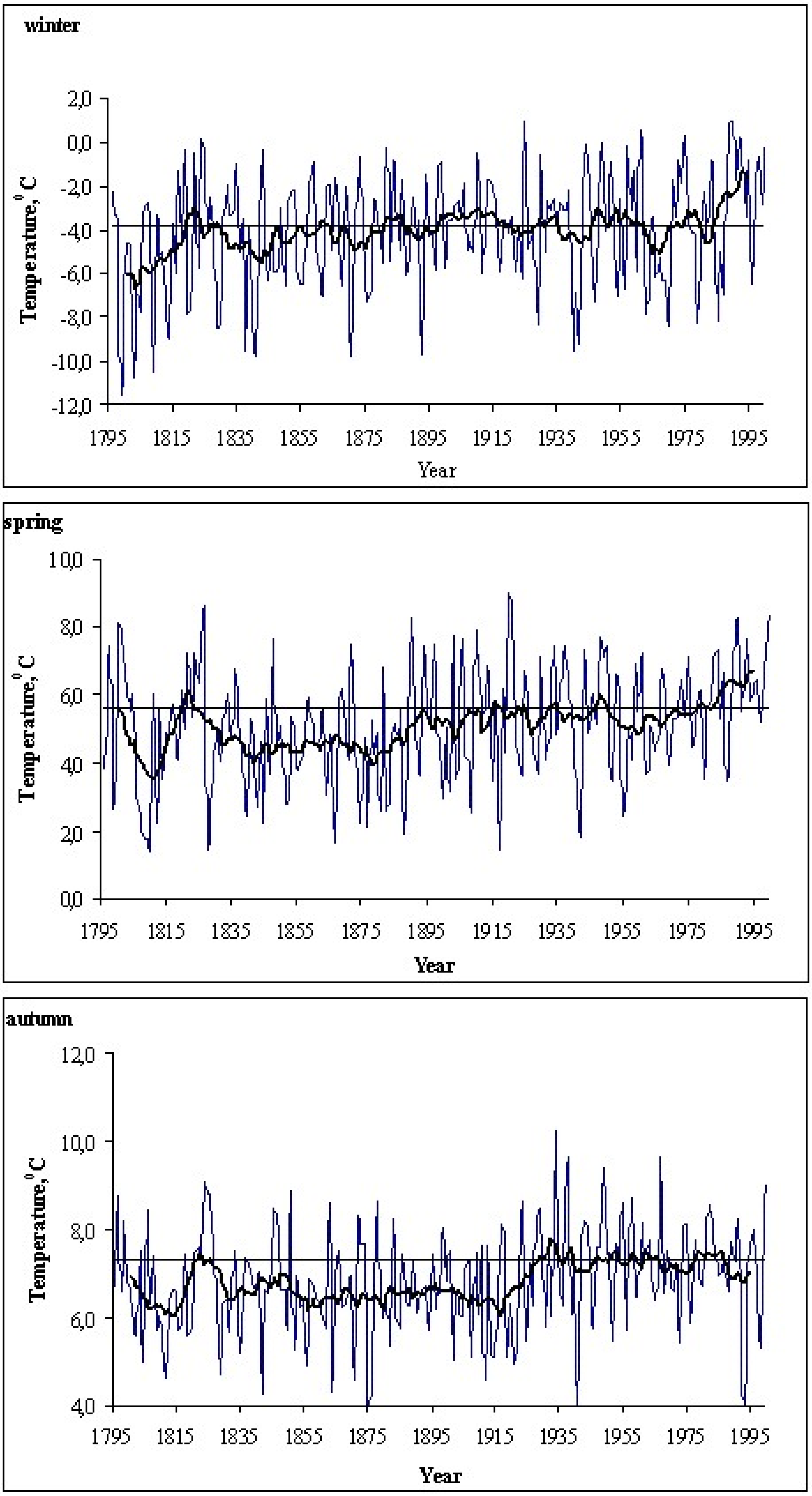

Figure 1. Mean annual temperatures observed in Riga for winter (December-February), spring (March-May), and autumn (September-November). The reference level is the mean, for the period 1961-1990.

Table 1

Basic characteristics and ice regimes of the rivers studied

River-sampling station	Distance from Baltic Sea or Gulf of Riga, km	Basin area, km^2	Runoff, km^3	Length of observations, years	Mean date of freeze over	Mean date of break-up	Average number of days with ice cover	Decrease, days/ 10year *p*=0.17 (95%)
Daugava-Daugavpils	370	64500	14.38	1925-2000	24. Nov.	03. Apr.	101	2.8
Lielupe-Mezotne	100	9390	1.76	1921-2000	26. Nov.	27. Mar.	86	3.0
Venta-Kuldiga	60	8320	2.09	1926-2000	02. Dec.	22. Mar.	65	3.2
Gauja-Sigulda	40	8510	2.23	1939-2000	01. Dec.	30. Mar.	78	4.1
Salaca-Lagaste	20	3220	0.97	1927-2000	26. Nov.	29. Mar.	77	5.1
Pededze-Litene	350	978	0.26	1959-2000	17. Nov.	02. Apr.	108	-
Berze-Balozi	50	904	0.16	1960-2000	05. Dec.	14. Mar.	80	-

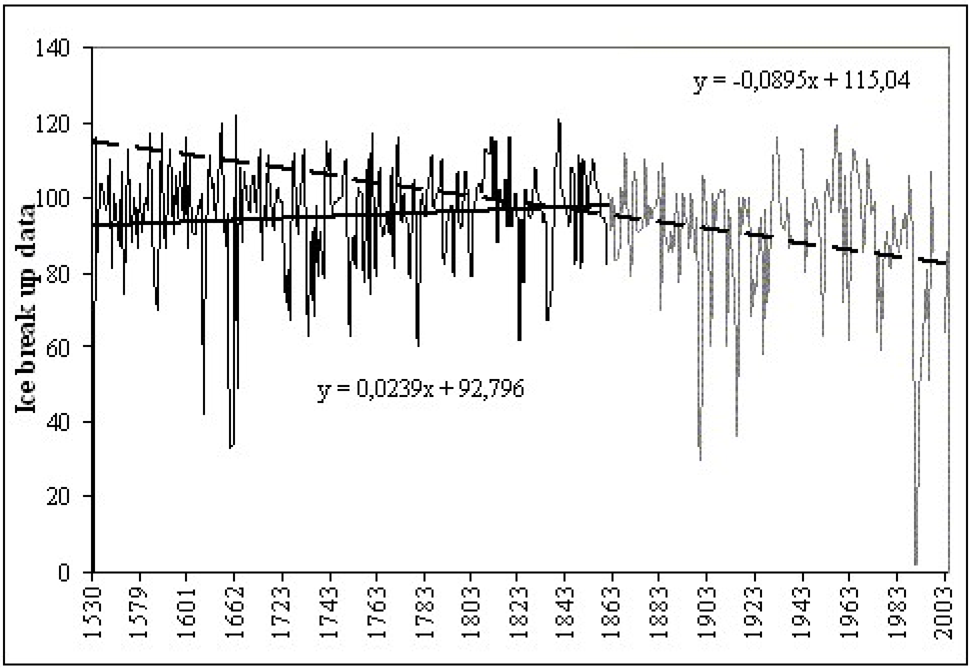

Figure 2. Time series of ice break-up dates in Daugava River (dashed line shows trend from 1860-2003, and continuous line from 1530-1859)

Similar trends of ice break-up were obtained using data from the Lielupe, Salaca, Venta, Berze, and Gauja rivers (Figure 3). The applied Man-Kendall test verified that the number of days during which a river is covered with ice has been significantly decreasing. A downward trend was obtained for all seven selected rivers, located in different parts of Latvia (Table 2). The trends were statistically significant (less than -2) for the Salaca, Gauja, and Berze.

As mentioned before, processes over North Atlantic have a significant influence on climate in winter season in Latvia (December, January and February). It is clearly shown by correlation coefficients recorded between days with ice cover in rivers and its correlation with NAO indexes (Table 2).

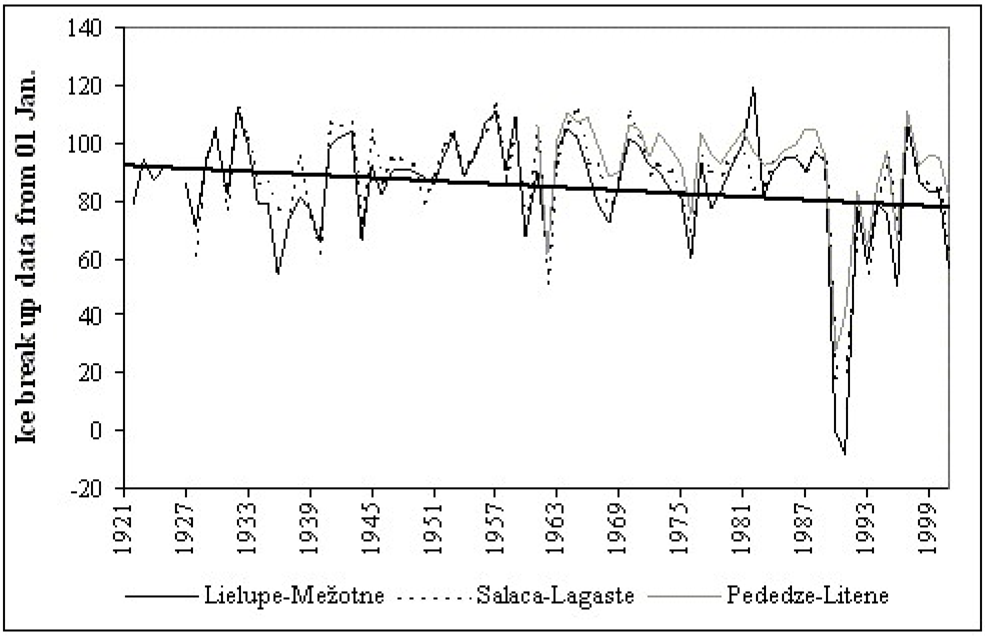

Figure 3. Time series of ice break-up dates in the Lielupe, Salaca, and Venta rivers.

Table 2

Days with ice cover in rivers and correlation with NAO indexes (December-March)

	Lielupe 1920-2000	Daugava 1925-2000	Salaca 1926-2000	Venta 1926-2000	Gauja 1939-2000	Pededze 1959-2000	Berze 1960-2000
Correlation with NAO-index-DJFM	-0.52	-0.54	-0.44	-0.62	-0.57	-0.60	-0.70
p-value (one-sided test)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mann-Kendall test criteria	-1.533	-1.849	-2.547	-1.737	-2.146	-1.831	-2.467
p-value (one-sided test)	0.063	0.032	0.005	0.041	0.016	0.034	0.007

* - The trend can be considered as statistically significant at the 5 % level if the test statistics is greater than 2 or less than -2

Figure 4 depicts the wintertime series of the NAO index during the 20th century and the sum of negative temperatures in Riga. In Figure 4 wintertime refers to the values averaged for the time span from December to February. Strong negative correlations between the NAO index and the sum of negative temperatures show that processes over North Atlantic are the driving forces for climate in winter in the territory of Latvia. According to our data, the same character appears for correlations of monthly mean temperatures and NAO winter indexes. Variability of spring and summer temperatures is not influenced by the NAO index. Strong correlations between NAO indexes are typical for the winter season (0.81) and also for autumn (0.44).

The relationship in the cold period highlights the fine linkages between the large-scale NAO forcing and the regional scale climate processes in Latvia. Moreover, the negative correlations of winter temperatures and NAO indexes are stronger for the last 100 years.

Conclusions

Several conclusions can be made concerning climatic, hydrological parameters, and ice break-up dates in the rivers of Latvia:

- A significant increasing temperature trend was observed for the winter period (1.9 ^{o}C since 1795). There is a pronounced linear change, overlain by periodic oscillations.
- The ice cover period in the rivers selected has been decreasing. For the last 30 years ice-covered period has been reduced from 2.8 up to 5.1 days for every 10 years.

- The pronounced negative correlation and periodicity have been obtained between the sum of negative temperature and NAO winter indexes. Moreover, negative correlations of winter temperatures and NAO indexes are stronger for the last 100 years. There is no marked interconnection between air temperatures in summer, spring and NAO indexes, due to possible influence of other atmospheric circulation patterns.
- Time of the ice break-up depends not only on meteorological conditions in a particular year and the distance from Baltic Sea, but also on changes in North Atlantic patterns. The trends are not consistent between periods, while changes between mild and hard winters are clearly seen. The periodicity cannot be considered as a fixed cycle and it appears more like a quasi-periodic process.

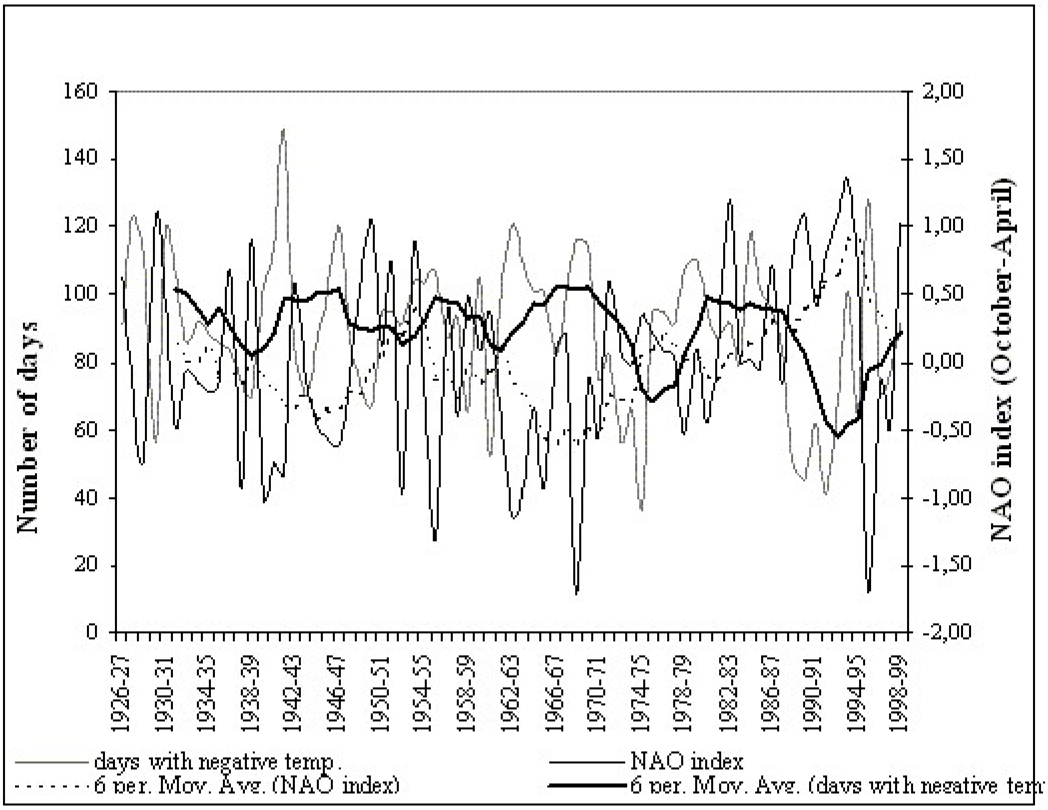

Figure 4. Time series of NAO (October to April) and sum of days with negative temperature (Meteorological Station, University of Latvia)

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