LONG-TERM TRENDS IN LAKE ICE COVER IN FINLAND

Johanna Korhonen
Finnish Environment Institute (SYKE), Helsinki, Finland

ABSTRACT
The longest ice break-up series in Finland started in spring 1693 (river Tornionjoki) and freezing and break-up records are available at least since the mid-19th century from three lakes - Kallavesi, Näsijärvi and Oulujärvi. The number of time series starting in the late 19th century amounts to at least twenty. A large number of ice observations were analysed in order to identify long-term changes in the ice regime. The analysis clearly showed that there is a statistically significant change towards earlier ice break-up in Finland, from the late 19th century to the present time. There is also a significant trend towards later freezing in the longest series and thus also towards a shorter ice cover duration. The series of maximum thickness of ice showed both decreasing and increasing trends. These trends were statistically significant for approximately half of the observation sites. Decreasing maximum ice thickness trends were found in the southern part of the country and increasing trends in central and northern regions.

KEY WORDS: lakes; break-up; freezing; ice thickness; trends

INTRODUCTION
Winter ice cover is a natural phenomenon in lakes and rivers in countries of high latitudes. Formation of ice and its disappearance are among the oldest hydrological observations in Finland. The long datasets of ice break-up and freezing are an interesting subject of analysis because they are good indicators of climate change and variations. Ice break-up datasets of many lakes go further back in time than air temperature records from the same areas. Moreover, Livingstone (1997) asserted that break-up dates are even better climatic indicators than air temperature itself.

The very first studies of cryophenological records in Finland (Hällström, 1841a,b) were reported by Kajander (1989). Later, Johansson (1932) presented a number of river ice records and Simojoki (1940) introduced data from many Finnish lakes. In addition, statistics of ice conditions were published in the Hydrological yearbooks starting a few years after foundation of the Hydrographical Bureau in Finland in 1908. During recent decades and years, e.g. Palecki and Barry (1986), Kuusisto (1987; 1993), Magnuson et al. (2000) and Yoo and D’Ororico (2002) have analysed the trends of some Finnish break-up and freezing records. Kuusisto (1994) and Kuusisto and Elo (2000) also presented long-term changes of maximum ice thickness for a few lake sites.
The aim of this study was to investigate long-term changes in the ice regime of several Finnish lakes. A large number of other lake sites are introduced in this study compared to the earlier analysis described above. In this study, the freezing and break-up records of almost ninety sites, and thickness records of over thirty sites were analysed in order to study average ice regimes in Finland and to identify long-term trends of ice cover. Most of the studied sites are lakes; only one river site (Tornionjoki) is included. All the sites studied have records at least since the 1960s. The data was analysed until year 2002. This paper is a summary of a more extensive study concerning ice conditions in Finland (Korhonen, 2005).

DATA AND METHODS

The longest continuous ice break-up series from the river Tornionjoki dates back to the late 17th century (Johansson, 1932; Kajander, 1995). The longest continuous freezing and break-up data series of lakes are from lakes Kallavesi, Näsijärvi and Oulujärvi. Break-up records are available from lake Kallavesi since the year 1822 and freezing data since 1833, from lake Näsijärvi since the winter of 1836-1837 and from lake Oulujärvi since 1853-1854. There are also some other lakes from which records exist since the late 19th century. A large number of sites have records starting from the 1910s. Continuous ice thickness observations were also started in the 1910s at some lake sites in central and southern Finland, but most of the ice thickness measurements began in the 1960s.

The date of permanent freezing of the whole area visible from the observation site was taken as the official freezing date in this study. The break-up date was chosen as the date when ice was no longer visible from the observation site. If there were several records for a same year, the earlier one was used. The duration of ice cover in days was defined as the difference between the break-up and the freezing dates. Ice thickness has been measured in the wintertime on the 10th, 20th and 30th of the month since the late 1970s. Before that, ice thickness was measured every 15th and 30th of the month. A manual measuring rod and drill are used to measure ice thickness and the average value from three different drillholes is defined as the official measurement. Since the late 1970s snow ice thickness has also been measured in addition to the total thickness of the ice cover.

Long-term changes were defined by linear regression, moving averages were also used. Trends were tested in order to determine whether changes were statistically significant. The 2-tailed t-test was used to determine the level of significance. Significances of trends were categorized to levels of 5% (p<0.05), 1% (p<0.01) and 0.1% (p<0.001).

RESULTS AND DISCUSSION

Average ice regime in lakes in 1961-2000

Freezing of lakes occurs in Lapland at some sites on average already in late October. In the southern coastal areas the freezing of lakes typically takes place at the beginning of December. There are considerable variations in the freezing date due to the area of the lake, but the lake depth is also important. Deep and large lakes in a certain area can freeze as much as one month later than shallow and small ones in the same area. The deepest parts of the largest lakes freeze over on average as late as at the end of December. In Lapland the largest open areas of lake Inari freeze on average at the end of November. The variation of the freezing date is greater in the southern part of the country than in the

-72-
The average standard deviation of the freezing date is approximately two weeks, which is about twice as high as that of the break-up.

The mean maximum ice thickness in southern Finland is below 50 cm, in central Finland 50 to 60 cm, in the southern part of northern Finland 60 to 70 cm and in Lapland mainly 70 to 80 cm, but even 90 cm in north-western Lapland. The date of the maximum thickness occurs in mid-March in the south and in April in Lapland – in southern Lapland at the beginning of April but in north-western Lapland as late as at end of the month.

The break-up of ice occurs in southern Finland typically at the end of April, in central Finland by the middle of May, in the southern part of northern Finland after the middle of May, in southern and central Lapland by the end of May and in northern Lapland at the beginning of June. In north-western Lapland the ice breaks up normally as late as after mid-June. Ice breaks up simultaneously within a certain region almost regardless of the size of the lake. There are no major differences between the south and north of Finland concerning standard deviation of the break-up date.

The mean duration of ice cover in the south is normally about 140 days, in central Finland mainly 150 to 180 days, in the southern part of northern Finland 180 to 200 days and in Lapland 200 to 220 days. The duration of the ice cover can be estimated rather well by the freezing date. When freezing occurs early, the ice cover period is very likely to be longer than the average value, and the ice thicker than the mean thickness. A thicker ice cover obviously needs more heat to melt than a thinner one. Thus in the years of thick ice cover the break-up will occur later than in average years.

**Connection between ice conditions and air temperatures**

Geographical factors have a considerable effect on the ice conditions. Latitude is quite important as it defines the amount of incoming solar radiation, which affects the air temperatures and also the ice conditions. Elevation of a lake is also of importance because the air temperature decreases as a function of elevation. The dates of both freezing and break-up of given year can be estimated rather well using air temperatures.

The correlation between Nov-Dec air temperatures and freezing dates and Apr-May air temperatures and break-up dates were calculated for the longest observation series. The coefficients were calculated for the longest observation periods available and for the period 1961-2000. Also moving correlation coefficients were used. The correlations for break-up dates were better than for freezing dates, because the depth of a lake affects the freezing date but not the break-up date. The squares of correlation coefficients for the period of 1961-2000 varied mainly from 0.40 to 0.65. There were a rather large variation between different periods which can be seen from the moving correlation coefficients. For some periods correlation is remarkably lower or higher than the average.

**Trends of freezing, break-up and duration of ice cover**

Less than half of the ice cover series studied had some statistically significant trends for the whole observation period before the year 2002. Most of the trends were found for the break-up date. The break-up date has become earlier and the freezing date later at many observation sites during the last few decades. The trends were statistically significant mainly in those sites which have records at least since the late 19th century. Trends of the series that started in the 20th century were in most cases not
statistically significant but some trends were also found for these shorter series, especially in southern Finland. In the series that started in the late 19th century, the ice break-up has moved generally 6 to 9 days earlier over one hundred years.

The freezing has been delayed since the late 19th century, in most cases by 5 to 8 days per hundred years. The duration of the ice cover has also significantly decreased at sites with the longest records, by about two weeks (12 to 16 days) per hundred years. Only some of the freezing and duration of ice cover trends were statistically significant. Some trends towards an earlier freezing date were also found for a few shorter series. In the late 1920s and early 1930s, freezing occurred extremely late. On the other hand, in autumn 2002 freezing occurred in small lakes in southern Finland extremely early. This results in a statistically significant trend towards earlier freezing in some small lakes in southern Finland, for example in lake Kuivajärvi (Fig. 1). The extremely late freezing in the winter 1929-1930 and very early freezing in 2002 make trend statistically significant.

The trends of break-up were stronger than those of the freezing date. The wide variation of freezing dates hides the trends of freezing, especially in lakes with only short periods of records. The trends of ice cover period were also more statistically significant than those of the freezing date. There were no statistically significant trends of break-up, freezing or duration of ice cover in northern Lapland, but the time series from this part of the country are still relatively short. Generally, trends were mainly stronger in the southern part of the country. The magnitudes of trends in this study were rather similar to those presented by Magnuson et al. (2000).

When examining the subsets of long time series, some short-term trends can be found. The freezing series of lakes Näsijärvi, Kallavesi and Oulujärvi show that no dramatic changes occurred from the mid-1800s to the late 19th century. From 1885 a number of other series can also be examined. At almost all of the sites freezing was delayed from the late 19th century to the 1930s, because of the very late freezing dates in some winters in the 1920s and the 1930s. After that, from the 1930s until the late 1960s freezing has moved earlier in most places. From the 1960s to the present, freezing has again been slightly delayed.

The break-up series of the river Tornionjoki has many subset trends. From the late 17th century until the 1740s no remarkable changes can be found, but from the 1740s to the early 1800s break-up varied considerably. Break-up of lake Kallavesi was clearly delayed during the period from 1822 to the 1870s, and similar trends can be seen in the time series from lake Näsijärvi and the river Tornionjoki. For many series the late 19th century was a turning point, after which the break-up started to move earlier. Simojoki (1940) determined the turning point for lake Kallavesi to be 1886. On the other hand, Eklund (1999) presented that a change to earlier break-up occurred in the early 19th century in lake Mälaren, Sweden. From the late 1880s, the break-up dates have been moving earlier rather consistently, although there is some variation between the years. A similar trend can be seen in the spring (March-April-May) air temperatures in Finland (Tuomenvirta, 2004). In the 1960s and the 1970s variation between the years was rather small and extreme break-up dates did not occur.

The duration of ice cover has decreased from the late 19th century to the 1920s. Of course, there is considerable variation from year to year. From the 1930s to the early 1950s ice cover periods were generally shorter than in the 1920s or late 1950s, especially in southern and central Finland. From the late 1950s to the present time ice cover period have decreased slowly. The decreasing trend has been stronger in the south. This examination of subsets of also shows clearly that by choosing different periods in the time series, different trends can be found.
Figure 1. Time series of break-up and freezing at different sites. The letters S, C and N stand for southern, central and northern Finland.
The fact that trends of break-up dates were stronger than those of freezing dates also agrees with the observed long-term changes in air temperatures in Finland (Tuomenvirta, 2004), northern Sweden (Klingbjer and Moberg, 2003) and north-western Russia (Filatov et al., 2005). These studies have shown that air temperatures have increased more in spring than in autumn or in winter. The study of Filatov et al. (2005) showed that the trend of spring temperatures was stronger in the southern part of north-western Russia than in the northern part. This result dovetails with the finding of stronger break-up trends in the southern part of Finland in this work.

Figure 2. Time series of maximum ice thickness at different sites. The letters S, C and N stand for southern, central and northern Finland.
Trends of maximum ice thickness

Both decreasing and increasing trends were found in the maximum ice thickness time series. At about half of the sites the trends were statistically significant. The maximum thicknesses have generally increased in central and northern Finland and decreased in the south. The series with records since the 1960s had significant trends of 2 to 3 cm per ten years, whereas for longer series the trend was mainly 1 to 2 cm per ten years (Fig. 2).

The time series of snow ice and snow thickness are rather short, about twenty years, and therefore no long-term analysis can be made. In the 1980s there was much snow and snow ice in southern and central Finland. Thus the snow ice thickness has in most cases decreased from the 1980s to the year 2000 in southern and central Finland. In northern Finland, the snow ice thickness has increased in some places during the twenty year period. Trends of maximum ice thickness are rather similar to the trends of snow water equivalent (Hyvärinen, 2004). Snow water equivalent has increased in northern and eastern Finland and decreased in southern and western regions. Accordingly, snow ice thickness probably explains the reason for maximum ice thickness changes. The effects of climate change on ice thickness are rather complex, because the ice thickness depends both on temperature conditions and on snowfall. Even very similar frost sums and snowfalls in different winters can result in different ice thicknesses, as was discussed earlier by Kuusisto (1994) and Kuusisto and Elo (2000).

CONCLUSIONS

This study consisted of investigating the average ice regime in Finnish lakes and looking for trends of ice cover time series. Almost ninety break-up and freezing series and over thirty ice thickness series were analysed. The freezing of lakes occurs usually from late October to early December when progressing from Lapland to southern Finland. The average year-to-year variation of freezing date is about two weeks. The variation of the break-up date is about half of the variation of the freezing date. Lake ice break-up occurs generally in late April in southern Finland and in early June in the north. The mean duration of ice cover in the south is about 140 days, in central Finland mainly 150 to 180 days and in northern Finland 180 to 220 days. The average maximum ice thickness from the south to the north is from 50 cm to 80 cm.

The analysis showed a statistically significant change towards earlier ice break-up in Finland from the late 19th century to the present time. The break-up has moved mainly 6 to 9 days earlier over a period of hundred years. The greatest change towards earlier break-ups occurred in the late 19th century. There was also a significant trend towards later freezing in the longest series and thus also towards a shorter ice cover duration. The delay of the freezing date was about 5 to 8 days in one hundred years for the longest time series. The duration of ice cover has decreased by about two weeks (12 to 16 days) per one hundred years. For those series which started in the 20th century, the trends were mainly not significant. However, some of the shorter break-up series did have statistically significant trends. The fact that trends of break-up were stronger than the trends of freezing agrees with observed long-term changes in air temperatures in Finland, Sweden and north-west Russia.

The series of maximum thickness of ice showed both decreasing and increasing trends. The trends were statistically significant for approximately half of the observation sites. Decreasing trends were found in the southern parts of the country, increasing trends in the central and northern parts.
REFERENCES

Eklund, A. (1999), "Islägging och is lossning på sjöar", Sveriges meteorologiska och hydrologiska institut, Nörrköping, SMHI Hydrologi NR 81.


