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CONTENTS

1 INTRODUCTION

This data report provides a descriptive overview of the long-term historical data on temperature and ice cover in lakes and rivers for Task 3(i) of Workpackage 1 of Euro-limpacs. The extent of the available data is outlined and some examples are illustrated. The most valuable data sets from the point of view of climate research are those that are not only long, but complete. However, most long-term environmental data series do have gaps, and those described here are no exception. Small gaps can often be filled by interpolation, but larger gaps can be a substantial problem. The frequency of occurrence of large gaps in most of the data sets described here is low enough not to have a serious effect on overall data quality.

The data sets described in this report include the following:

- Daily river water temperature data covering the last 25-35 years. Examples include data from the Rhine (1969-2002) and Rhône (1968-2002).

- Monthly mean river water temperature data covering much of the 20th century. Examples include data from the Rhine, Danube and Inn (all 1901-1990).

- Monthly lake water temperature profiles covering much of the second half of the 20th century. Examples include data from the Swiss lakes Zürichsee (1936-40; 1945-2004), Greifensee (1956-2004) and Walensee (1972-2002).

- Daily lake surface water temperatures covering the last part of the 20th century. Examples include data from Lough Feeagh, Ireland (1960-2004); Windermere, UK (1960-2000); and Müggelsee, Germany (1976-2004).

- Monthly mean lake surface water temperatures covering much of the 20th century. Examples include data from Lake Constance (1901-1990), Zeller See (1901-1990), Traunsee (1905-1990) and Mondsee (1909-1990), all in Austria.

- Historical observations of the timing of ice-on and ice-off on rivers and lakes distributed throughout Europe and the rest of the Northern Hemisphere, including many data sets that go back to the 19th and 18th centuries, and some that extend back even further. Examples include the Tornionjoki River, Finland (ice-off, since 1692/93); the Miramichi River, Canada (ice-off, since 1829/30); Kallavesi, Finland (ice-on and ice-off, since 1833/34); Lej da San Murezzan, Switzerland (ice-off, since 1831/32); Lake Baikal, Russia (ice-off, since 1868/69); and Lake Suwa, Japan (ice-on, since 1443/44).

Very few of the data sets described here have been published and access to the vast majority of them is by arrangement with the respective owners on a case-by-case collaborative basis only.

2 LONG-TERM WATER TEMPERATURE DATA

2.1 Long-term river temperature data

By far the best set of data on river and stream temperatures is that for Switzerland, listed in Table 2.1 and illustrated in Fig. 2.1A. These data have been sampled at intervals of 1 minute at 25 stations since at least 1977, with some of the sampled data going back as far as 1964 (Hari and Zobrist, 2003; Hari et al., 2004, 2005; Jakob et al., 2000).

Table 2.1. Long-term river and stream temperature data in Switzerland. The table lists the following: the rivers; sampling stations with abbreviations; mean altitudes of the sampling stations and their catchment areas upstream to the next large lake; the percentage of glaciers in the catchment area (G); and the extent of the data series. The sampling interval was 1 minute.

River	Station	Abbrev.	Alt. station [m a.s.l.]	Alt. c. a. [m a.s.l.]	G [%]	Data from	Data to
Aare	Bern	BE	502	803		1977	2002
Aare	Brienzwiler	BW	570	2140	21.0	1977	2002
Aare	Brugg	BR	332	654		1964	2002
Aare	Brügg Ägerten	BG	428	437		1971	2002
Aare	Hagneck	HA	437	1011		1971	2002
Aare	Thun	TN	548	571		1964	2002
Arve	Genève	AR	380	1834	6.1	1969	2002
Birs	Münchenstein	BI	268	762		1972	2002
Broye	Payerne	BY	441	717		1969	2002
Emme	Emmenmatt	EM	638	1069		1964	2002
Kleine Emme	Littau	KE	431	1050		1970	2002
Limmat	Baden	BA	332	541		1969	2002
Linth	Mollis	MO	436	1730	4.4	1976	2002
Linth	Weesen	WE	419	608		1970	2002
Reuss	Luzern	LU	432	455		1970	2002
Reuss	Mellingen	ME	345	738		1976	2002
Reuss	Seedorf	UR	438	2012	9.5	1972	2002
Rhein	Rekingen	RE	323	628		1971	2002
Rhein	Rheinfelden	RH	262	645		1965	2002
Rhein	vor Bodensee	VB	410	1732	1.4	1969	2002
Rhône	Chancy	CH	336	1701	6.1	1970	2002
Rhône	Porte du Scex	PO	377	2099	14.3	1978	2002
Rhône	Sion	SI	484	2295	18.4	1964	2002
Thur	Andelfingen	TR	356	778		1969	2002
Ticino	Riazzino	TI	200	1649	1.1	1968	2002

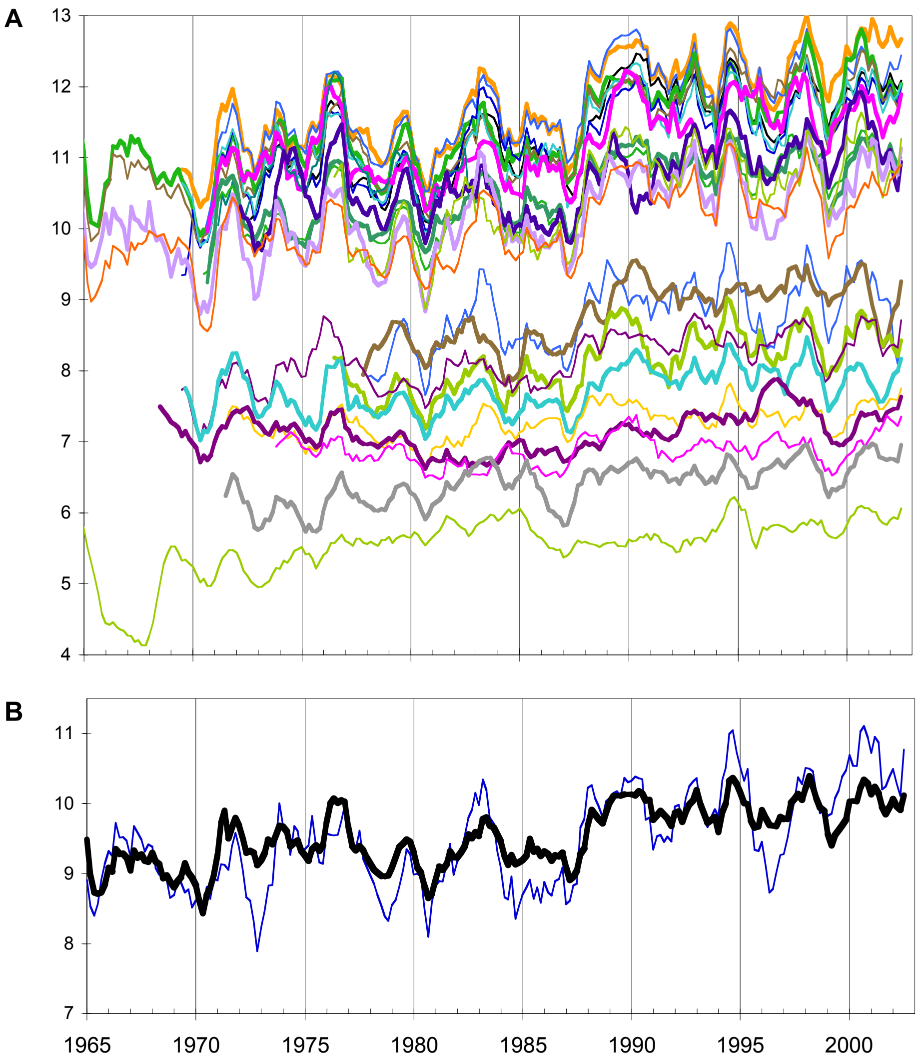

Fig. 2.1. A) River and stream temperatures measured at 25 stations in Switzerland. The data illustrated are annual running means based on daily means calculated from the original measurements made at intervals of 1 minute. B) Comparison of the arithmetic mean of the water temperatures illustrated in (A) (thick black curve) with the mean air temperature measured at the meteorological stations of Basle and Zurich (annual running means; thin blue curve), which is representative of the mean air temperature prevailing on the Swiss Plateau. Adapted from Hari et al. (2005).

From Fig. 2.1A it is apparent that the river temperatures show a high degree of regional coherence on interannual and interdecadal time-scales, implying a common, coherent response to regional climatic forcing on these time-scales. The absolute differences in water temperature from river to river are primarily a result of the general decrease in water temperature that occurs with increasing altitude, but the degree of coherence also decreases somewhat as the mean altitude of the catchment area of the sampling station increases (and is disproportionately low under the influence of glaciers or hydro-electric power stations). On time-scales exceeding the interdecadal time-scale, a coherent warming can be seen to have occurred at all altitudes. This coherent warming reflects a corresponding long-term increase in regional air temperature (Fig. 2.1B). Much of the long-term water temperature increase occurred as an abrupt increase between two approximately stationary periods from 1978-1987 and 1988-2002. This abrupt shift reflects a similar shift in air temperature and appears to be related ultimately to a shift in the North Atlantic Oscillation (Hari et al., 2005).

A further set of long-term river temperature data useful for climate studies is available from Austria (Hydrographisches Büro, 1964a,b; 1973; 1985; 1994). These data are in the form of monthly means, calculated from daily measurements. The Austrian rivers for which such data exist include the upper part of the Rhine, the Danube, and the Inn (all from 1901-1990), and several other smaller Austrian rivers (e.g., Webb, 1996; Webb and Nobilis, 1994, 1995).

2.2 Long-term lake temperature data

2.2.1 Lake temperature profiles

The most useful data for studying the direct influence of climate forcing on lakes are long-term historical series of temperature profiles (Table 2.2). Some of the longest such time-series, extending back in one case to 1936, are to be found in Switzerland, but other useful long-term temperature profile data are available from lakes in Austria, Germany and Sweden. In most cases, sampling was conducted monthly, but weekly sampling was conducted in Müggelsee (Germany). In Lake Erken (Sweden), hourly temperature profiles have been measured since 1988, but many gaps in the data exist. Monthly temperature profiles from Sweden's largest lakes, Mälaren, Vänern and Vättern, have been measured since 1979, but only from spring to autumn (March/May to October). In addition, hourly temperature profiles from the Galten and Ekoln basins of Lake Mälaren have been measured since 1997, but some gaps in the data exist. Some shorter lake temperature profile data series are available from 7 other Swedish lakes, in which temperature measurements have been made 4-6 times a day at 2-3 depths, starting in 1998.

Table 2.2. Long-term historical lake temperature profile data.

Lake	Country	Extent of data	Sampling frequency
Lake Zurich	Switzerland	1936-40; 1945-2004	Monthly
Zugersee	Switzerland	1950-53; 1969-2004	Monthly
Greifensee	Switzerland	1956-2004	Monthly
Upper Lake Zurich	Switzerland	1972-2004	Monthly
Walensee	Switzerland	1972-2004	Monthly
Aegerisee	Switzerland	1975-2004	Monthly
Lac de Neuchâtel	Switzerland	1981-2004	Monthly
Traunsee	Austria	1958-84	Monthly
Piburgersee	Austria	1975-2004	Monthly
Lake Constance	Germany	1963-2004	Monthly
Stechlinsee	Germany	1960-2004	Monthly
Müggelsee	Germany	1978-2004	Weekly
Heiligensee	Germany	1978-2004	Monthly
Lake Erken	Sweden	1988-2004	Hourly (but with gaps)
Mälaren	Sweden	1979-2004	Monthly (spring-autumn only)
Vänern	Sweden	1979-2004	Monthly (spring-autumn only)
Vättern	Sweden	1979-2004	Monthly (spring-autumn only)

Some of the long-term Swiss temperature profile data series have been analysed by Livingstone (1993, 1997, 2003). The time-series confirm that water temperatures have been undergoing the fastest long-term increase in the surface mixed layer, but that temperatures in the epilimnion and metalimnion have also been increasing rapidly (Fig. 2.2). Hypolimnetic temperatures are increasing, but less rapidly than epilimnetic temperatures, resulting in a general increase in thermal stability, a lengthening of the period of stratification and a corresponding diminution in the period of homothermy.

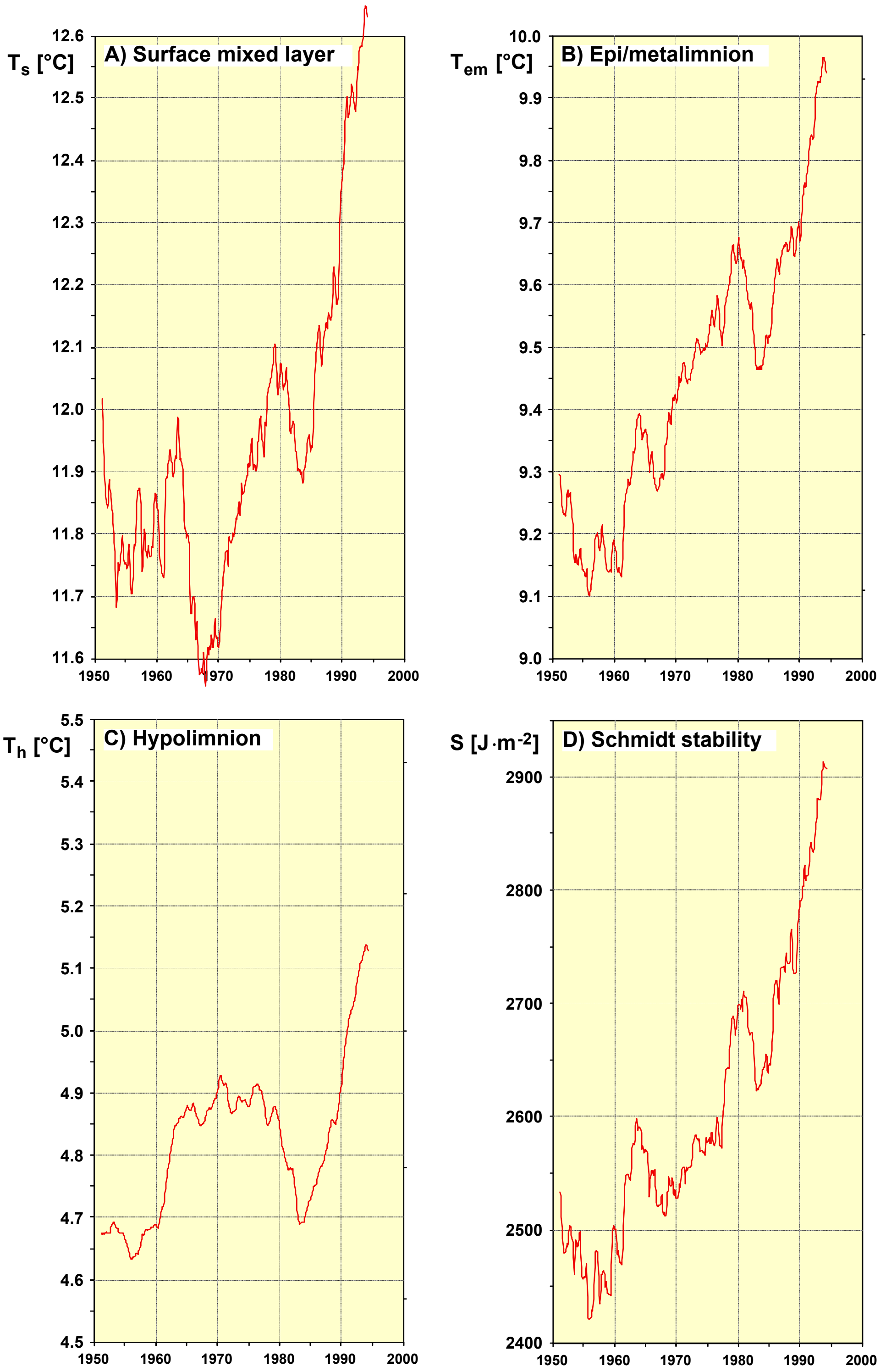

Fig. 2.2. Secular changes and decadal variability in the water temperature of Lake Zurich. A) mean temperature (T_s) of the surface mixed layer (0-2.5 m); B) mean temperature (T_{em}) of the epi/metalimnion (0-20 m); C) mean temperature (T_h) of the hypolimnion (20 – 136 m); D) Schmidt stability (S), a measure of overall thermal stability. All curves shown are centred decadal (120-month) running means. Adapted from Livingstone (2003).

2.2.2 Lake surface water temperature data

While full temperature profiles are generally measured at a sampling interval of a few weeks, lake surface water temperature (LSWT), which is substantially easier to measure, is often measured much more frequently. Long-term time-series of LSWT measurements conducted with a sampling interval of 1 day or less exist for several European lakes (Table 2.3). However, many small gaps and some large ones (of up to 3 months duration) exist in these data sets.

Table 2.3. Long-term daily lake surface water temperature data.

Lake	Country	Extent of data
Lough Feeagh	Ireland	1960-2004
Windermere	UK	1960-2000
Stechlinsee	Germany	1960-2004
Müggelsee	Germany	1976-2004

For Austria, a comprehensive set of monthly mean LSWT data exists that covers much of the 20th century (Hydrographisches Zentralbüro, 1964a, b, 1973, 1985, 1994; Table 2.4).

Eight of the longest of these data sets, which were analysed by Livingstone and Dokulil (2001) in relation to regional coherence and climatic forcing, are illustrated in Fig. 2.3.

Table 2.4. Austrian long-term monthly mean lake surface water temperature data (actually measured at ~50 cm depth). These monthly means are based on daily measurements. Only the longest Austrian data sets are listed (those beginning before 1950 and extending up to 1990); shorter data sets also exist.

Lake	Extent of data
Lake Constance	1901-1990
Hallstätter See	1901-1990
Zeller See	1901-1990
Traunsee	1905-1990
Wolfgangsee	1907-1990
Millstätter See	1908-1911; 1913-1990
Altauseer See	1909-1990
Attersee	1909-1990
Mondsee	1909-1990
Lunzer See	1909-1940 (summer only); 1941-1990 (entire year)
Fuschlsee	1911-1990
Ossiacher See	1911; 1913-1921; 1924-1990
Wallersee	1923-1990
Grundlsee	1936-1990

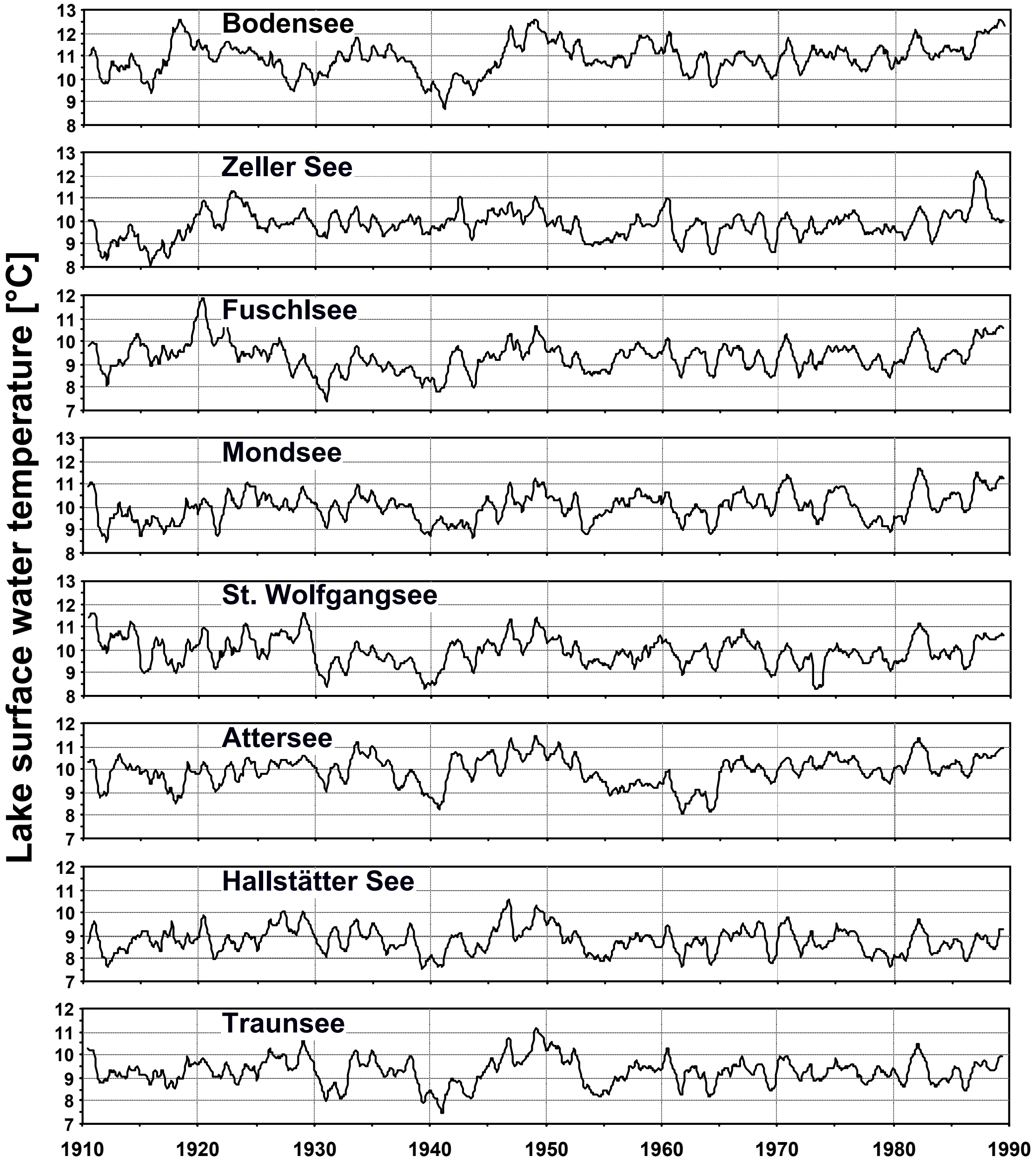

Fig. 2.3. Long-term time-series of surface water temperature in eight Austrian lakes (12-month running means).

For Sweden, LSWT data sampled monthly are available from 9 basins of Lake Mälaren from 1968 at the latest; the longest Mälaren LSWT series is that from the Görväln basin, commencing in 1943. Additional LSWT data are available from 427 lakes in Sweden that have been sampled several times a year since 1965, with more frequent sampling since 1988. At the time of writing, a total of 14480 LSWT samples from Swedish lakes existed.

3 LONG-TERM ICE-COVER DATA

Long-term data on the ice cover of rivers and lakes are confined essentially to observations of the timing of ice-on and ice-off. Such observations are available for approximately 950 Northern Hemisphere rivers and lakes located in 13 countries covering northern and central Europe, northern and central North America, and northern Asia (Table 3.1). Some of the longest of these data sets have been analysed for long-term climate-related trends by Magnuson et al. (2000).

Table 3.1. Available long-term observational data on the timing of ice cover on Northern Hemisphere rivers and lakes. The duration of the time-series varies from several years to several centuries, with most time-series being several decades long.

	Total	Rivers	Lakes
EUROPE	316	1	315
Sweden	**203**	**0**	**203**
Finland	**90**	**1**	**89**
Russia	**13**	**0**	**13**
Germany	**3**	**0**	**3**
Switzerland	**3**	**0**	**3**
Estonia	**1**	**0**	**1**
Austria	**1**	**0**	**1**
Hungary	**1**	**0**	**1**
United Kingdom	**1**	**0**	**1**
NORTH AMERICA	547	184	363
Canada	**464**	**184**	**280**
Ontario	111	27	84
Northwest Terr./Nunavut	73	19	54
British Columbia	68	34	34
Québec	61	27	34
Manitoba	42	16	26
Alberta	37	27	10
Yukon	21	11	10
Saskatchewan	18	8	10
Newfoundland/Labrador	15	5	10
New Brunswick	9	6	3
Nova Scotia	8	3	5
Prince Edward Island	1	1	0
USA	**83**	**0**	**83**
Wisconsin	31	0	31
Minnesota	28	0	28
New York	21	0	21
Michigan	2	0	2
Maine	1	0	1
ASIA	86	50	36
Russia	**82**	**50**	**32**
China	**3**	**0**	**3**
Japan	**1**	**0**	**1**

3.1 Long-term observations of ice cover on rivers

Historical data on the timing of ice cover on European rivers are scarce, the only long data series available being that from the Tornionjoki River in northern Finland, which exists uninterruptedly since 1693 (Fig. 3.1). The continual long-term shift towards earlier ice-off on the Tornionjoki River (at a mean rate of 4.2 d per century) is apparent from Fig. 3.1. At the end of the 17th century the river thawed on average on 21 May; now it thaws on average on 8 May, about 2 weeks earlier.

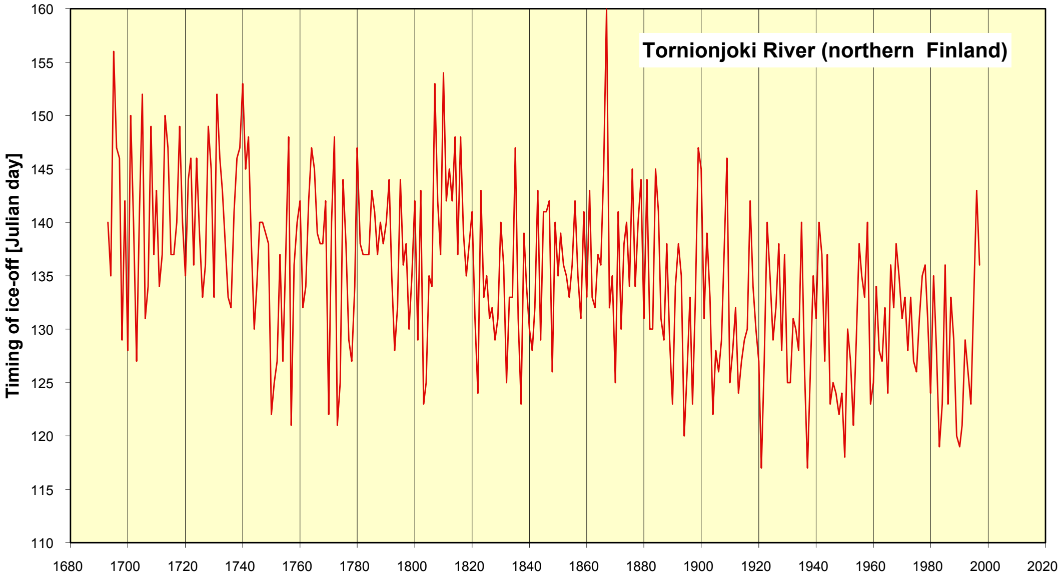

Fig. 3.1. Three centuries of data on the timing of ice-off on the Tornionjoki River, northern Finland. The continual long-term shift towards earlier ice-off is apparent.

Available historical data on river ice are much more plentiful in North America (Canada) and Asia (Siberia), with 184 and 50 data sets, respectively. However, compared to the Tornionjoki data, most of the Canadian and Siberian data sets are relatively short. Two notable exceptions to this are the Miramichi River (New Brunswick; uninterrupted since 1830) and the Red River (Manitoba; since 1798, but incomplete).

3.2 Long-term observations of ice cover on lakes

In Europe, historical data on the timing of ice cover are much more plentiful for lakes than for rivers. These data are available principally from lakes in Sweden and Finland, although some data are also available from individual lakes in Switzerland, Austria, Germany, Hungary, Estonia and European Russia (Table 3.1). One example of a long-term data set on the timing of ice-out from a mountain lake in Switzerland is shown in Fig. 3.2. This time-series commenced in 1832. The structure of the time-series has been shown to display similarities with a time-series of climatically-relevant explosive volcanic eruptions (Livingstone, 1997). The unusually late timing of ice-out apparent in the late 1830s coincides with the explosive eruption of the volcano Cosaguïna in Nicaragua.

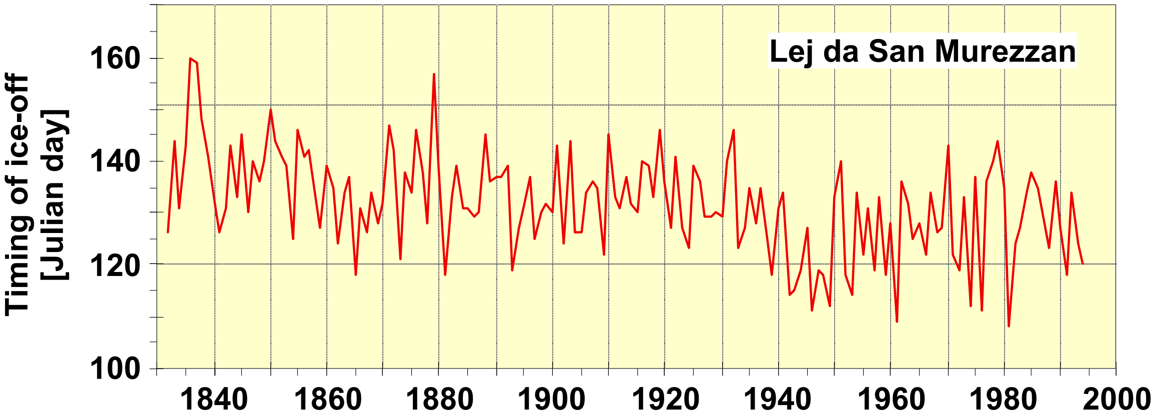

Fig. 3.2. Three centuries of data on the timing of ice-off on Lej da San Murezzan, located at 1740 m a.s.l. in the Swiss Alps. As in the case of Tornionjoki (Fig. 3.1), the continual long-term shift towards earlier ice-off is again apparent. Adapted from Livingstone (1997).

The set of data on the timing of ice-on and ice-off is particularly comprehensive for Sweden, where the large number of lakes for which data are available make it possible to investigate the dependence of the temporal characteristics of the lake ice cover on latitude, and hence on air temperature (e.g., Weyhenmeyer et al. 2004, 2005). Figs. 3.3 and 3.4 illustrate the timing of ice-on and ice-off, respectively, for those Swedish lakes for which complete data sets exist from 1961 to 2002. A shift towards later freezing and earlier thawing is apparent. However, the magnitude of these shifts is not constant with latitude. Because of the non-linearity in the relationship between the timing of ice-on and ice-off and air temperature, the shift in these timings has been much more pronounced in southern Sweden than in northern Sweden (Weyhenmeyer et al., 2004, 2005). Additionally, the effects of some extreme events are also seen to be latitudinally dependent as a consequence of this non-linearity. The extremely warm winters in 1989 and 1990 (associated with extreme positive values of the North Atlantic Oscillation) had an effect on the timing of ice-out, for instance, that was much more pronounced in southern Sweden than in northern Sweden (Fig. 3.4).

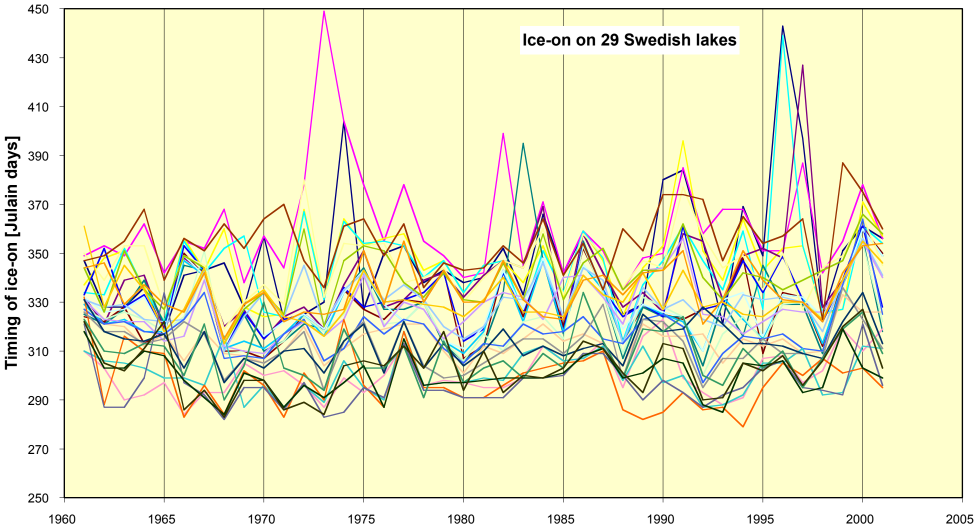

Fig. 3.3. Time-series of the timing of ice-on for 29 lakes in Sweden.

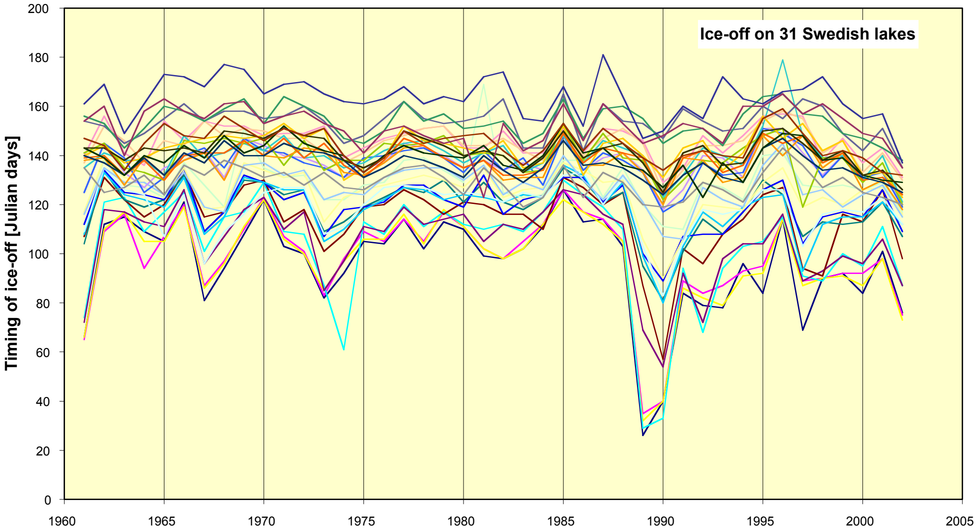

Fig. 3.4. Time-series of the timing of ice-off for 31 lakes in Sweden.

Data from North America cover 11 Canadian provinces (from the Maritimes to British Columbia and Manitoba to the Yukon), and 5 US states. Data on the timing of ice cover in Asian lakes cover parts of Russia (Siberia), China and Japan. The sole Japanese data set, from Lake Suwa, deserves special mention here. The time-series of ice-on data from this lake is the longest in existence, beginning in in the winter of 1443/44 (although one isolated observation does exist from the winter of 1397/98). Unfortunately, the data set is not completely uninterrupted, but is still one of the most valuable ice phenology data sets in existence (from 1443/44 to 1681/82 there are only 3 missing observations).

4 CONCLUSIONS

This report has presented an overview of some long-term historical data on water temperature and ice cover in rivers and lakes, with a major focus on Europe, that may be of use in investigating empirically the direct physical impact of climate trends and fluctuations on surface waters. Such investigations will be facilitated by the availability of relevant data in some areas (e.g., northern and central Europe), but are likely to be hindered by the paucity of data in some other areas.

5 ACKNOWLEDGEMENTS

This brief report summarises the long and hard work of numerous people, most of them unknown, who took the trouble to make observations and measurements at a time when their practical utility was not immediately apparent. Without the foresight of these people, to whom short-term economic benefit was not the overriding principle it has become today, these historical data would not be available for the use of modern researchers.

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