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Bogusław Pawłowski

Department of Cryology and Polar Research
Institute of Geography, Nicolaus Copernicus University
Gagarina 9, 87–100 Toruń, Poland
bogus@uni.torun.pl

LONG-TERM VARIABILITY IN THE COURSE OF ICE PHENOMENA ON THE VISTULA RIVER IN TORUŃ

Abstract: Our first information of ice cover on the Vistula River in Poland dates from the Middle Ages. However, only since the 19th century have continuous observations been available. This study makes use of a data series, obtained mainly from IMGW (Institute of Meteorology and Water Management), covering the years 1861–2003 for ice phenomena and 1814–2003 for ice cover. Considerable shortening has been observed in the duration of both ice phenomena (from 60–120 days to 30–80 days) and ice cover (from 40–100 days to 20–60 days). These trends correspond well with the trend in winter temperatures becoming warmer. However, the transformation of the ice regime on the Vistula River in Toruń has also been affected by the river control, the construction and operation of the Włocławek Dam and (to a lesser degree than at Korzeniewo) icebreaking activities.

Key words: Vistula River, ice phenomena, trends, human impact

Introduction

Disastrous ice jam related floods usually bring about a growing interest in the course of ice phenomena. This was the case in the Polish territory annexed by Prussia in the second half of the 19th century, shortly before the river Vistula fell within the new boundaries of Prussia. Later, along with articles on ice-jam phenomena, various general studies were published, providing characteristics of the conditions and space-time diversity of the course of

Fig. 1. The Vistula River in Toruń with the location of the gauging station. The pictures shows a stage in the ice-cover build up – 19 December 1995, photograph by Bogusław Pawłowski.

ice seasons in the Vistula River. The most important of these studies include works by Lambor (1948, 1959), Gołek (1957, 1964) and Grześ (1991). The first observations of the water condition and ice cover were made before the official hydrological service was established in the 19th century. According to Mikulski (1965), Toruń has the oldest preserved records of water levels, dating from the period 1760–1772. Ice seasons are said to have been examined as early as in the 1720s. Nevertheless, the exact date of the use for the first river gauge in Toruń is not known. Apparently, in the 18th century it was placed at the bridge joining Mostowa Street with Kępa Bazarowa, an islet on the left bank of the river. In 1898 the river gauge was situated in the place where it is today (Fig. 1). It has always been within the proper centre of the city.

Outline of hydrological changes

The first instance of human influence on the channel of the Toruń Vistula significant for the course of ice phenomena was an attempt at controlling the river in the territory annexed by Prussia. The design came from 1879 (Makowski 1998) and work began in 1880 and was roughly completed in 1892. A number of supplementary structures had to be constructed, which were finished by 1907. Even though not all the project's objectives were attained, the tightened channel considerably improved the ice flow.

Since 1970s the Vistula's regime has been largely influenced by the dam and reservoir built at Włocławek. Below the dam a bed scour has been formed (Babiński 1992) and the peak demand period of the power plant operation triggers short-term variations in the water stage which hinder the formation of ice cover and may lead to ice run (e.g. from border ice), resulting in ice jams. The reservoir and the dam both hold most of the debris and suspended matter, as well as the ice flowing down the river.

Icebreaking activity has been carried out on the Vistula since the end of the 19th century. Its purpose is to breach a passage in the ice that would be wide enough to enable the free flow of the ice floe from the spring thaw. Icebreaking begins at the river mouth, so that the ice floe can easily float to the sea (Wrycza 1998). As a result of the icebreaking the natural ice-cover holding period is reduced. However, large amounts of ice or a low water level often make icebreaking difficult.

Data series and analysed parameters

The following parameters have been used to determine the characteristics of an ice season: ice-cover thickness, the duration of ice season phases and the occurrence of individual ice types (IMGW 1977), the extent of the filling of the river channel with ice and the frequency of ice-jam phenomena (Grześ 1997; Grześ and Pawłowski 2005, 2006). This study makes use of a data series for the Vistula in Toruń, obtained mainly from the IMGW, covering the years 1861–2003 for ice phenomena and the longer period of 1814–2003 for ice cover. The following elements have been analysed: the variable start and end dates of ice phenomena and ice-cover holding, the variability of the duration of ice phenomena and ice cover, and the frequence of occurrence of ice cover and its changeable share (%) in the whole ice-season cycle. The duration of ice phenomena is the number of days in a given season when any form of ice is found on the river. This includes the duration of ice cover and, additionally, the time of freeze-up and break-up. Data series going back to the early 19th century are questionable as regards the uniformity of the method with which the long-term observations were made. For this reason the present study disregards the duration of individual ice phenomena types.

First information of an ice cover on the Vistula comes from the Middle Ages. The ice cover was found on the river even in October (18.10.1225), and early November (1.11.1518), and the totally frozen-over surface was not an uncommon sight in mid-November back in those days. The break-up of the ice cover usually took place in April, often towards the end of the month (23.04.1432). During the winter of 1431–1432 the Vistula was frozen for 150 days and in the winter of 1518–1519 – for 132 days (Cyberski 1982).

Results

In the study period the duration of the ice season decreased from the maximum of 139 days in 1865 to just 6 days in 1975. The average duration of ice phenomena on the Vistula in Toruń was 60–120 days in the 19th century and 50–110 days in the first half of the 20th century; bigger changes did not take place until the second half of the 20th century, when ice phenomena lasted only approximately 30–80 days.

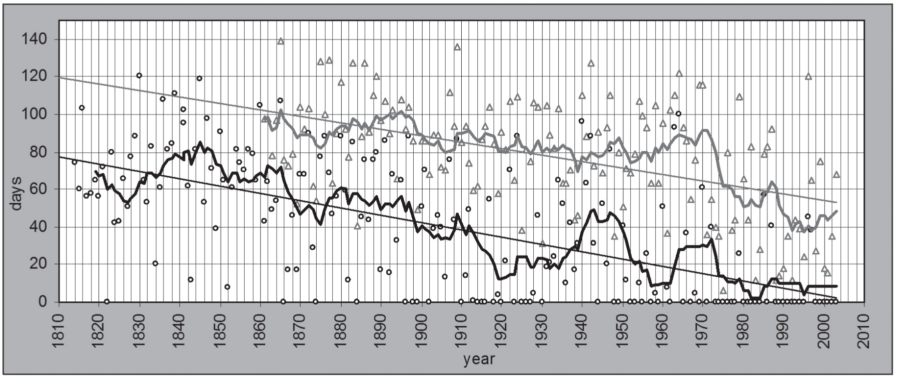

Fig. 2. The duration of ice phenomena (1861–2003 upper curve) and ice cover (1814–2003 lower curve) on the Vistula in Toruń along with the linear trend and ten-year consecutive averages.

It has been found that the duration of ice cover periods changed with substantial variability. The number of days with ice cover initially increased from 40–100 days (with a maximum of 120 days in 1830), but from the mid-19th century it started decreasing and went down to 30–80 days in the early 20th century, and – in the second half of the century – even further, to 20–60 days. However, enormous changes occurred in the frequency of ice cover, showing some multidecadal oscillations. In the 86 winter seasons analysed in the 19th century, there were only 8 years when no ice cover was recorded in Toruń. After 1910, nearly 40% of all years had winter seasons without ice cover. Starting from the 1970s winters without ice cover have been predominant in Toruń, and the occasional appearance of ice cover takes place once every five years.

The analysed data made it possible to capture the changes in the structure of the ice season, and – more specifically – the share of the ice cover in the whole ice cycle. In the 19th century, the share of the ice cover in the whole of the ice phenomena in Toruń usually remained at about 50%. The variability pattern of the dates on which the ice phenomena and ice cover occurred and disappeared has been analysed in five-year periods. For the period of 140 years, the average start date shifted from about 20th November to 15th December.

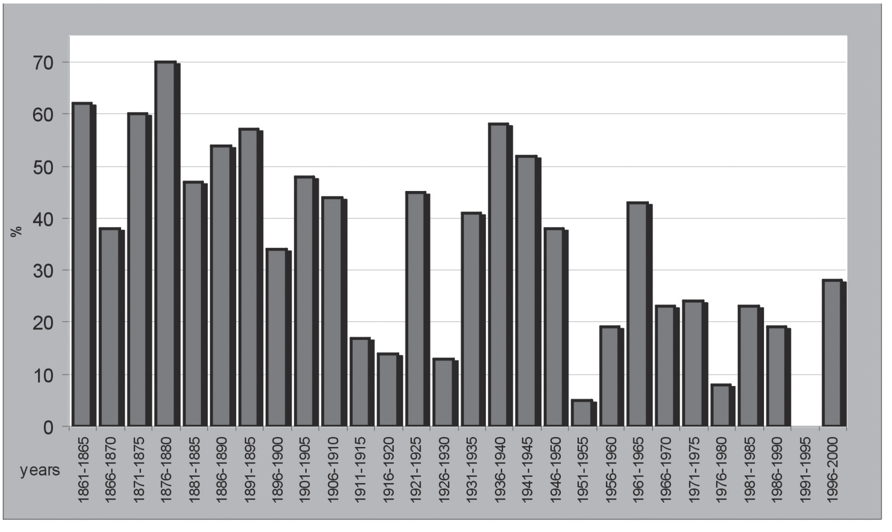

Fig. 3. Percentage share of days with ice cover out of all days with ice phenomena in Toruń.

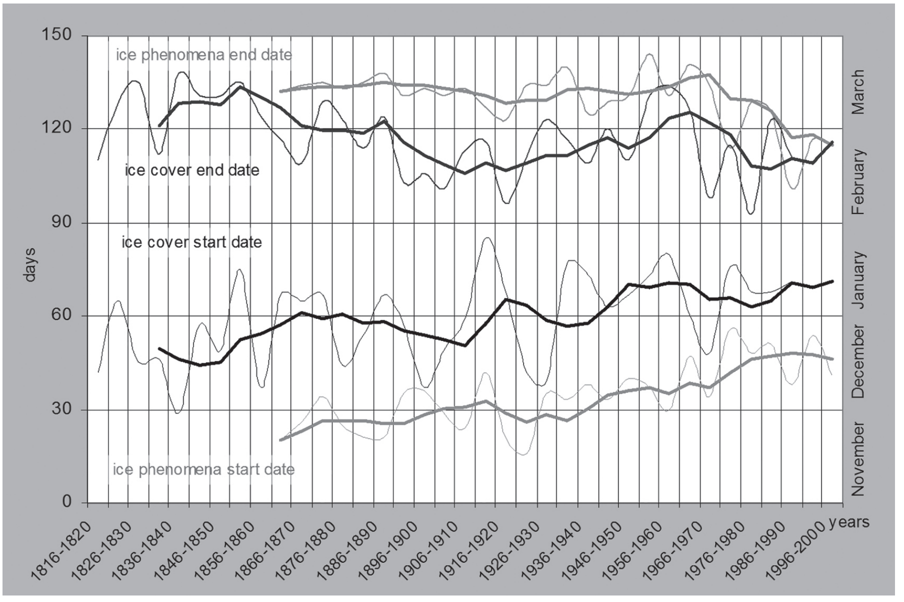

Fig. 4. The average start and end dates of ice phenomena and ice-cover duration in Toruń. The courses are shown as averages over five-year and twenty-year consecutive years.

Early in the 20th century the share dropped to 40% and, by the end of the century, it was at 20%; only some of the longest and most frosty winters in the 1930s and 1940s were characterised by a high share of ice cover, of nearly 50-per cent. A subsequent decrease which progressed through several stages was observed in the second half of the 20th century. Today, the share of ice cover in the whole of the ice phenomena in Toruń does not exceed 20–30% (the share was determined as the total holding time of ice cover in relation to the total duration of all ice phenomena in individual five-year periods).

As shown in Figure 4, the last day of ice phenomena has been falling earlier and earlier. In the second half of the 19th century, ice phenomena usually disappeared around 15th March. At present, the last day when such phenomena occur typically falls at the end of February or the beginning of March. These changes did not develop uniformly over the analysed period. There was a slightly negative trend in the years leading up to 1920. From the 1920s to the 1960s, ice phenomena tended to fade away later (a positive

Table 1. Variability trends of selected parameters of ice seasons for the Vistula in Toruń

Parameter (ice phenomena in 1861–2003, ice cover in 1814–2003)	Change (days/100 years)
Duration of the ice phenomena	-34
Start date	19
End date	-11
Duration of the ice cover	-39
Start date	13
End date	-8
Share of days with ice cover in the ice phenomena	-31%
Formation of the ice cover	-70%

trend). In the following years, a strong negative trend, followed by a slight delay, was observed.

Similarly, changes in the date on which the ice cover first appears are characterised by a positive trend, indicating a delay. The average time of first occurrence of the ice cover changed in the study period from about 20th December to 10th January.

The average time of the break-up of the ice cover changed during the course of the almost 190-year study period from the beginning of March to the middle of February. A more detailed analysis reveals that for the years 1860–1920 a negative trend was typical, whereas later a slight positive trend developed, to be replaced by a strong negative trend after 1970.

The variability trends of selected parameters of ice seasons have been presented in Table 1.

The results obtained have been compared with the course of the ice season at the Korzeniewo gauging station. This river gauging station is situated approximately 130 km downstream from Toruń, in the section of the river that is free of impact from the power plant in Włocławek. Unfortunately, there is no such long and continuous series of data for this point of reference (series start from 1900). From the beginning of the 20th century the duration of ice phenomena at Korzeniewo shows a very similar pattern to that of Toruń, though the ice phenomena lasted from between around 12 to 20 days less, partially due to a shorter ice-cover holding period. In the 20th century, the share of ice cover out of the rest of the phenomena was in most cases lower than in Toruń. It averaged at 23%, whereas in the corresponding period in Toruń the share was 28%. From the 20th century onwards, the end of ice-cover holding period at Korzeniowo (with the exception of some random cases) always occurred earlier than in Toruń (12 days difference in the same period). The reasons for the differences most likely lie in the icebreaking activities starting from the river mouth and working upstream – icebreakers thus reach Korzeniewo earlier and more often than Toruń.

Discussion

Over the last 200 years the ice regimes of Polish rivers have changed as a result of both natural processes (such as climatic changes) and anthropogenic processes (whose impact has already become evident in the short series of observation data). These changes confirm strong connections between the ice-cover holding period, the duration of the ice phenomena, the mean value of air temperature in the winter season and the NDD (i.e. the total of all average daily negative air temperatures recorded in the winter season – the so-called 'cold sum'). The correlations have been observed for the Vistula in Toruń by Mroziński (2006) and are confirmed by the results of studies of the ice season on the Lower Vistula, carried out in the second half of the 1990s by the Institute of Geography at the NCU.

The course of the ice season on the Vistula in Toruń has changed fundamentally since the 19th century. The warming of the climate is clearly reflected in the changed mean temperatures of winter. The transformation of the ice regime on the Toruń Vistula has also been affected by anthropogenic factors: river control, the construction and operation of the Włocławek Dam and (to a lesser degree than at Korzeniewo) icebreaking activities. There is no doubt that some of the changes can be attributed to other factors, such as changes in the water chemistry of the river – an issue that has not been investigated in this study.

Conclusions

In the study period (1861–2003), the usual moment of occurrence of ice phenomena was delayed from about 20th November to 15th December, while the time of their disappearance moved from 15th March to the end of February / beginning of March. Correspondingly, the time of occurrence of the ice cover (in the years of 1814–2003) was delayed from about 20th December to 10th January, while its disappearance advanced from early March to mid-February. Thus considerable shortening has been observed in the duration of both ice phenomena (from 60–120 days to 30–80 days) and ice cover (from 40–100 days to 20–60 days). Also, winter seasons without ice cover have become more and more frequent, and have prevailed in recent years. The variability trends of selected parameters of ice seasons have been presented in Table 1.

The variability trends in the ice cycle of the Vistula, observed in Toruń, are typical of the rivers and lakes of the Northern Hemisphere (Kuusisto and Elo 1998; Yoo and D'Odorico 2002). According to Magnuson (2000), over the last 150 years the start date of ice-cover build-up for rivers and lakes such as the Mackenzie, Lake Suwa and the Angara has been postponed by 5.8 days/100 years, on average, whereas the date of disappearance of ice phenomena falls 6.5 days/100 years earlier than before. The main reason for this is the increase of the annual mean air temperature, estimated at 1.2°C/100 years, on average, particularly apparent in the cold half of the year.

Ice-cover duration trends on some rivers in the Arctic in 20th century are diverse, but generally on most of the rivers trends are negative for 11 out of 16 rivers (digital media: Global lake and river ice phenology database, Russian river ice thickness and duration, Nenana Ice Classic). The greatest trend was on the Yukon river in Dawson in 1970–1990 (-24.2 days/100years).

In Toruń, the extent of changes has been as much as two or three times bigger than that noted by Magnuson. However, in this area in the last 50 years the mean winter temperature has increased by approximately 1.7°C (Marciniak 1996). Moreover, climatic changes in Toruń are not the only factor conditioning the course of the ice season. The influence of river control works on the Vistula (in the years of 1880–1907) brought about a shorter ice-cover holding period and reduced its share in the ice phenomena in general. Since the early 20th century the frequency of ice cover has evidently dropped.

Aside from the trends referred to above, when the dam in Włocławek was built the duration of ice phenomena was shortened by changes in the start and end dates. Here, the main factors included the obstruction of passing of pancake ice in the dam reservoir, the lack of frazil crystallisation nuclei in the water (suspension deposition) and the varied flow rate resulting from the operation of the hydroelectric power plant. It is difficult to provide a conclusive answer as to the extent of the impact the dam has had on the ice season in Toruń, especially given the data from the period immediately following the construction of the dam. The 1970s were warmer than the 1960s and ice phenomena naturally appeared later. Based on the courses of winter thermal conditions (mean temperature of 3 subsequent months: December, January and February), before and after the dam was erected (Marciniak 1996), and taking into account the duration of ice phenomena periods, the correlations of the data series have been calculated, both for the years before and after the dam. A comparison of the data unambiguously implies the significance of the dam and the reservoir as factors substantially affecting the duration of ice phenomena in moderately cold winters (at t=-3ºC the ice season was 19% shorter, but at t=-1ºC it the reduction reached 34%). However, in colder winters (t=-7ºC) their role was minor or even insignificant.

What follows from the analysis of the data collected at Korzeniewo is that the decrease in the frequency of the occurrence of ice cover in Toruń attributable to the dam and the power plant may not exceed around 15%. It should be noted that the ice cover on the Vistula builds up upstream (there have been winters with ice cover only at Korzeniewo, not reaching Toruń).

The present study disregards the issue of ice jamming phenomena in Toruń. Some of them have been marked on the city walls with plaques of the Vistula High Waters (Pawłowski 2000). In the analysed period, such flood marks were placed for the ice jam floods of 18th February 1879 and 13th March 1891. In later years, the threat of ice jams was substantially reduced as a result of river control works. After 1970 (e.g. in January 1996) there were minor instances of damming as a result of the peak demand operational cycle of the hydroelectric power plant in Włocławek (Pawłowski 2003).

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