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Methodological Aspects on River Cryophenology Exemplified by a Tricentennial Break-up Time Series from Tornio

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Abstract

Cryophenological observations have traditionally been used as climatological indicators, especially for the pre-instrumental period. The phenomenon that has produced the longest records is ice break-up in rivers. As a case study, a break-up series of 300 years is examined. The main emphasis is on discussing the sources of cryophenological information and the construction of the time series.

By using several sources whenever possible, errors can be detected and the homogeneity of the time series improved. Special attention must be paid to the verbal character of cryophenological information and the thereof following problems of interpretation.

The time series from Tornio begins during the Maunder minimum and thus displays a strong trend. The break-up now occurs on the average 13 days earlier than 300 years ago.

Temperature observations are available as comparison material for the last 134 years. The break-up dates have an excellent correlation with mean temperatures of April and May, thus allowing the estimation of these temperatures for the earlier period. Estimates of winter temperatures are less accurate but might be of some use.

1. *Introduction*

Cryophenology is a boreal science *par excellence.* The winters in the boreal region are long and cold enough to produce a strong ice cover of long duration in rivers, lakes and seas. As a consequence, the ice break-ups, especially in rivers, are often spectacular events and well-documented. Moreover, this great drama of nature is performed every spring, a fact that enables the construction of time series. In the temperate zone, the winters are often too warm to produce an ice cover of long duration. Instead of one unique break-up, there may be several less impressive freezings and break-ups or no ice cover at all. In mountainous regions, the winters are cold enough, but good observation sites like shallow lakes or stretches of quiet water in rivers are not common.

Another important condition for the formation of long time series is the availability of observations. The oldest records were made by voluntary observers that may have developed their interest in systematic documenting of cryophenological dates either independently or encouraged by someone else. The probability of such annotations being made by an arbitrarily chosen person and conserved and continued by his/her heirs or friends is not very high. Accordingly, most of the longest records have been made in river-mouth towns and other places with a considerable concentration of population, and only a few in the countryside. The level of education was also of importance: literacy was necessary for potential observers, but reading scientific journals certainly promoted the interest in voluntary observations.

The golden age of cryophenology was the period before the establishment of meteorological observation networks. The temperature records were few, unreliable and too short to give the desired information. The relative importance of cryophenological records was estimated much higher than in our days. Now there are plenty of good temperature records long enough to be used as time series. There are also paleoclimatological methods that can give information far beyond the instrumental as well as cryophenological and phenological records. Accordingly, cryophenology can now play only a secondary role in climatology. However, they are still of interest as sources of information on the climate history of the late preindustrial and early industrial periods not covered by instrumental records.

Tornio has all the qualifications of being an important cryophenological observation site. It is located on a large river (known by the name *Tornionjoki* by Finns, *Torne älv* by Swedes and *Tornionväylä* by the local people speaking a Finnish dialect; here we use the name *Tornio River* instead of the usual monstrous constructions including the word 'river' in at least two different languages), notorious for its spectacular and often disastrous break-ups. The cold climate guarantees the uniqueness and the annual occurrence of the break-ups: the mean ice cover time (the longest continuous duration of ice covering the entire surface of water in the area within sight) is almost 6 months, and ice cover times less than 4 months have not yet been observed. The break-up at Tornio is usually independent of the upstream ice phenomena, as the river is somewhat narrower at the town. The rapids are not high enough to disturb the ice cover; the nearest large one, Kukkolankoski, is 16 km upstream.

Besides climatological and physiographical factors, history has also favoured Tornio as a cryophenological observation site. The town was founded as early as in 1620 and was an important centre of trade during the 17th and 18th centuries. In 1809, the Swedish-Russian border was drawn along Tornio River and the town of Haparanda was founded next to Tornio by the Swedish riverside. These two towns, both attracting the attention of their national monitoring organizations and both served by their own newspapers, are likely to have produced more data than a unified town of Tornio in one country would have done. Moreover, the river survived the hydropower construction boom that put an end to some of the old cryophenological records and had major heterogenizing effects on some others. An important reason for the conservation of Tornio River was the disagreement on the conditions, certainly promoted by the existence of double municipal and state authorities. Another complicating factor was natural, Europe's greatest bifurcation in Junosuando.

There is a hydropower plant in the tributary Tengeliönjoki, but its influence is very limited. Of the neighbouring large rivers the receiving part of the Junosuando bifurcation, Kalix River (Kalix älv, Kaalasväylä), has also maintained its freedom, but the time series is rather modest. Kemi River (Kemijoki) has a long record (1793-) from Keminmaa village, but the site is now entirely different, a part of the power plant reservoir situated close to the dam.

Break-up records from Tornio are available in numerous sources, printed and unprinted. An explicit version of the time series was already published by Hellant (1747). In the version of Johansson (1932), the documentation of the older parts is careful but the more recent material is rather narrow and not always well-documented. After this, most

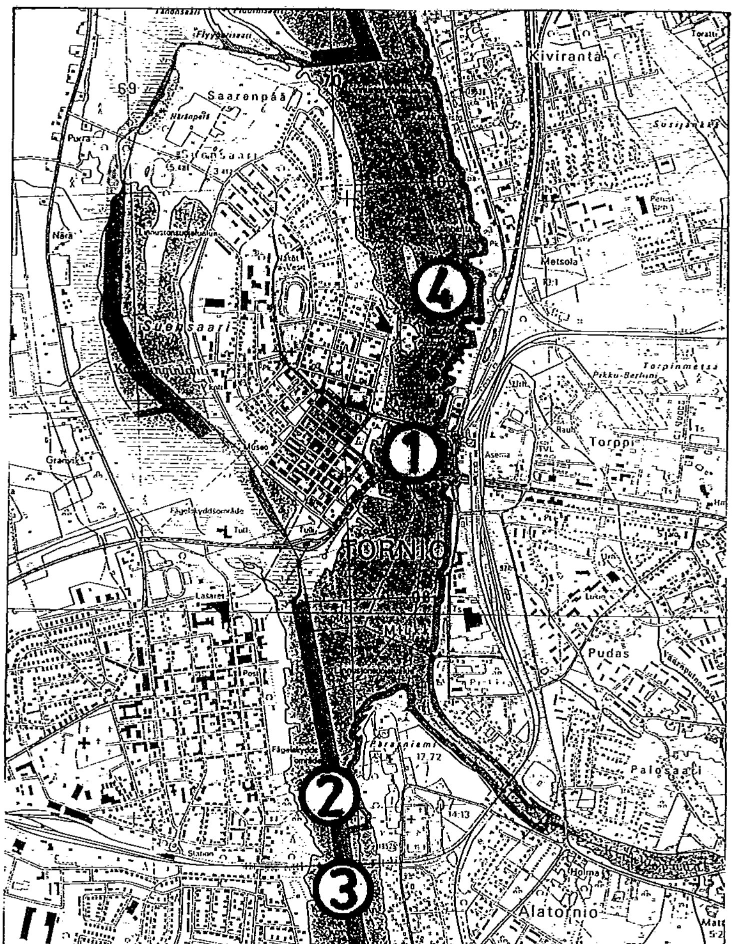

Fig. 1. Cryophenological observation sites in Tornio-Haparanda: (1) The area between the bridges, or between the downtown Tornio and Tornio railway station, (2) The area between downtown Haparanda and Alatornio church, (3) Kristineberginkorva rapids, (4) Kuljunkorva rapids.

papers do not contain the data in an explicit form. The version of this paper is somewhat different from a recently published version (Kajander, 1993a).

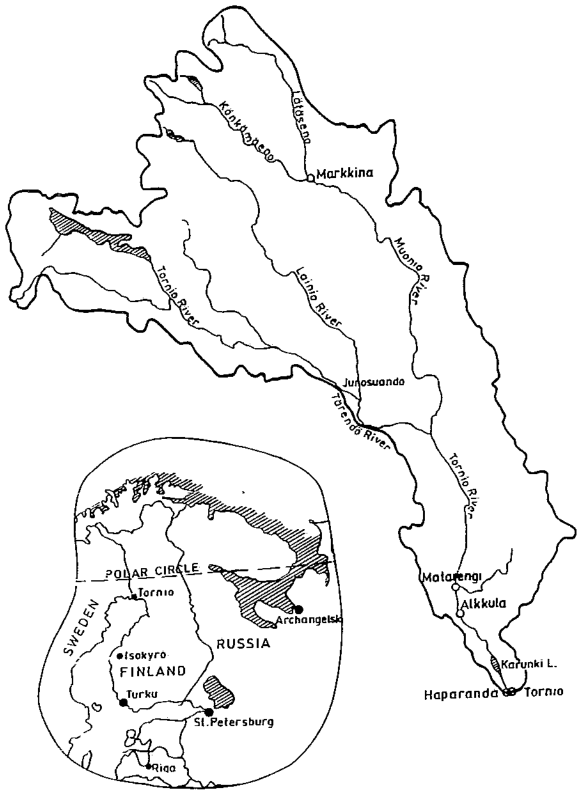

Fig. 2. Location of some of the most important cryophenological observation sites.

2. *Break-up as a process*

The initial conditions of a break-up are formed during the autumn and winter months. The water level in the river at the time of freezing is essential, as the ice cover cannot suffer being raised much above it. The strength and volume of the ice are mainly determined by weather conditions during the freezing and shortly after it. The weather of the break-up period is, however, the most important factor affecting the break-up time.

There may be short melting periods throughout the winter, but in the spring, usually in April, melting begins to dominate. Local melting makes the ice weak and porous, but the more important melting process occurs in the snow cover of the catchment. Snowmelt increases runoff, and the water level in the river rises. The strong current increases the stress on the ice cover, until it is broken up in parts and carried away by the current.

The shift of color from light to dark, the occurrence of holes in the ice and the presence of a layer of liquid water on the ice are visible signs of an approaching break-up. Still more important are the local break-ups in small rapids like Kuljunkorva above the old highway bridge, Lasimestarinkorva below the new highway bridge and Kristinebergipkorva below the railway bridge. The break-ups in neighbouring small rivers or creeks (Keräsjoki, Kråklundinpuro etc.) have also served as signs. Some traditional signs are still widely used, while others have been forgotten or abandoned as no longer valid. The most popular sign in the early 20th century, the opening of Kråklundinpuro, was gradually abandoned in the 1930's after a major clearing.

When the water level has risen sufficiently, large parts of the ice cover get loose and begin to move. The pressure from ice coming down the river often compels parts of the ice cover to move, even if they were not ready to break up independently. The break-up usually occurs earlier in the area above the railway bridge and between Haparanda and Parasniemi, and a little later at the Tornio railway station. If the water level is high and rises rapidly, the time difference is negligible, but it may be several days, if the water level remains low. The broad part of the river, called Tanskinselkä, above Kuljunkorva rapids, usually keeps its ice somewhat longer than the more narrow areas at the towns. The ice from the broadest part of the river, usually called "the Lake" ("järvi", Karunginjärvi, Karungi träsk etc.; some 20 km upstream from Tornio) comes down in great amounts several days after the general break-up in the river parts.

The local people can often tell not only the date but also the hour and even the minute of the break-up in a certain place. This happens when a major part of the ice cover suddenly begins to move downwards. Sometimes, especially when the water level is low, the break-up is so slow and gradual, that no certain moment can be pointed out as more significant than any other. Moreover, a part of the ice cover at the shores may remain fixed several days after the break-up. The break-up process is over when the ice-run has ceased and the ice cover has entirely melted away. There may, however, remain large blocks of ice on the shores left there by the flood.

3. *The nature of semantic information*

Unlike instrumental records consisting of numerical values of a variable for a given time, obtained by using a more or less well-calibrated instrument, cryophenological records consist of verbal expressions referring to an event that occurred at a given time. The expressions are of different lengths, from single words to several long sentences. In general, the longer descriptions contain more information. Even a very short expression can, on the other hand, contain the essential information of the phase of the process and the site.

The semantic problems of cryophenological vocabulary have been briefly discussed elsewhere (Kajander, 1990; Hussi, 1993) and a more comprehensive treatise will be published in near future (Hussi, 1994). In our case, the ambiguities are not very serious, as will be pointed out in the following discussion.

The key words referring to the phase of the process are usually either nouns or verbs. The most common nouns, the Finnish 'jäänlähtö' (literally "the departure of ice") and the Swedish 'islossning' (literally "the loosening of ice") can be used as referring to the whole process, beginning from the local phenomena, or of a certain event in which the process culminates. In Tornio, these words together with a single date but without further specifications, have referred either to the beginning of the large-scale disintegration and movement of the local ice cover or the most intensive stage of this part of the process. The time difference between these two events is not always negligible, but it is in any case tolerable compared with other possible errors.

More dangerous is the ambiguity with such expressions as 'jäänlähtö alkaa' or 'islossningen börjar' (both: "break-up begins"). These sentences may refer to the beginning of the whole process, becoming evident with a local displacement of ice, or to the beginning of the general break-up . One of the examined sources actually refers to the local break-up. Time differences of two weeks between the two events are not uncommon. If no other data are available, the reported date may easily be interpreted erroneously.

Some of the commonly used expressions contain verbs of motion or nouns derived from them, such as the Swedish noun 'isgång' or the Finnish sentence 'jäät menevät'. In this case it is obvious, that the expression does not refer to a local displacement of ice in rapids. It may, however, refer to the later stages of the ice-run. In Finnish, the case of the noun is often conclusive. The nominative in the sentence 'jäät menevät' suggests that *the* ice is now floating away. Interpreting the sentence 'jäät huilaavat' is more difficult, as the verb refers to a non-violent but transitive movement: the event may be *the* break-up or the ice-run after the break-up. The partitive in the sentence 'jäitä huilaa' suggests that the culmination is over but some ice still keeps floating down.

A cryophenologist, sitting in his/her office in Helsinki, should not be ignorant of the dialects and the local variants of the language. In Northern Finland, the verb 'huilata' refers to being carried in a certain direction by something else, in this case by the water. In Southern Finland, the same term refers to rest. The ignorant cryophenologist may think that the progress of ice was stopped by an ice jam, while in reality there was a continuous ice-run.

4. *The conservation of historical information*

For the first 153 years of the time series, there are no institutionally organized observations. The records now available have been made by at least 12 voluntary observers. It is not unlikely that there have been others whose records have been lost and forgotten. It may, e.g., be asked whether the dates for the first 47 years, written down by the merchant Olof Brynielson Ahlbom, would have been conserved to our days, if Anders

Hellant had not used them in his own research. Hellant himself left his papers by will to the Royal Swedish Academy of Sciences, but there are relevant manuscripts by him in other archives as well.

The first institutionally organized record begins in 1846. The establishing of learned societies, public archives, national libraries and governmental research institutes have all contributed to the formation and conservation of these records. Some parts of the records are, however, not currently available as primary sources even if it is probable that they still exist. For instance, some years ago it would have been practically impossible to find certain relevant documents in the archives of the Finnish Meteorological Institute, as the material was unorganized. At the time of writing the catalogization is still not finished, but the documents are now available. Some of the documents have been deliberately destroyed, after extracting all (or some) information. Others might be unintentionally destroyed by fire, humidity or mould, or deteriorate as old acid paper does. They may also be thrown away, lost, or put in disorder by ignorant or careless staff. The archives of the Hydrological Office are currently endangered by the consequences of an old water damage, but the lack of funds, the reorganization of the environmental administration and the lack of executive rules for the archives have so far prevented the necessary actions.

5. The sources

The information content of a cryophenological statement is to a great extent determined by the conditions of recording. The sources can be classified according to the kind of statements the documents contain. A detailed discussion of the individual sources will be available in a separate volume (Kajander, 1994)

5.1. Simple data compilations

The simplest type of document is a list of break-up dates. The phase of the process may be mentioned in the heading, but in most cases the event is simply called 'break-up' (Finnish 'jäänlähtö', Swedish 'islossning' or 'isgång'). The site may be pointed out more or less accurately. These data compilations are secondary sources and may have lost relevant information that had been available in the original. Moreover, this form of presentation makes even the most heterogeneous records look homogeneous. These data compilations are, however, the only sources that are available for most of the first 150 years.

Hellant (1747) gives single dates for the years 1693-1714 and either periods or single dates for the years 1722-1747, while in the manuscripts (KB-X503h, Fol. 9, 10, 174) he gives single dates for the years 1693-1787, and in another manuscript source, reported by Johansson (1932), the dates for 1693-1770. The initial dates of the break-up periods for 1722-1747, reduced to the Gregorian calendar system, are identical with the single dates of the manuscript sources. This fact, as well as the use of the term 'isgång', suggest that the event is the beginning of the large-scale movement of ice. (Another source, the weather journal of Wegelius, confirms this interpretation, even if the dates are not identical.) The site is reported only as the town of Tornio.

Another simple data compilation of crucial importance is that of Johan Portin (RA-KSVA-MO/1a:57), covering the years 1792-1826. The table gives the date of break-up ('islossning') and, in the next column, a verbal comparative estimate of the water level during the break-up. Another manuscript in the same collection contains the dates for 1827-37. These dates are from Övertorneå (Matarengi), some 80 km upstream from Tornio, and should not be be taken as more than estimates of the break-up in Tornio. The averages for the few common years are, however, almost identical, and the dates from Övertorneå were used without corrections by Johansson (1932) and are used as such in this paper too.

Dates of the break-up in Tornio for the years 1769, 1801, 1816-1825 and 1841-1844 have been published by Moberg (1857 and 1894); they are also found in a secondary manuscript source (VA-SSF-Ddb1). The event is called 'islossning', the site is Tornio and the observers are known in most of the cases. Some of these dates must, however, be rejected. The dates for 1769 are identical with the dates reported by Mallet (1770) and it is plausible to believe that they have been taken from that paper. Mallet made his observations in Pello, some 125 km upstream from Tornio. The dates for 1819 and 1823 are far too early to refer to a large-scale movement of ice; they are either errors or refer to a local break-up in the Kuljunkorva rapids. Johansson (1932) rejects all these dates from Tornio in favour of the more reliable dates reported by Portin.

Several lists of break-up dates have been published in local newspapers during the last 100 years. In most cases, these lists confirm (or are originated by) some data available in another source. There are, however, some deviances, and in such cases the original source must be considered more reliable. For instance, the local newspaper *Haparanda-bladet* used to publish lists of break-up dates almost every year, together with a notice on the current year's recently occurred break-up. The break-up date for 1890 was given as 3rd May in the lists published in 1894, while in 1895 and in all the following versions it was changed to 8th May. Before 1905, the break-up dates for 1897,1898 and 1900 were given as 3rd, 13th and 24th May respectively, but in the 1905 version and all the subsequent versions they were given as 13th, 8th and 27th May respectively. In all these cases, the old dates are compatible with other records, while the new dates are not supported by any other sources. Nevertheless, instead of being detected and eliminated in the following editions, these misprints began to live their owns lives in the newspaper.

5.2. *Observation forms for break-up dates*

Printed booklets for phenological observations were distributed to voluntary observers by the Finnish Society of Sciences (Societas Scientiarum Fennica, SSF) during the years 1846-1894. These booklets devoted one page to break-up and other cryophenological observations. Below the printed text there was a space of 3 cm, in which the name of the watercourse and the date or the dates should be written. The printed text was simply 'islossning' or 'jäänlähtö' (break-up), and the observers were not asked to specify the event, but some of them did that. Booklets from Tornio were received in the years 1846-1855, 1866 and 1881-1894. The observations for 1846-1855 were published in a separate volume (Moberg 1871) and the observations for 1862-1894 in the yearbooks of SSF (ÖFVS 1862-1894). The original booklets are preserved in the Finnish State Archives (VA-SSF-Eb1...Eb19). In 1895, the phenological observations were reorganized and the cryophenological part was discontinued.

The Central Meteorological Institute, also run by the Finnish Society of Science, began to distribute forms for snow and ice observations in 1890. The form, of which there are several versions, contained a one-row space for break-up observations, with the printed text 'islossning'. The observations for the years 1890-1909 were published as yearbooks (for the different types, see Heinrichs (1894), Heinrichs (1904) and Korhonen (1912), or any of the yearbooks with the same titles). Information on the phase of the process is seldom available. Many of the records of the phenological observers, among them one from Tornio and two others from the river system, were continued in this monitoring program. In 1910, the network was reorganized. No documents from Tornio are currently available among the organized material from the more recent periods.

The Hydrological Office reorganized its cryophenological observations in the early 1970's. An observation form, with fields for the dates of 4 different phases of the break-up, were to be filled by all water level observers. The form was more suitable for observing lake ice break-up, but it was used for rivers as well. In 1991, a new form, requesting different dates for lakes and rivers, was introduced. The fields for these events in rivers are shown in Table 1.

Table 1. Requested break-up events in the Hydrological Office break-up form (translations).

code	1973 version	1991 version
a0		Open water in rapids
a1	Thawing of shores	Thawing of shores
a2	Open water further off	
a4	Ice is moving	Ice begins to move
a5		Ice is generally moving (the break-up)
a6		Ice-run after the break-up
a8	No ice within sight	Ice-run has ceased

The new version gives somewhat more accurate information on the course of events than the old one. The difference between the dates a4 and a5 will probably be a good indicator of the inaccuracy of the earlier observations. As for the other requested phases of the process, a1 is ambiguous and of little relevance for a streamy river site like Tornio. The items a0 and a2 can be considered referring to the opening of Kuljunkorva.The meaning of a6 is obvious, but the intensity variations of ice-run are missed. Finally, the old a8 was sometimes misunderstood as referring to the removal of the last pieces of the local ice cover. The time difference between this event and the intended situation could easily be more than one week. The new a8 is still ambiguous, as the observer must decide whether the last small pieces of ice should be waited for or not. The ambiguities could be removed by asking the dates of locally well-defined phenomena such as the opening of Kuljunkorva, the passing of the float and the passing of the ice from "the Lake". This kind of more accurate monitoring would be applicable to a few stations, but not to the national network. To construct and use individual forms for each of the more than 400 cryophenological stations would be far too arduous.

5.3. The break-up guessing competitions

Attemps to guess when the ice breaks up are probably almost as old as the settlement in the Tornio River valley. There are many documents in old newspapers on such speculations. In the late 1950's, the newly established Lions Clubs in Tornio and Haparanda began to arrange break-up date guessing competitions that immediately became great local institutions with several thousands of participants. The price of a guessing coupon has been 5 marks or 10 crowns during the last years. The time - date, hour and minute - are filled in, and the coupon is returned to a certain place before 1st May. The three best guesses win a price, e. g. a bicycle, while the income is used for some charity purpose. There are several other similar guessing competitions arranged by various organizations, e. g. guessing the temperature minimum of the winter, the arrival time of the first ship at the harbour, the highest water level in spring etc. In Tornio, the break-up guessing is much more popular than any of the others.

It is not enough to have only the date or the hour guessed to find a winner among several thousands of participants, Accordingly, the river must be observed continuously during the critical season. This is done voluntarily by the members of the club, and at least during the daytime there may be a great crowd of other people watching as well. Any uncertainty of the time would immediately raise objections. To avoid the scandal, the observers must have well-calibrated clocks, and, what is more, the event must be exactly defined. In Tornio, as well as in Haparanda, the break-up time is defined as the moment when a float, built and left on the ice some weeks earlier, passes a certain line.

The passing of the float corresponds quite well to the event traditionally reported as break-up. Catching the time of the event with an accuracy of one minut is a great benefit

- even the accuracy of one hour would be enough for scientific purposes, but to settle the competition, the minutes are needed. The time, as well as the names of the winners and their guesses are announced in the local advertisement newspapers and often in other newspapers as well.

The break-up guessing institution is most likely to survive in places like Tornio, Haparanda and Övertorneå. With a sufficient population basis, it is possible to get a profit large enough to motivate a break-up watch around the clock. There have been similar break-up guessing competitions in several smaller villages, arranged either by Lions Clubs or by other organizations like athletic clubs or boy scouts, but many of them have been short-lived.

5.4. Daily ice observations

Weather journals and other similar documents of daily observations often have remarks on ice conditions and other events not belonging to the observation program. For Tornio, the oldest conserved document of this kind is the manuscript "Observationes Meteorologicæ Tornenses 1737-49", now in Uppsala University Library. This weather journal, written in Latin, contains quantitative observations of air pressure, temperature, and the direction and magnitude of wind, as well as qualitative remarks on the weather. The observations were usually made twice or thrice a day, somewhat irregularly. There is no separate column for cryophenological or phenological observations. Some short cryophenological remarks have been written in the margins, but not regularly or according to any regular scheme. It is plausible to assume, that the observer was aware of other efforts to record the break-ups and was not very concerned about making his own version. Johansson (1932), following a remark written by a later hand on the titel page of the weather journal, identified the observer as the Rev. A. Fougt, but another remark, points out the schoolmaster Johan Wegelius as the observer (see Kajander, 1994a). In any case, these observations are independent of those by Olof Ahlbom and Anders Hellant. In 3 cases out of 8, there is a difference between the dates of the two records.

Among the manuscripts of Johan Portin, there are also weather journals with daily remarks on phenological and cryophenological events. As usual, their information content is more sophisticated than the simple compilations would suggest. The same collection contains two weather journals of much shorter duration from Tornio (RA-KSVA-MO/1a54-1a55), both with some phenological and cryophenological remarks.

The Finnish Society of Science started to organize a network of climatological stations in 1846. There already was a barometer-thermometer station in Tornio at the beginning, but only the journals for 1865-1879 are currently available (HY-ML). In the observation book, there was a column for remarks. The beginning of the movement of ice has always been reported, while the dates of other events have been written down less regularly.

Still more important was the climatological station in Haparanda, only 2 km away from the one in Tornio. This station was established in 1859 and is still in function. Remarks on ice for the years 1859-1956 have been extracted from observation journals in 1950's. This compilation of verbal data, existing as a manuscript at the Swedish Meteorological and Hydrological Institute, can be used as such. The ortography of the statements is modernized, and some less important remarks are omitted, but in general the information is preserved. The compilation also contains ice observations from winter road traffic reports and the papers of the log-driving association.

The observations at water level stations are the bulk of many cryophenological time series. In Tornio, their role is also important, but only in periods. The Tornio water level station was established in 1896, but it was discontinued already in 1920, probably because the observations could not be used for calculating runoff. During the years 1937-42 and since 1960 there have again been water level observations, and the gauge has recently been evaluated as useful for flood protection purposes. As a less important station, it has escaped the disaster of automatization. The observer of an ordinary gauge visits the site every morning and the ice observations can be made at the same interval. During the time the station has existed, water level observers have been expected to give some kind of report on the ice break-up. The information in water level observation forms consist of short sentences similar to those in early weather observation books. During the three last decades the observer has, however, primarily used the cryophenological forms to report ice phenomena.

Another type of source of daily observations are the almanacs of private persons. Separate notebooks may sometimes be used for writing down remarks on natural phenomena, but using almanacs is more common among the non-organized observers. The space for writing is even smaller than in water level forms or weather books, and the sentences must accordingly be short. The non-organized observations are not bound to any official scheme and may contain valuable additional information. For instance, one observer has often written down the date of the major ice-run from "the Lake", one of the important events not included in the official scheme. - Many of the almanacs containing this kind of data have probably been thrown away by ignorant heirs.

5.5. *Daily cryophenological reports*

As a by-product of other observations, cryophenological remarks are not found on every row in the observation form. It is plausible to assume that some potentially valuable information has been lost as being considered irrelevant by the observer. This loss of information is to some extent avoided, if the observer has to write down something about the ice on every row. This is the case with the special observation forms used for 4 river ice stations at Tornio River in the years 1960-83. Unfortunately, this part of the ice monitoring program was discontinued in a minor reform of ice thickness observations.

Moreover, a considerable part of the break-up processes of this period is not covered by the data, which is probably due to the loss of the original forms.

These forms also contain daily quantitative estimates of the portions of solid ice cover, floating ice and open water surface, given with an accuracy of 10 % ("magnitude 0 to 10").

5.6. *Newspapers*

The most comprehensive descriptions of break-up are found in newspapers, for several reasons. The space is not limited to one row only, the language is often more diversified, and the attention is focused on events of general interest. This is, of course, only true about places like Tornio, with much settlement and potential informants or even local journalists, and with spectacular break-ups. The information consists of one or several sentences, and even the single sentences are almost always longer and more comprehensive than those in the observation journals. On the other hand, the newspaper material is less standardized with respect to the phase of the process as well as the site. It also occurs less regularly, and there are great differences between the various years. Dramatic and disastrous break-ups are more thoroughly reported than quiet and gradual ones. The cryophenologically relevant information can also be drowned in the flood of flood disaster news.

In this study, the newspaper material was systematically collected from the most important local and regional newspapers (*Haparandabladet* 1882-, *Pohjolan Sanomat* 1915-, *Tornion Lehti* 1905-26, and several short-lived ones). For practical reasons, the bulk of the material was chosen from the material available as microfilms at the Helsinki University Library. Together with samples from other newspapers, there were almost 300 microfilms. Searching through a microfilm usually takes 30 to 90 minutes, depending on the condition of the films and the reading and copying devices - at least one order of magnitude more than extracting the relevant information from a water level form. Reading of all the relevant newspapers can hardly be recommended as a routine for constructors of cryophenological time series. In this study, however, the intention was also to investigate the regularity of occurrence of cryophenologically relevant information, the historical development of reporting cryophenological events and the linguistic structure of the reports. Moreover, the newspaper material has been an indispensable source for the period 1921-1959 with very few organized observations. In this case the use of an extensive newspaper material can be motivated by the unusual length of the time series.

Since 1882 there has been at least one local newspaper in Tornio or Haparanda. Before this, newspapers in other parts of Finland and Sweden occasionally wrote about break-ups in the Tornio River. For the time before 1891, there is a cartotheque of headlines in Finnish newspapers at the Helsinki University Library. There are some 1500 cards under the keyword 'snow and ice', of which 15 are concerned with the break-up in Tornio. The break-up in Tornio was - and is - reported only accidentally by the newspapers in Southern Finland.

In later material, the reporting is dominated by the interests of sufficiently large groups of readers rather than the availability of information services. As for daily regional newspapers, break-ups in Tornio are more thoroughly reported in *Pohjolan Sanomat* than in *Lapin Kansa* or *Kaleva.* The explanation is obvious: *Pohjolan Sanomat* is published in Kemi, 20 km from Tornio, and has a coverage of more than 90 % in the Kemi-Tornio region. *Lapin Kansa,* published in Rovaniemi (105 km from Tornio), is the leading newspaper in large parts of Lapland, and *Kaleva,* published in Oulu (115 km from Tornio), is the market leader of its own area and the leading newspaper of Northern Finland as a whole, but both of them have a coverage of about 20 % in the Kemi-Tornio region. Even *Helsingin Sanomat,* the leading national newspaper, has a coverage of about 20 %, but it is certainly not subscribed to because of its reporting of any kinds of events in Tornio. The weekly local newspaper in Tornio is owned by *Pohjolan Sanomat* and doesn't even attempt to report daily events. *Tornion lehti* and the other old local newspapers used to be good sources.

The pattern is somewhat different on the Swedish side. The local twice-weekly newspaper *Haparandabladet* is a good source of cryophenological information. The leading regional newspapers *Norrländska Socialdemokraten* and *Norrbottenskuriren,* both published in Luleå (90 km from Tornio), are also relevant as sources, but they fail more often than *Haparandabladet* to report on the routine of break-ups in Haparanda.

5.7. *Ice maps*

Between 1969-1979, 76 maps on the ice situation were drawn by the observer of Tornio water level and ice station. They describe the occurrence of open water in the town area during the freezing period and the early phases of the break-up period. The growing of the open water surface at the Kuljunkorva rapids can be followed in the sequences of maps. For the spring 1973 there are no less than 10 maps, and for 6 springs more than one map.

5.8. *Substitute values*

For 41 of the 301 years, no dates from the Tornio-Haparanda area have been available. As mentioned before, the dates reported from Övertorneå by Johan Portin are suitable substitutes as such, and some of them (not, however, all of them), as in Johansson (1932)) are preferred to suspected dates from Tornio. It should be noticed that Johansson used a compilation made by Portin himself, instead of the original weather journal. This compilation is, however, heterogeneous with regard to the site: some of the dates refer to the main channel, while others refer to a minor channel. The date for 1838, mentioned by

Johansson (1932) as being a substitute value from Kemi, is actually from Alkkula, 65 km upstream, and is accepted as such. For 1845, Johansson used the date from Kemi without correction. For the 6 other years for which Johansson used corrected or uncorrected substitute dates from other rivers (Kemijoki and Oulujoki), a date from Tornio has been found.

Table 2. Correlation of the break-up record from Tornio with other similar records supposed to be useful in reconstructing missing values. For the five most distant records, a common period of 44 years (1742-1787, 2 missing years) is used. For the important substitute record from Matarengi, recent records are used instead of the few common years from early 19th century.

River	Locality	Coord.	Dist. km	F km^2	CC	n	Risk level % 0.1	1	5
Tornionjoki (Torne älv)	Haparanda	65°50'N 24°09'E	1	40 130	0.973	35	+	+	+
Tornionjoki (Torne älv)	Alkkula (Ylitornio)	66°19'N 23°41'E	65	38 900	0.905	20	+	+	+
Tornionjoki (Torne älv)	Matarengi (Övertorneå)	66°23'N 23°40'E	80	35 130	0.851	35	+	+	+
Muonionjoki (Muonio älv)	Enontekiö (Markkina)	68°24'N 22°18'E	305	4 880	0.639	21	-	+	+
Kemijoki	Keminmaa	65°49'N 24°34'E	20	51 100	0.632	50	+	+	+
Kyrönjoki (Kyro älv)	Isokyrö (Storkyro)	63°01'N 22°18'E	320	4 338	0.586	44	+	+	+
Dvina (Sev. Dvina)	Archangelsk	64°33'N 40°32'E	830	365 000	0.438	44	-	+	+
Neva	St. Petersburg	59°56'N 30°16'E	760	282 300	0.378	44	-	-	+
Aurajoki (Aura å)	Turku (Åbo)	60°27'N 22°17'E	640	874	0.408	44	-	+	+
Daugava (Düna)	Riga	56°57'N 24°06'E	1010	85 400	0.171	44	-	-	-

Unable to find any records from Tornio or its neighbourhood for the two decades 1771-1790, Johansson left a gap in his version of the time series. The Kungliga Biblioteket collection of the Hellant manuscripts (KB-X503h) contains, however, dates up to 1787. For the remaining 3 years, somewhat satisfying substitute values can be obtained by using some of the few records from more distant rivers. Of the records examined, only the one from Riga proved to be too far away in the South to display correlation of any significance (table 3). In this paper, the dates for the years 1788-1790 are obtained by using the dates from two much smaller rivers, Muonio River at Markkina (305 km North of Tornio) and Kyro River at Isokyrö (320 km South from Tornio), corrected by a constant:

$$d_T = \frac{1}{2}[(d_K + \langle d_T - d_K \rangle) + (d_M + \langle d_T - d_M \rangle)] \quad (1)$$

Using two or several stations in different directions reduces the risk of obtaining bad substitutes. The distances are long enough to allow large regional differences in weather as well as radical changes in weather patterns during the progress of the spring. As for documentation errors, the scarcity of records does not allow an effective quality control. E.g., the break-up in Kyro River occurred according to the records as early as 3rd April in both 1776 and 1779. Using Kyro River only the break-up estimate for Tornio would be as early as 24th April - an absolute extreme in the whole time series. Of the two dates from Kyro River, the latter is supported by records from Turku and Riga, while the former is more likely to be erroneous. For 1779, the real date from Tornio is 14th May and the difference between the observed date and the simple estimate is no less than 20 days. An estimate using both Muonio River and Kyro River is not available, but using River Dvina together with Kyro River would give 4th May, a much better estimate.

6. *Principles of selecting the values for the time series*

For most purposes it is sufficient to give the value of break-up time variables as dates. Such a coarse quantification entails that the values of a well-defined variable are either correct or erroneous, instead of being more or less accurate. Most values are, however, correct with respect to the observed variable. The principal problem is that of identifying the events and knowing or guessing whether a value belongs or at least corresponds to the variable that is chosen for the time series.

If only one value is available, there is only the choice of accepting or rejecting it. This case is easy but undesirable. In an ideal case, there are several sources and all of them give the same date. In many cases, however, a choice must be made between two or several reported dates. In these cases, a consensus of several sources is preferred to a dissenting date, if there are not special reasons to think otherwise. Detailed sources are considered more reliable than simple data compilations. A date from Haparanda is used as such if nothing else is available, but a date from Tornio is generally preferred. In many cases the choice must be more or less arbitrary. It should be emphasized that a simple version of the time series like that of table 3 is only one of numerous alternatives. A discussion about the individual cases, when necessary, will be found elsewhere (Kajander, 1994).

7. *Some remarks on the time series*

The main purpose of this paper is to discuss the process of construction and homogenization of river ice break-up time series, and a complete statistical analysis would be beyond the scope. To motivate further research, some features are, however, pointed out.

The traditional Finnish method of cryophenology, already applied by Hällström (1839, 1840, 1841) and Eklöf (1849), the method of least square sums or the regression analysis, is still useful. In our case, it confirms the visual impression (Fig. 3) of an unusually strong trend. The break-up now occurs now on an average 13 days earlier than in late 17th century.The correlation is significant on the risk level 0.1 % (R = 0.48 for the complete series of 301 years). The trend is easily explained by the fact that the records happen to begin during the coldest years of the Maunder minimum, affectionally known as "the Little Ice Age".

The homogeneity of the time series in any other respect than as a climatological factor can be questioned in many ways. The uncertainty of event and site are discussed above, and they are, after all, found to be small compared with many other sites with long records. Environmental changes, both in the catchment and in the channel, may have been more important.

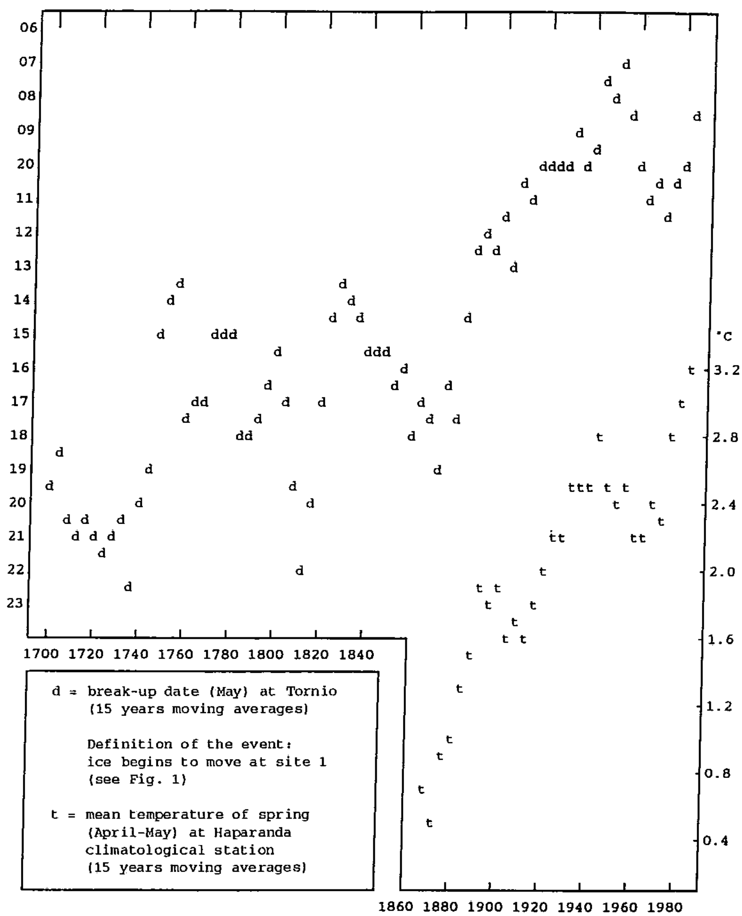

Fig. 3. The time series of break-up date and spring mean temperature at Tornio-Haparanda (15 years moving averages).

Table 3. Dates of ice break-up in Tornio river at downtown Tornio (area 1 in Fig. 1). For the last 32 years, the dates reported by the water level station observer, referring to the beginning of the movement of ice, are chosen instead of dates referring to the passing of the Lions Club float (see Tab. 4). The mean difference between these dates is 0.6 days. For information on choices for each of the 301 years, see Kajander (1994).

Year	Date	Year	Date	Year	Date	Year	Date	Year	Date	Year	Date
1693	20.5	1744	9.5	1795	24.5	1846	21.5	1897	3.5	1948	1.5
1694	15.5	1745	14.5	1796	15.5	1847	22.5	1898	13.5	1949	4.5
1695	5.6	1746	20.5	1797	18.5	1848	5.5	1899	27.5	1950	28.4
1696	26.5	1747	20.5	1798	10.5	1849	20.5	1900	24.5	1951	10.5
1697	26.5	1748	18.5	1799	15.5	1850	15.5	1901	11.5	1952	6.5
1698	9.5	1749	18.5	1800	21.5	1851	19.5	1902	19.5	1953	1.5
1699	22.5	1750	2.5	1801	9.5	1852	15.5	1903	13.5	1954	9.5
1700	7.5	1751	5.5	1802	23.5	1853	15.5	1904	1.5	1955	18.5
1701	30.5	1752	6.5	1803	3.5	1854	13.5	1905	8.5	1956	14.5
1702	20.5	1753	17.5	1804	4.5	1855	16.5	1906	6.5	1957	13.5
1703	7.5	1754	7.5	1805	15.5	1856	21.5	1907	9.5	1958	20.5
1704	20.5	1755	17.5	1806	14.5	1857	15.5	1908	17.5	1959	3.5
1705	1.6	1756	27.5	1807	2.6	1858	11.5	1909	26.5	1960	4.5
1706	11.5	1757	1.5	1808	21.5	1859	21.5	1910	5.5	1961	14.5
1707	14.5	1758	16.5	1809	17.5	1860	12.5	1911	8.5	1962	8.5
1708	28.5	1759	20.5	1810	3.6	1861	23.5	1912	11.5	1963	7.5
1709	17.5	1760	21.5	1811	22.5	1862	13.5	1913	4.5	1964	11.5
1710	23.5	1761	12.5	1812	24.5	1863	12.5	1914	7.5	1965	4.5
1711	14.5	1762	14.5	1813	22.5	1864	16.5	1915	9.5	1966	16.5
1712	16.5	1763	22.5	1814	28.5	1865	16.5	1916	9.5	1967	12.5
1713	30.5	1764	26.5	1815	17.5	1866	25.5	1917	22.5	1968	17.5
1714	27.5	1765	25.5	1816	27.5	1867	9.6	1918	14.5	1969	15.5
1715	17.5	1766	19.5	1817	19.5	1868	11.5	1919	10.5	1970	11.5
1716	16.5	1767	18.5	1818	15.5	1869	15.5	1920	6.5	1971	13.5
1717	20.5	1768	17.5	1819	18.5	1870	5.5	1921	27.4	1972	7.5
1718	29.5	1769	22.5	1820	20.5	1871	21.5	1922	7.5	1973	13.5
1719	20.5	1770	2.5	1821	11.5	1872	9.5	1923	20.5	1974	7.5
1720	14.5	1771	20.5	1822	4.5	1873	18.5	1924	14.5	1975	6.5
1721	24.5	1772	27.5	1823	23.5	1874	20.5	1925	9.5	1976	10.5
1722	26.5	1773	1.5	1824	12.5	1875	14.5	1926	12.5	1977	15.5
1723	16.5	1774	5.5	1825	15.5	1876	24.5	1927	18.5	1978	16.5
1724	25.5	1775	24.5	1826	11.5	1877	14.5	1928	7.5	1979	11.5
1725	19.5	1776	17.5	1827	12.5	1878	20.5	1929	17.5	1980	3.5
1726	13.5	1777	9.5	1828	8.5	1879	24.5	1930	5.5	1981	15.5
1727	16.5	1778	7.5	1829	11.5	1880	10.5	1931	5.5	1982	8.5
1728	28.5	1779	14.5	1830	20.5	1881	24.5	1932	10.5	1983	29.4
1729	25.5	1780	26.5	1831	16.5	1882	10.5	1933	10.5	1984	2.5
1730	13.5	1781	18.5	1832	4.5	1883	10.5	1934	8.5	1985	16.5
1731	1.6	1782	17.5	1833	13.5	1884	24.5	1935	20.5	1986	3.5
1732	25.5	1783	17.5	1834	13.5	1885	21.5	1936	5.5	1987	13.5
1733	23.5	1784	16.5	1835	27.5	1886	11.5	1937	27.4	1988	8.5
1734	18.5	1785	23.5	1836	10.5	1887	9.5	1938	6.5	1989	30.4
1735	13.5	1786	21.5	1837	3.5	1888	17.5	1939	15.5	1990	29.4
1736	11.5	1787	17.5	1838	19.5	1889	9.5	1940	10.5	1991	1.5
1737	21.5	1788	19.5	1839	14.5	1890	3.5	1941	20.5	1992	8.5
1738	26.5	1789	18.5	1840	9.5	1891	14.5	1942	17.5	1993	6.5
1739	27.5	1790	20.5	1841	8.5	1892	17.5	1943	7.5		
1740	1.6	1791	24.5	1842	12.5	1893	15.5	1944	16.5		
1741	25.5	1792	14.5	1843	23.5	1894	30.4	1945	3.5		
1742	28.5	1793	8.5	1844	8.5	1895	6.5	1946	5.5		
1743	18.5	1794	12.5	1845	21.5	1896	12.5	1947	4.5		

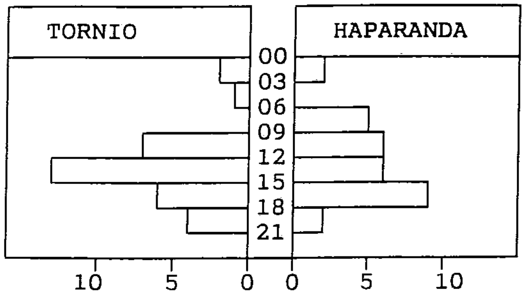

Fig. 4. Hourly distribution of "break-up times" (passing of the Lions-Club floats) at Tornio and Haparanda, in groups of 3 hours.

The most long-known (see e.g. Gadd & Kekonius, 1786) and most often mentioned of these environmental changes are the clear-cuts and the bog drainages. It is obvious that they have speeded up the snowmelt, runoff and breakup processes, but the available data is insufficient for quantitave estimates. We can assume, that the effect of these two activities has been strongest during the last five decades, with a culmination in the 1950's and the 1960's. Agricultural clearing and draining, as well as tar production and timber cutting have been practised throughout the entire period (Åström, 1978).

The floating constructions have been mentioned as an important factor affecting the break-up and spring flood (Zachrisson, 1988, 1989). Most of the floating dams were removed when the floating ceased in the early 1970's. As a result, the runoff has been speeded up. The effect is strongest immediately below the former dams, in the upper parts of the river system.

The regulating effect of "the Lake" (Karunginjärvi) may in fact cut off most of the effect of the changes in the catchment. This idea is supported by the results of the guessing competitions (Tab. 4 and Fig. 4). In Tornio, the break-up occurred during the afternoon (noon to 6 P.M.) in 19 of the 32 cases. In Haparanda, break-ups during the daytime also dominate, but they are not to such an extent concentrated to the afternoon hours.

On the other hand, changes in the river channel have had the opposite effect. In Tornio, the most important channel changes have been caused by bridges: the railway bridge constructed in the 1910's, the old highway bridge from the 1930s and the new highway bridge from the 1970s. According to local thumb estimates, the break-up between Haparanda town and Alatornio church has been delayed by up to 2 days by the railway bridge, and the break-up between the two highway bridges in Tornio would have been retarded by up to 4 days by the new bridge. The results of the break-up guessing competitions suggest, however, that at least the latter effect is exaggerated. The Haparanda float usually passes its goal line somewhat earlier than its counterpart in Tornio. Before the construction of the new bridge, the average time difference was 0.5 days and after the construction 1.5 days, only 1 day more (see table 4) The *maximum* time difference is actually 4 days, which has occurred thrice since 1958, once before and twice after the construction of the bridge.

Table 4. Data produced by break-up guessing time competitions. In 1983, 1989 and 1990, the float passed the line already in April, before the deadline of leaving the coupons had run out and any watch was organized. In these cases, only the dates are available. In 1965 and 1978, the Haparanda float was went under the ice and disappeared before it passed the line.

	Tornio		**Haparanda**			**Tornio**		**Haparanda**	
Year	Date	Time	Date	Time	Year	Date	Time	Date	Time
1958	20.5	14.30	16.5	14.21	1976	10.5	15.30	10.5	09.17
1959	03.5	18.51	03.5	17.38	1977	15.5	13.58	15.5	08.37
1960	04.5	11.52	03.5	17.29	1978	16.5	19.38	15.5	---
1961	14.5	12.04	14.5	11.04	1979	11.5	20.17	10.5	15.19
1962	08.5	13.36	06.5	00.58	1980	05.5	10.54	03.5	19.57
1963	07.5	11.15	05.5	13.01	1981	15.5	15.42	15.5	02.17
1964	11.5	12.53	11.5	10.25	1982	08.5	16.50	07.5	12.28
1965	04.5	11.44	01.5	----	1983	30.4	----	29.4	----
1966	17.5	14.12	16.5	----	1984	06.5	13.00	05.5	15.32
1967	12.5	16.59	11.5	07.59	1985	17.5	01.43	13.5	19.19
1968	12.5	12.38	14.5	12.31	1986	07.5	19.49	07.5	08.08
1969	16.5	15.11	16.5	14.15	1987	13.5	14.41	09.5	17.24
1970	12.5	04.40	12.5	10.08	1988	08.5	18.08	08.5	07.24
1971	13.5	17.04	14.5	15.16	1989	30.4	----	29.4	----
1972	07.5	11.00	06.5	17.05	1990	29.4	----	27.4	----
1973	13.5	02.47	13.5	10.24	1991	05.5	14.56	03.5	07.14
1974	07.5	13.27	07.5	15.33	1992	08.5	11.37	07.5	16.54
1975	06.5	12.16	05.5	16.44	1993	06.5	11.47	05.5	14.24

A serious challenge to the homogeneity of our time series is the fact that the sea ice may have delayed the movement of river ice during the 18th and 19th centuries. The difference between the mean water levels in the sea and at Tornio water level station is only 0.8 m. The land uplift rate in the Tornio area is about 0.8 cm/a. If hydraulic changes are neglected, Tornio would still have been at the sea level in the late 19th century. There are, however, documents proving that the Kristineberginkorva rapids had already existed for decades in the 1860's. Even the earliest documents use the word 'river' instead of referring to estuary-like conditions. Considering the topography of the town area and the size of the river and its catchment, it is not probable that the sea ice would have had any significant effect except during low-water break-ups. Land uplift may have affected the time series, but the principal explanation of the trend is still climatological.

The Tornio-Haparanda region also happens to have a long continuous air temperature record. The break-up dates have a persuasive correlation with the mean temperatures of April and May (R = 0.76 for both cases). Accordingly, break-up time series can be used to reconstruct spring temperatures. For instance, the mean temperatures of April and May would be

$$T_4 = (0.89 - 0.1777d)°C \qquad (2)$$

$$T_5 = (5.81 - 0.0625d)°C \qquad (3)$$

where d is the break-up date counted from the beginning of May (30th April = 0). The correlations between the break-up dates and other monthly mean temperatures are much weaker, but the coefficient of correlation is still significant at the risk level of 0.1 % for February, March and June. If months are lumped together to seasons, the estimates for winter (December to March) and spring (April and May) temperatures are

$$T_w = (-7.86 - 0.159d)°C \quad (R = 0.44) \qquad (4)$$

$$T_s = (4.09 - 0.1833d)°C \quad (R = 0.85) \qquad (5)$$

These simple models cannot cope with irregularities caused by extreme discharge or precipitation conditions. These are, however, of minor importance compared with changes in weather pattern: e. g., the 10 largest discrepancies between the observed and the estimated spring temperatures ($1.5° \leq |\Delta T_s| \leq 2.1°$) are all cases with extreme temperatures either in early April or in late May. Estimates for some other periods than those consisting of entire calendar months would certainly be more accurate.

For the reverse purpose, reconstructing break-up dates from temperature records, it is best to use individually constructed temperature variables. In fact, a simple break-up forecasting model using degree-day factor has been in operative use in connection with the runoff model for Tornio River (Vehviläinen et al., 1988).

8. *Concluding remarks*

The time series from Tornio is not a typical one. It is unusually long and the abundance of sources of information is also rare. On the other hand, a large portion of the time series could not have been constructed without the time-consuming use of newspapers. As an observation site, Tornio is affected by environmental changes in catchment and channel, but not to such a fatal extent as the corresponding sites in some neighbouring rivers. The possibility of a retarding effect of sea ice in the early parts of the period cannot be excluded, but its effect is not crucial. The homogeneity with respect to site and the event is good.

Using several sources requires more work, but as a reward it gives a more homogeneous time series. Severe errors have been detected in previously used versions of the time series. The accuracy of the respective values can also be estimated.

The strong trend of the time series is compatible with the general features of the climatic history of Northern Europe during the last 300 years. The time series also correlates with time series of spring and winter temperatures, a result that makes it possible to contribute to the knowledge of the climate in the early late preindustrial and early industrial periods.

References

1. *Manuscripts*

HY-ML-SSF: University of Helsinki, Department of Meteorology, the SSF observation books. Not organized.

HYT-J: Hydrological Office (Water and Environmental Research Institute, Helsinki), ice maps. organized according to the water level station number and time.

HYT-JL: ibid., "Jäänlähtö" (ice break-up). Organized according to year and station number.

HYT-JT: ibid., "Jäätilanne" (ice situation). Organized according to water level station number and time.

HYT-W: ibid., monthly water level reports. Organized into units of 4 to 6 years, with a running number given in station number order, for cohorts of 8 to 30 years.

IL-LJ: Meteorological Institute (Ilmatieteen laitos, Helsinki), "Lumi ja jää" (snow and ice). Organized according to winters.

KB-X503h: Kungliga biblioteket (Royal Library of Sweden, Stockholm), Department of manuscripts, unit X 503 h, "Anders Hellant: Strödda Anteckningar och Samlingar öfver Meteorologiska Observationer, Väderleksförändringar m.m.". 1 volume, bound.

RA-KSVA-MO: Riksarkivet (State Archives of Sweden, Stockholm), archives of the Royal Swedish Academy of Science, meteorological observations. Organized according to area. Units 1a54-1a58.

SMHI-IE: Swedish Meteorological and Hydrological Institute (Norrköping), Isexcerpt. Organized according to a station code.

UUB-OMT: Uppsala University Library, Department of manuscripts, Observationes Meteorologicæ Tornenses 1737-49. One volume, bound.

VA-SSF-SaKA: Valtionarkisto (State Archives of Finland, Helsinki), archives of Societas Scientiarum Fennica, collection "Meteorologiska iakttagelser", unit Ddb1 (not organized), bound volume "Samling af Klimatologiska Anteckningar"

VA-SSF/Eb: ibid., collection "Klimatologiska iakttagelser", units Eb1-Eb19, organized according to years.

2. *Printed sources and research literature*

Eklöf, J. H., 1849: Jäänlähtö-aiaat Kokemäen virrassa vuosina 1801-1849, todenvaihe-laskulla... *Suomi,* 189-195.

Gadd, P.A. and Kekonius, N.J., 1786: Undersökning, om orsakerne till flodvatnets öfversvämningar i Finland. (dissertation, Academia Aboënsis). Åbo.

Heinrichs, A., 1894: Snö- och isförhållandena i Finland år 1891. Bidrag till kännedom af Finlands natur och folk. H. 54. Helsingfors. (Similar title for the years 1890 and 1892).

Heinrichs, A., 1904: Etat des glaces et des neiges en Finlande pendant l'hiver 1892-1893. Kuopio. (Similar title for the years 1893-1898)

Hellant, A., 1747: Almanach för Skott-Åhret, efter Christi födelse, 1748. Til Torne Horizont... Hwarjemte bifogas... Anmärkning. öfwer tiden af Is-gången uti Torne Elf..., Stockholm.

Hussi, M., 1993: Jokien jäänlähtösanaston lingvistisistä kuvausmenetelmistä. *XVI Geofysiikan päivät/kaukokartoituksen päivät*, 153-158, Helsinki.

Hussi, M. 1994: Zur semantischen Analyse der Ausdrücke für Eisaufbruch in Flüssen im Finnischen, Deutschen und Schwedischen. Licenciate Thesis (unprinted), University of Helsinki, department of German philology (in preparation).

Hällström, G. G., 1839: Specimina mutanti currente seculo temporis, quo glacies fluminum annuæ dissolutæ sunt, *Acta Societatis Scientiarum Fennica*, I, 129-148. Helsingfors.

Hällström, G. G., 1840: De tempore regelationis et congelationis aquarum fluminis Kyro. *Acta Societatis Scientiarum Fennica*, I, 387-394. Helsingfors.

Hällström, G. G., 1841: Calculus observationum, quibus tempora regelationis et congelationis aquarum fluminis Dwinæ determinantur. *Bulletin Scientifique publié par l'Académie Impériale des sciences de Saint-Pétersbourg*, VIII, 289-298, St. Petersbourg.

Johansson, O. V., 1932: Isförhållandena vid Uleåborg och i Torne älv. *Bidrag till kännedom af Finlands natur och folk*, H. 84, n:o 3, Helsingfors 1932.

Kajander, J., 1990: Semantiska problem i kryofenologin. *Nordisk hydrologisk konferens 1990*, 371-380, Kalmar.

Kajander, J., 1993a: Tornionlaakson kryofenologian kolme vuosisataa. *XVI Geofysiikan päivät/kaukokartoituksen päivät*, 123-128, Helsinki.

Kajander, J., 1994: Cryophenological records from Tornio. Vesi- ja ympäristöhallituksen monistesarja, nr. 552, Helsinki (in preparation).

Korhonen, W. W., 1912: Schnee- und Eisverhältnisse in Finland im Winter 1898-1899. Helsinki. (Similar title for the years 1899-1909)

Mallet, F., 1770: Om Is-gången och Vår-Floden uti Torne Älf, år 1769, *Kongl. S. Vet. Ac. Handl. 1770, Vol. 31, 249-254.*

Moberg, A., 1857: Naturalhistoriska daganteckningar. *Notiser ur Sällskapets pro fauna et flora fennica förhandlingar, Bihang till Acta Societatis Scientiarum Fennica*, 3, Helsingfors.

Moberg, A., 1871: Klimatologiska iakttagelser i Finland, första delen, II. *Bidrag till kännedom af Finlands natur och folk*, 18, Helsingfors.

Moberg, A., 1894: Fenologiska iakttagelser 1750-1845. *Bidrag till kännedom af Finlands natur och folk*, H. 55, Helsingfors.

Vehviläinen, B., J. Forsius, G. Zachrisson and M. Häggström, 1988: Transboundary co-operation on flood forecasting and ice control in the river Torneälven/Tornionjoki. *Nordisk hydrologisk konferens 1988*, I, 53-62.

Zachrisson, G., 1988: Svåra islossningar i Torneälven i relation tll klimat- och miljöförändringar. *Nordisk hydrologisk konferens 1988*, I, 33-42, Rovaniemi.

Zachrisson, G., 1989: Climate variations and ice conditions in the River Torneälven. *Conference on Climate and Water (The Publications of the Academy of Finland 9/89)*, I, 353-364, Helsinki.

Åström, S.-E., 1978: Natur och byte, Ekenäs.

ÖFVS (1862-1894): Sammandrag af de klimatologiska anteckningarne, *Öfversigt af Finska Vetenskaps-Societetens förhandlingar*, Helsingfors.