INTERPRETATION OF CLIMATIC, HYDROLOGICAL AND ANTHROPOGENIC IMPACTS ON THE MULTIDEcadal CHANGES OF RIVER AND LAKE ICE REGIME IN THE CARPATHIAN BASIN

THESSES OF DOCTORAL DISSERTATION

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1. Introduction and aims

The rivers and lakes in the arctic and temperate climatic zone are often covered with some kind of ice in winter (Beltaos and Prowse 2009), as well as in the Carpathian Basin. Ice occurrence and ice duration are in strong relation with winter weather conditions and temperature regime, therefore it is a good indicator of climatic change and variability (Prowse et al. 2007). It was soon recognized that there is a great potential for climatic research in the analysis of long-term freshwater ice observations (Williams 1970), because information can be provided before the start of instrumental temperature observations (Korhonen 2006).

Recently it has been indicated in numerous publications that the first ice occurrence and freeze-up have shifted later and break-up and final ice disappearance have become earlier, therefore the duration of ice cover and icy season have decreased (Magnuson et al. 2000, Smith 2000, Hodgkins et al. 2002, Duguay et al. 2006). The changes in river ice regime are caused by the changes of winter temperature regime, as due to the increasing temperatures and milder winters, the frequency of ice phenomena has decreased (EEA 2012). Freshwater ice regime is not only influenced by climatic conditions, but it is also affected by anthropogenic interventions (Brimley and Freeman 1997), – like river regulation, hydropower use and water pollution. These effects can accelerate or hide the natural trends, therefore they should not be excluded from climate related research (Takács et al. 2013).

In the view of the above mentioned, the main objectives of this study are as follows:

1. What kind of changes have happened in the freshwater ice regime of the Carpathian Basin over the last 150 years?
2. How these alterations are fitted to the locally, regionally and globally detected changes?
3. Regarding the analysis of the natural drivers, what kind of relationship can be found between freshwater ice regime and winter temperature conditions?
4. Are the ice regimes affected by anthropogenic interventions? Can these effects be detected by any method?

5. Are the ice observations and historical ice records suitable for temperature reconstruction of the non-instrumental period in our region?

2. Methods

The analysis of long-term trends in freshwater ice regime in the Carpathian Basin were carried out based on the data of selected stations, which are located by the Hungarian section of the River Danube and Raba (Komárom, Nagymaros, Budapest, Mohács and Szentgotthárd, Körmend, Ragyogóhid, Árpás, Győr), the lower section of the Drava River (Őrtilos, Barcs, Drávaszabolcs, Osijek) and Lake Balaton (Siófok).

The trend analysis were performed by linear regression, the rate of changes was estimated from the slope of the regression line (verified by t-statistics), and is expressed in 100 year averages (days/100 years). The results of the trend estimation were checked by Mann-Kendall trend test (Mann 1945, Kendall 1975) as well, which is a non-parametric trend estimation method and is insensitive to missing data (Futter 2003). The magnitude of trend was estimated by Sen’s method (Sen 1968). The temporal variation of the estimated trend was analysed by fitting a LOWESS function (locally weighted scatterplot smoothing; Cleveland 1979).

The relationship between ice phenomena and temperature conditions – represented by monthly and multi-monthly averages – was examined by correlation analysis, because the relation between ice and temperature could be characterized by linear regression (Williams et al. 2004, George 2007) and verified by t-statistics.

Anthropogenic effects on ice regime could be detected by 2 methods. The first method is based on the existing strong (high correlation coefficient) and natural relationship between ice phenomena and temperature conditions. The harmony between ice and temperature could be disturbed by human impacts, therefore the correlation coefficient has decreased. The temporal variations of the correlation coefficient could be examined by a
moving window analysis. In this study a 31-years long moving window was applied. The other method could be applied, when just one intervention was made (for instance building a dam). In this case the anthropogenic effect could be detected by the comparison of the ice regime of the period before and after the intervention. The ice regime of winters with similar temperature conditions were compared to exclude the effect of temperature change (Takács et al. 2013).

There are more methods for temperature reconstructions based on ice observation data. In this study the linear regression method were applied (Palecki és Barry 1986, Livingstone 1997, Mundelsee 2012), where past temperatures were estimated based on the linear relationship between ice phenomena and temperature conditions. The linear regression model was calibrated based on the 1780–1875 period to exclude the potential anthropogenic effects.

3. Results and conclusions

1. Changes in the ice regime of rivers and lakes in the Carpathian basin

Based on the nearly 150 years long time series of ice observation data changes can be detected in the ice regime of rivers (Danube, Drava, Raba) and Lake Balaton. **Thesis 1: On the study area, in spite of the same climatic conditions, the detected trends of the ice regime of rivers and the Lake Balaton have the same direction, but different rates:**

   − Thesis 1/a: Dates of first ice appearance: have shifted significantly later. The rates of the changes on the River Danube and Drava are higher (20–30 days/100 years and 16–27 days/100 years), than the changes on the Raba (4–12 days/100 years) and the Lake Balaton (11 days/100 years). It can be concluded, that the changes were faster on the rivers with higher discharge in the study area.

   − Thesis 1/b: Freeze-up dates: have shifted later on all sites (5–14 days/100 years), but the changes are not significant. No significant difference can be found between the rates of rivers and Lake Balaton.
Thesis 1/c: Break-up dates: have shifted earlier on rivers, but the changes are not significant, except for Raba. The trend of Raba has shown 1.5–2 times faster changes (13–27 days/100 years), than it has been found on the Danube (9–11 days/100 years) or Drava (3–19 days/100 years). Consequently the rates of changes were higher on the rivers, which have lower discharge. No significant changes can be detected on Lake Balaton.

Thesis 1/d: Dates of final ice disappearance: have shifted significantly earlier on all sites. There was only a slight difference between the trend rates. The river with higher discharge – Danube and Drava – have higher rates of changes (16–24 days/100 years and 12–26 days/100 years), than Raba (10–16 days/100 years). Also slower changes can be detected on the Lake Balaton (8 days/100 years).

Thesis 1/e: Ice-covered seasons: decreasing trends have been detected, but they are not significant, except Raba River. The changes were faster on Raba (14–21 days/100 years), than on the Danube (7–15 days/100 years) or the Drava (9–21 days/100 years). No significant changes can be detected on Lake Balaton.

Thesis 1/f: Icy seasons: significant decreasing trends have been detected on all sites. Slightly higher rate changes can be found on the Danube and Drava (21–37 days/100 years and 21–50 days/100 years), than on Raba (19–30 days/100 years). Consequently the rates of changes were higher on the rivers, which have higher discharge. Lower rates of changes have been found on the Lake Balaton (8 days/100 years), than on the rivers in the study area.

2. Changes in the ice regime on continental and global scale

Freshwater ice regime in the Northern Hemisphere was analysed on many sites and the published results were compared with the trends in the Carpathian Basin. Thesis 2: The direction of the detected trends in freshwater ice regime in the Carpathian Basin coincided with the observed changes in the Northern Hemisphere, but the rate of changes differed from the average:

Thesis 2/a: Dates of first ice appearance: later ice appearance was observed, the magnitude of trends are similar to the average of the
Northern Hemisphere, except in the case of the Danube (Mohács) and the Drava (Eszék), where the date of ice appearance were shifted later 1.5–2 times faster, than the average.

- Thesis 2/b: Freeze-up dates: later freeze-up was detected, the rate of trends are similar to the average of the Northern Hemisphere, except in case of the Danube (Mohács), where the date of freeze-up became later nearly 2 times faster, than the average.

- Thesis 2/c: Break-up dates: earlier break-up was observed, the magnitude of trends are similar to the average of the Northern Hemisphere, except in case of the Danube (Budapest), where the date of break-up were shifted earlier 3 times faster, than the average. On Lake Balaton slightly later break-up was detected.

- Thesis 2/d: Dates of final ice disappearance: earlier ice disappearance was detected, the rate of trends are slightly slower, than the average of the Northern Hemisphere, except in case of the Danube (Mohács), where the date of ice disappearance became earlier a bit faster.

- Thesis 2/e: Ice-covered seasons: decreasing trends were detected, the changes were slower in the Carpathian Basin, than the average of the Northern Hemisphere.

- Thesis 2/f: Icy seasons: decreasing trends were observed, the rate of changes are similar to the average of the Northern Hemisphere, except in case of the Danube (Mohács), where the shortening of icy season was faster, than the average.

**Thesis 3:** Changes in freshwater ice regime and the geographical location and hydromorphological characteristics of water bodies are in interactive relationship:

- Thesis 3/a: Latitude: water bodies located on higher latitude had slower changes in the ice regime. Significant relationship was found between the latitude and the later ice appearance dates and shorter icy seasons by the rivers and European water bodies. By Asian water bodies the later freeze-up date and the shorter ice-covered season were in significant relation with latitude.
- Thesis 3/b: Longitude: water bodies located on higher longitude in a more continental position had slower changes in river ice regime. In Europe the earlier break-up dates by lakes and the shorter icy season by rivers were in significant relation with longitude. Also a significant relationship was found between the later freeze-up dates, shorter ice-covered season and longitude in Asia.

- Thesis 3/c: Altitude of lakes above sea level: lakes located on higher elevation had faster changes in the ice regime. Earlier break-up dates were in significant relationship with the altitude.

- Thesis 3/d: Lake surface area: lakes with larger surface area had slower changes in lake ice regime. The shortening of ice-covered season was in significant relation with lake surface area in Europe.

- Thesis 3/e: River discharge: river with higher discharge had slower changes in river ice regime. The shortening of ice-covered season was in significant relation with river discharge.

3. Relationship between the trends in ice regime and air temperature regime

The freshwater ice regime is mainly driven by the air temperature regime. Significant relationship can be detected between ice phenomena and temperature conditions. In case of rivers not only the by the observation site, but also the upstream air temperatures can affect the occurrence of ice phenomena. Thesis 4: According to the results of this study, by the hydrological and climatic conditions of the Middle-Danube Valley, the following statistically significant relations were detected between freshwater ice regime and air temperature regime:

- Thesis 4/a: Date of first ice occurrence was in moderate relation \((r=0.4–0.6)\) with November-December mean air temperature. In case of rivers ice appearance was affected by the air temperature conditions of the upstream section.

- Thesis 4/b: Freeze-up date was in moderate relation \((r=0.5–0.7)\) with November-December and December mean air temperatures. In case of rivers freeze-up was affected by the air temperature conditions in the environment of the observation.
– Thesis 4/c: Break-up date was in moderate relation \((r=-0.6–-0.8)\) with January-February, February and January-February-March mean air temperature. In case of rivers, break-up was driven by the local air temperature conditions, but mostly by the upstream air temperature conditions.

– Thesis 4/d: Date of final ice disappearance was in moderate relation \((r=-0.6–-0.7)\) with January-February, January-February-March and February-March mean air temperature. In case of rivers, ice disappearance was affected by the air temperature conditions of the upstream river section.

– Thesis 4/e: Ice-covered season was in strong relation \((r=-0.7–-0.8)\) with January, January-February and mean winter temperature. In case of rivers, the duration of the ice-covered season was driven by the local air temperature conditions, but mostly by the upstream air temperature conditions.

– Thesis 4/f: Icy season was in strong relation \((r=-0.7–-0.9)\) with the mean winter air temperature. The duration of the icy season was driven by the local air temperature conditions.

4. Anthropogenic effects on ice regime

The freshwater ice regime can be affected by not only the climatic conditions but also by anthropogenic interventions, which can change the strength and the temporal stability of the natural relationship between air temperature and ice phenomena. Anthropogenic impacts could exaggerate or hide natural trends in the river ice regime if they operate either in the same or opposite direction as the natural forces. **Thesis 5: All of the studied rivers were affected more or less by the most common anthropogenic interventions like river regulation, hydropower usage and water pollution.** This thesis is supported by the following results:

– River regulation: on River Danube, at Budapest, the frequency and duration of ice occurrence and ice-cover has decreased after the regulation works.

– Hydropower usage: on Raba River, upstream to the hydro power station, after the damming, the frequency and the duration of ice
phenomena has increased. Downstream to the damming opposite changes were detected, the frequency and duration of ice occurrence has decreased. The same trends were observed on Drava River, because after the damming, downstream to the hydropower station, based on the long-term relationship between ice phenomena and air temperature, longer icy season should have occurred, than it was observed.

- Water pollution: it was detected on the River Danube, at Budapest, that much lower temperatures are needed to create the same ice phenomena compared to the start of the observations. The duration of ice phenomena has decreased under water pollution.

5. Potential for winter temperature reconstruction based on ice regime observations

Freshwater ice phenomena and air temperatures are in strong and significant relation, based on simple and well-known physical laws, therefore temperature parameters can be estimated from the observed ice phenomena. In this study based on the ice observations on the River Danube, at Budapest, the estimation of the following temperature parameters were tested:

- December mean temperature was estimated based on the date of freeze-up.
- January-February mean temperature was estimated based on the date of break-up.
- January-February-March mean was estimated based on the date of ice disappearance.
- Mean winter temperature was estimated based on the duration of ice-cover.

The results are promising, the trend of the estimated air temperatures coincide with the observed air temperatures, but this method obviously has some drawbacks:

- In case of ice free winters, the estimation of air temperatures did not lead to appreciable results.
– Just a few items of information related to before the start of the instrumental temperature observations was included in the river ice observation data series of the River Danube, at Budapest.

4. References


Mundelsee, M. 2012: A proxy record of winter temperatures since 1836 from ice freeze-up/break-up in lake Näsijärvi, Finland. Climate Dynamics 38, 1413–1420.

5. Publications related to the dissertation


