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ICE REGIME DYNAMICS OF INLAND AND COASTAL WATERS IN LATVIA AND FACTORS CONTROLLING IT

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Annotation. Sea ice is considered a sensitive indicator of climate change. In this study, long term changes in ice levels in the Rīga Gulf on the coasts of Latvia are compared with ice levels on inland water. The duration of ice cover on both sea and inland waters has decreased during the recent decades. In addition to this, long term observational records of ice break in the studied region exhibit a pattern of periodic changes in the intensity of ice formation. Ice levels are shown to be strongly influenced by large–scale atmospheric circulation processes over the North Atlantic that manifest in close correlation with the North Atlantic Oscillation index.

Keywords: ice regime, long term changes, coastal waters.

Introduction

Records of the dates of ice freeze-up and break-up are good indicators to assess inter-annual and seasonal climate variability, especially in relation to long-term climate change (Granskog *et al.* 2006; Johannessen *et al.* 2004). Three major reasons for studying sea ice regimes are as follows: a) the calendar dates of freezing and thawing of ice cover have been recorded for a long period; b) ice conditions are sensitive and reliable indicators of climate; c) sea and coastal ice regime affects the ship transport, fishery and other aspects of economy.

The temperature change patterns and ice regimes have been observed to be related with the North Atlantic Oscillation (NAO) pattern (Hurrell, van Loon 1997) of large-scale anomalies in the North Atlantic atmospheric circulation. The Southern Oscillation, too, has been argued to exert influence over the ice regime 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 winters later their start and early springs (Paeth *et al.* 1999). The changes of air temperature and the occurrence of rainfalls, influenced by airflow from the North Atlantic (indicated by NAO), significantly affect the ice regime (Loewe, Koslowski 1998). On the other hand, a major factor possibly influencing the ice regime is the process of global warming (Morse, Hicks 2005). The records of the last two centuries of ice break-up dates on the rivers in the Northern Hemisphere provide consistent evidence of later freezing and earlier break-up (Magnuson *et al.*, 2000). Several studies have analyzed ice regime trends for inland waters, since easily identifiable parameters describing ice break-up have been recorded for a long period of time (Hodgkins *et al.* 2002). These studies have clearly shown long-term changes in climate, and have also argued that natural processes and the ice regime in the Northern Europe are related to the changes in NAO (Yoo, D'Odorico 2002). The sea ice conditions of the Baltic Sea have been previously studied using a historical time series of ice break-up at the port of Riga (Jevrejeva 2001) and along coastline of Estonia (Sooaar, Jaagus 2007).

The aim of this article is to study character of long-term changes of the sea ice regime at the coastline of Latvia and factors affecting it in relation to long-term climate change (temperature) and large scale atmospheric circulation processes (North Atlantic Oscillation (NAO).

Data sources and methods

The data of ice regime (starting data of establishment of permanent ice cover, data of ice break-up and calculated length of ice-cover) were extracted from the Bulletins of hydrological observations (1925–2013) at the Latvian Centre of Environment, Geology and Meteorology. The time series of the River Daugava ice break-up dates were first published by P. Stakle (1931). The air temperature records for the period 1795 to 2013 were obtained at the Meteorological Station Riga-University. During the studied period the sampling and observation methods followed standard approaches and historical observations were re-evaluated to adjust them to the existing principles of time measurement (Stakle 1931). This study used only observation data and no data were substituted.

Table 1. **Basic characteristics and ice regime of the study sites in Latvia and its coastline**

River-sampling station	Length of observations, years	Mean date of freeze over	Mean date of break-up	Average number of days with ice cover	Decrease, day/10year p=0,17 (95%)
Baltic Sea – Liepāja	1949-2013	24 Dec	03 Mar	71	2.8
Baltic Sea - Ventspils	1949-2013	26 Dec	27 Mar	76	3.0
Baltic Sea – Kolka	1950-2013	03 Jan	22 Feb	58	2.5
Gulf of Rīga - Mērsrags	2000-2013	24 Dec	03 Mar	53	0.7
Gulf of Rīga - Jūrmala	2000-2013	02 Jan	05 Mar	52	0.2
Gulf of Rīga - Salacgrīva	1949-2013	12 Dec	12 Mar	64	2.7
Venta - Kuldīga	1926-2013	02 Dec	22 Mar	65	3.2
Gauja - Sigulda	1939-2013	01 Dec	30 Mar	78	4.1

The non-parametric Mann-Kendall 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 and it lacks strict requirements regarding data heteroscedasticity. The Mann-Kendall test was applied separately to each variable at each site, at a significance level of $p<0.05$. A trend was considered as statistically significant at the 5 % level if the test statistic was greater than 2 or less than -2. The code COND/MULTIMK (Libiseller, Grimvall 2002) was used for trend analysis.

Results and discussion

Ice development begins in the bay of Pärnu, where the first new ice formations occur in the middle of December. Thereafter the ice-covered area extends along the north-eastern coast of the Gulf of Riga, and in the middle of January it's width is 5 to 6 nautical miles on average. At the same time some new ice formation near the southern and western coast of the Gulf occurs.

The most intensive ice development occurs in February when under favourable conditions the Gulf of Riga becomes completely ice-covered. In the middle of the month the pack ice brought by currents freezes and covers the Irbe Strait with rigid and ridged ice. At the same time along the rest coastline of the Gulf the width and thickness of the fast ice increases, and various ice forms intensively develop also in the Central part of the Gulf. In moderate winters by the end of the month the Gulf and the Irbe Strait becomes completely ice-covered. However during severely cold winters a solid and rigid ice-cover over the Gulf of Riga can occur already in the middle of January, but in mild winters the Gulf can remain mostly ice-free throughout all the winter season.

The development of the pack ice usually begins in the coastal waters and extends in parallel to isobaths, however it's development is uneven, reflecting alterations of the cold and warm spells. The maximum of the pack ice occurs in late February – early March, and during moderate and severe winters the pack ice completely covers both the Gulf of Riga and the Irbe Strait.

During winters the surface water is cooled so much that ice may form also in the coastline of the Baltic Sea. However, the extent of the ice varies widely from year to year depending on whether the weather is mild or cold. Mostly the territory is ice free, and only during the most severe winters the water territories are covered with ice. However, ice is mostly thin and fragile, and if the wind direction is favorable, the ice rapidly floats from the shore to the open sea. In the coastal waters of the Baltic Sea the ice development begins at the end of December, sometimes in the middle of November.

With the prevailing westerly winds the ice break-up begins in the western part of the Gulf and gradually progresses to the east. The first area of the Gulf to become ice-free is the Irbe Strait followed by western and southern part of the Gulf, but in the north, north-east areas the melting and rotten pack ice remains the longest.

During late and cold springs there can be some differences in the disappearance of ice: at first the ice disappears in the comparatively shallow north-eastern part of the Gulf as the water temperature begins to rise due to the river inflow. In this case the pack ice longer remains in the central part of the Gulf.

The average length of the ice season is the longest in the Bay of Pärnu and in the north part of the Gulf of Riga – 145 days or almost 5 months. The shortest ice season of 2 months is characteristic for the south-western part of the Gulf, the Irbe Strait and near the Latvian coast of the Baltic Sea, but in the south part of the Gulf as well as in the region near Kolka the average ice season is 2.5 to 3 months long. The maximum observed length of the ice season in the Gulf of Riga is 168 days, but in the coastal waters of the Baltic Sea – 127 days. The most severe winter during the observation period has been the winter season of 1941/1942. During this winter the maximum ice cover in the coastline of the Baltic Sea was observed at the end of March – beginning of April, with the ice thickness of about 60 cm. The measurements of ice thickness show that 6.4 km from the coast near Liepaja the ice was 55.7 cm thick and at 14.5 km from Ventspils it was 48.6 cm thick.

The ice conditions are observed in 6 marine observation stations of Latvia. The stations of Ventspils and Liepāja which are situated in the east of the Central part of the Baltic Sea represent the ice conditions characteristic for the open part of the Sea, where usually the concentration of ice is the smallest and the length of the ice season is the shortest. The station of Kolka represents the ice conditions in the shallow Irbe Strait, but the station of Mērsrags represents the conditions of the western part of the Gulf. Both of these stations are subjected to comparatively rapid changes in the concentration of ice as with the prevailing westerly winds the ice tends to break up and drift to the east, forming an ice-free areas. The observation station of Jūrmala represents the shallow southern coast of the Gulf. The station Salacgrīva represents the north-east part of the Gulf where the ice extent usually is the greatest and the ice season is the longest.

Table 2. **Long term trends of ice cover duration according to Mann-Kendall normalised test statistic**

River - Sampling Station	Period of observation	Normalised test statistic	*p*-value (one-sided test)
Baltic Sea – Liepāja	1949-2013	-2.61	0.009
Baltic Sea - Ventspils	1949-2013	-3.34	0.009
Baltic Sea – Kolka	1950-2013	-2.85	0.014
Gulf of Rīga - Salacgrīva	1949-2013	-4.42	0.001
Venta - Kuldīga	1926-2013	-1.21	0.113
Gauja - Sigulda	1939-2013	-2.87	0.002

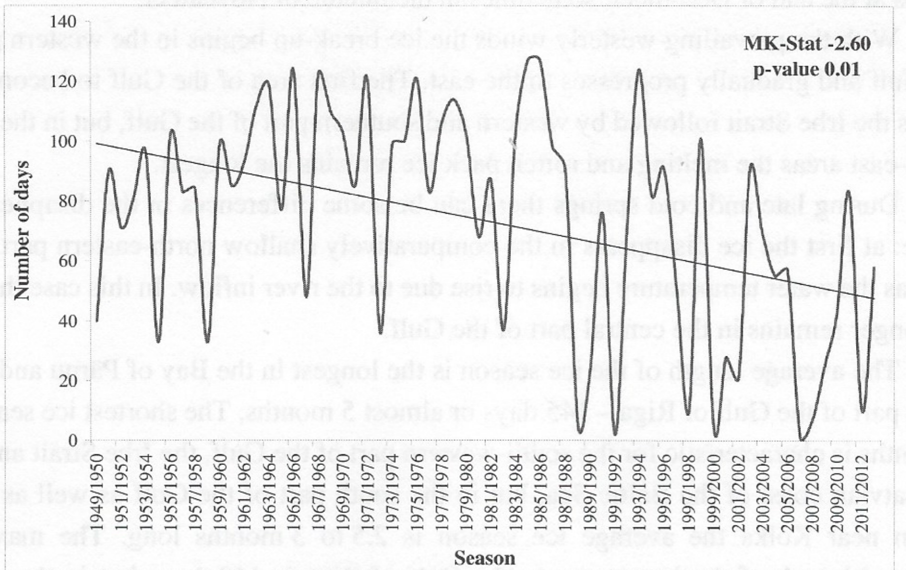

Figure 1. **Trend in the length of the ice season in the coastal areas of the Baltic Sea (Liepāja) for the period 1949–2013**

During the past ~150 years there has been a significant increasing trend in the values of the air temperature, which is even most obvious during the winter season

(Klavins *et al.* 2002). The changes in the air temperature have also lead to significant changes in the ice conditions both in the Latvian coastline of the Baltic Sea and in the Gulf of Riga (Jevrejeva 2001). A significant decreasing tendency of the length of the ice season for the period 1949–2013 has been observed in the coastline of the Baltic Sea (Figure 1).

Conclusions

The duration of sea ice cover on the Baltic Sea and in Riga Gulf during last 60 years is decreasing and is related to decreasing start of the ice cover and earlier ice melt. Exist significant differences in respect to ice cover in Riga Gulf and coastline at the Baltic Sea. The time of ice break-up depends on global climate change and can be related to increasing air and sea water temperatures, however the trends of sea ice regime not consistent between periods and changes of mild and severe winters are clearly seen.

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AKTUĀLIE LĢIA PROJEKTI FOTOGRAMMETRIJĀ

Pēteris Pētersons

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Anotācija. Fotogrammetrija ir zinātne informācijas iegūšanai par Zemi, tās apkārtējo vidi un citiem fiziskiem objektiem. Datu ieguve norit ar bez kontakta attēlu veidojošām un citām sensoru sistēmām.

LĢIA ir vadošā institūcija Latvijā ģeomātikas jomā, kurā tiek uzturēti divi aktuāli fotogrammetrijas projekti – aerofotografēšana un aerolāzerskenēšana. Aerofotografēšana ir noritējusi vairākas reizes visai Latvijas teritorijai un turpinās arī turpmāk. Aerolāzerskenēšana visai Latvijas teritorijai norit pirmo reizi un plānots to pabeigt 2018. gadā. Rezultātā tiks iegūti 3D dati ar augstu vertikālo un horizontālo precizitāti. Lai arī vēl aerolāzerskenēšana nav beigusies, tomēr pēc lietotāju vēlmēm var saskatīt, ka tā ir jāturpina atkārtoti visai valsts teritorijai.

LĢIA Fotogrammetrijas daļa strādā arī pie jaunu produktu testēšanas, lai maksimāli efektīgi izmantotu tās rīcībā esošos datus. Viens no testētiem projektiem ir virsmas modeļa izveidošana no aerofotografēšanas attēliem.

Jāatzīmē arī tas , ka katru gadu pieaug fotogrammetrijas daļas saražoto produktu lietotāju skaits un datu lietošanas iespējas. Publiski pieejamā LĢIA karšu pārlūkā interesanti var iepazīties ar aerofotografēšanas un aerolāzerskenēšanas produktiem un atrast pielietojumu datiem atbilstoši savām vēlmēm.

Atslēgas vārdi: fotogrammetrija, aerolāzerskenēšana, aerofotografēšana, reljefa modelis, ortofoto.

Fotogrammetrija ir zinātne informācijas iegūšanai par Zemi, tās apkārtējo vidi un citiem fiziskiem objektiem. Datu ieguve norit ar bezkontakta attēlu veidojošām un citām sensoru sistēmām. Latvijas Ģeotelpiskās informācijas aģentūras uzdevumi saskaņā ar valdības lēmumu ir nodrošināt visas Latvijas datu noklājumu ar aerofotografēšanas un aerolāzerskenēšanas datiem. LĢIA par fotogrammetrijas nozari ir atbildīga fotogrammetrijas daļa, kuras uzdevums ir pārraudzīt aerolāzerskenēšanas un aerofotografēšanas projektus valsts mērogā.

Līdz ar Latvijas neatkarības atgūšanu drīz tika uzsākta Latvijas aerofotografēšana. 1994. gadā sadarbībā ar Zviedrijas Zemes dienestu tīklu nofotografēta daļa Latvijas, kuru var uzskatīt par digitālās fotogrammetrijas 1. aerofotografēšanas cikla sākumu. Turpmākos gadus Latvijas teritorijas aerofotografēšana ir sekmīgi turpināta visai Latvijas teritorijai. Līdz 2015. gadam Latvija ir nofotografēta piecas reizes. Katrā aerofotografēšanas ciklā ir veikti uzlabojumi, lai izgatavotās ortofoto kartes būtu lietojamas plašākam lietotāju lokam. Pirmās aerofotogrāfijas bija melnbaltās ar 1 m izšķirtspēju. Pēdējā piektajā ciklā Latvijas centrālā daļa tika noklāta ar aerofotogrāfijām, kuru izšķirtspēja sasniedza 0.25 m un attēli ir arī infrasarkanā krāsu spektrā (1. attēls).