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ON WATER TEMPERATURES OF LAKES IN FINLAND

BY

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Abstract

Water temperature observations operated by Hydrological Office during the period 1961—1975 are analyzed. Both surfece water temperature and the vertical distribution of temperature are discussed. In order to estimate the representativity of the period mentioned above, comparisons are made with the longest observation series of water temperature from Lake Saimaa at Lauritsala, where observations were started in 1916.

1. *Introduction*

The first systematic measurements of water temperature were made in the lakes Lohjanjärvi, Ladoga, Päijänne and Inari during the period 1892—1906 (HOMÈN [1]). From 1910 to 1926 over 1200 vertical measurements of water temperature were carried out in Lake Lappajärvi by the Hydrographical Office (ODENWALL [3]). The observations of surface water temperature began in 1916 in Lake Saimaa at Lauritsala; they still continue and thus they represent the longest continuous observation series of water temperature in Finland.

The first extensive data on the temperature conditions in a lake in winter were gathered in Lake Kallavesi in 1937—38 (SIMOJOKI [4]). Comparisons between the water temperature of different parts of a lake were included in the observations in Lake Päijänne during the period 1950—59 (SIMOJOKI [5]).

A significant increase in the number of water temperature stations took place in 1961, when 21 new stations were established by the Hydrological Office. Today there are 24 stations in lakes and 26 in rivers (Fig. 1). At most stations only surface water temperature is measured. At eight observation sites the vertical distribution of temperature is also measured (KUUSISTO [2]).

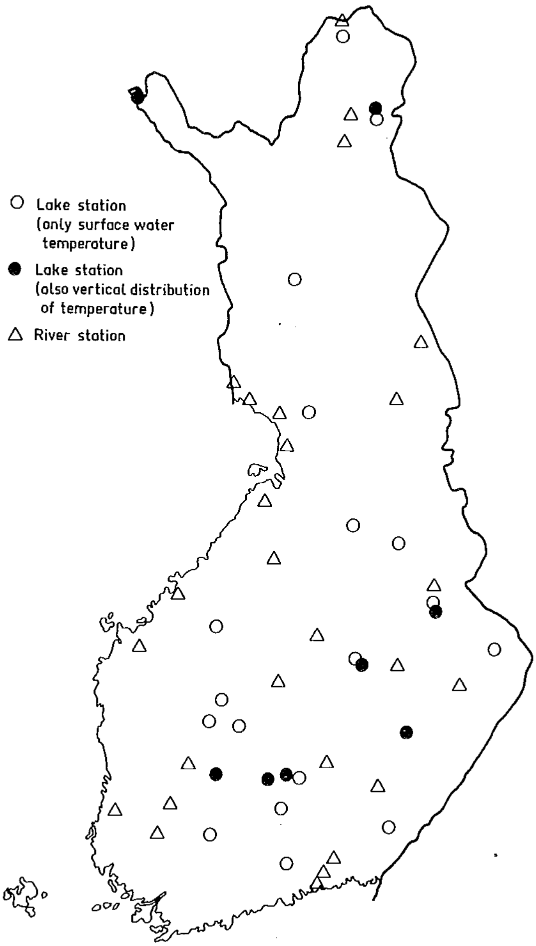

Fig. 1. The network of water temperature stations of the Hydrological Office.

2. *Surface water temperatures*

The increase of surface water temperature after the break-up of ice depends on weather conditions and the characteristics of the lake. Temperature differences between neighbouring lakes can be several degrees; these differences usually diminish later during summer but increase again towards autumn.

The average course of surface water temperature at some stations during open water period is shown in Fig. 2. Also the extreme temperatures with a

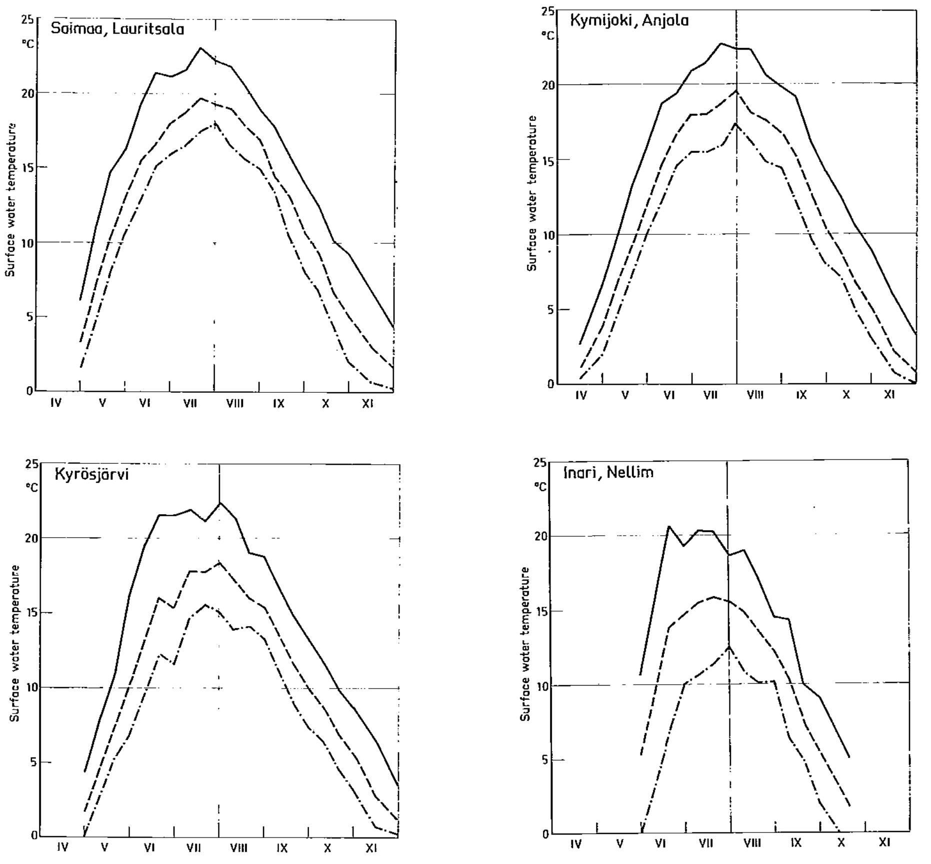

Fig. 2. The average course and 90 per cent confidence limits of surface water temperature at some stations in 1961—75.

return period of 10 a are shown. They are estimated graphically on normal probability papers.

It is obvious that the characteristics of the observation site have an essential effect on surface water temperatures. This means that the climatic differences are indicated only when the stations are far apart. It is further evident that the variations from year to year are quite different at different stations.

The comparison between the lake and river stations does not reveal any significant differences. The average maximum temperature in rivers is almost as high as that of major lakes in the same region. This is a consequence of the fact that the vertical mixing of water in lakes leads to a homogenous surface layer, which extends beyond the threshold level of the outlet.

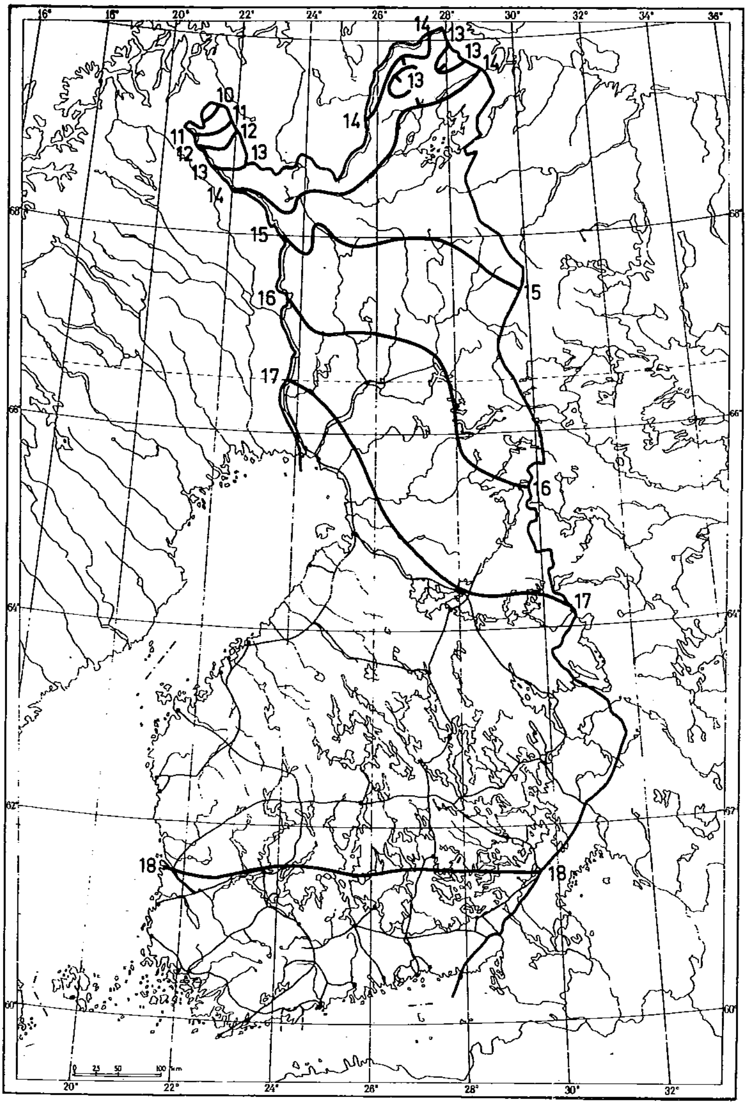

Fig. 3. The average temperature of surface water in Finnish lakes in July in 1961—75.

In Fig. 3, the average surface water temperature of lakes in Finland in July is shown. The regional differnces are very small in southern and central parts of the country. In Lapland, however, surface waters stay cool throughout the summer.

The most essential meteorological variable affecting the temperature of surface water is the air temperature of the preceeding period. The following regression models were obtained:

$$TS_{30.6} = 3.4 + 0.93\ TA_6 \qquad r = 0.79 \qquad (1a)$$
$$TS_{31.7} = 1.8 + 1.02\ TA_7 \qquad r = 0.86 \qquad (1b)$$

where

$Ts_{30.6}$= surface water temperature at the end of June, °C
$TS_{31.7}$= surface water temperature at the end of July, °C
TA_6= average air temperature in June, °C
TA_7= average air temperature in July, °C

Both models are significant at the level of 99.9 per cent. When the area of the lake was included in the models, the multiple correlation coefficient increased by 0.03 and 0.02, respectively. Major lakes had lower surface water temperatures — however, the influence of the area of the lake was actually smaller than could have been anticipated.

3. *Vertical distribution of water temperature*

Although the temperature of surface water is important e.g. in the estimation of evaporation, it is of minor importance for the biological processes in the lake. The temperature at different depths essentially affects the kinetics of biochemical reactions and the solubility of different gases in the water. The temperature gradient and especially the depth of the thermocline play an important role in the energy balance and mixing of the water in the lake.

The important dates in the annual course of water temperatures in a lake are as follows:

1. The ice break-up date. The mixing of water due to wind and rapid increase of water temperature begin.
2. The date of maximum mean temperature of the water mass. The amount of heat energy stored in the water mass reaches its maximum.
3. The date of the beginning of the autumn homothermy.
4. The date of the water density maximum, *i.e.* the whole water mass has a temperature 4.0 °C.
5. The freezing date. The wind mixing effect ceases and winter conditions begin.
6. The date of the minimum mean temperature of the water mass. The amount of heat energy stored in the water mass reaches its minimum.

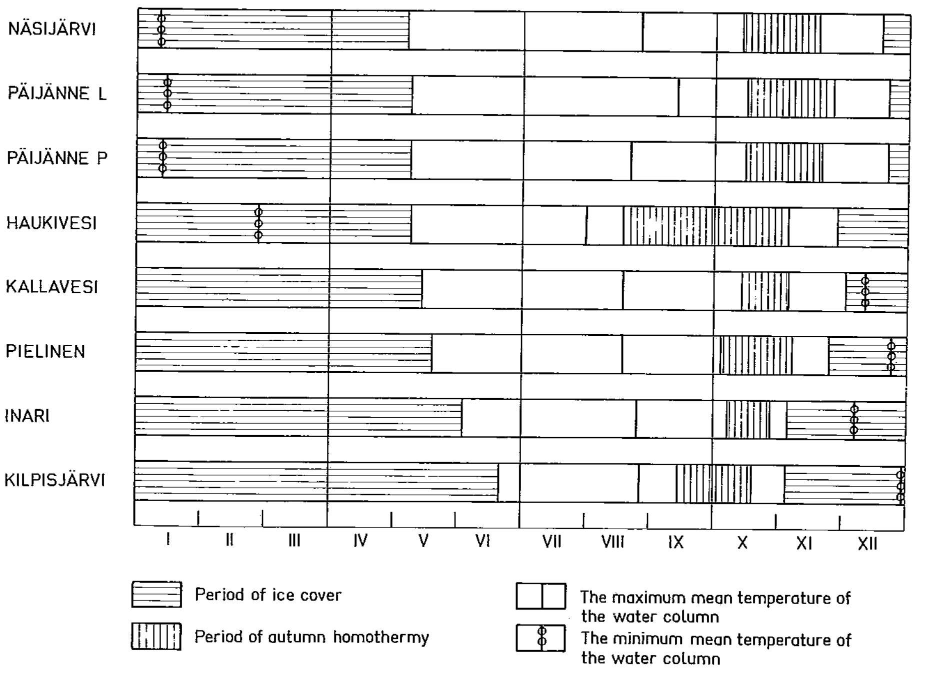

Fig. 4. Some important dates of the thermal year of some lakes in 1961—75.

These dates have been estimated for each observation site in each year for the period 1961—75 (Fig. 4). However, because most observation sites are located in major lakes with a complicated bottom topography, it has not been possible to determine the dates of maximum and minimum temperature of the whole water mass. Therefore the maximum and minimum mean temperatures of the vertical water column at the observation site are used instead.

The ice break-up date is mainly dependent on the sum of positive degree-days of air temperature in spring, and thus it occurs considerably later in northern Finland. The length of the period from the ice break-up date to the maximum mean temperature of the water column is a function of the water depth and the area of the lake represented by the observation site. In the shallow Haukivesi station (11 m) the length of this period is only 83 d, but in the deep Päijänne Linnansaari station (69 m) it is 128 d. The length of the autumn homothermy tends to be more at shallow observation sites, but other factors also affect; thus in northern Finland the rapid decrease of air temperatures leads to a short period of homothermy.

The average annual mean, maximum and minimum temperatures of the water column at each observation site are given in Table 1. The shallow observation site at Haukivesi has the highest mean and maximum temperature and the lowest minimum temperature. The means and maxima are lower at the two observation sites in Lapland — Inari and Kilpisjärvi — than in southern and central Finland. On the other hand, their minimum temperatures are considerably higher than in other lakes. This is mainly due to the rapid freezing in the lakes of northern Finland.

Table 1. The average annual mean, maximum and minimum temperatures of the water column.

Observation site	Depth	Average annual temperature (°C)		
	(m)	Mean	Maximum	Minimum
Näsijärvi, Tampere	50	5.3	11.2	1.09
Päijänne, Linnansaari	69	5.3	11.2	0.89
Päijänne, Päijätsalo	42	5.5	12.3	0.52
Haukivesi, Oravi	11	6.8	19.0	0.38
Kallavesi, Kuopio	46	5.2	11.6	0.99
Pielinen, Nurmes	28	5.8	15.0	1.09
Inari, Nellim	42	4.2	9.2	1.91
Kilpisjärvi	39	4.4	10.1	2.18

The mean annual variation of the heat energy storage in the water columns at each observation site were also compared. This variation was largest at Päijänne Linnansaari, 300 kJ cm^{-2}, and smallest at Haukivesi, 88 kJ cm^{-2}. However, it is more relevant to compare the variation of heat energy per one meter of the water column. The largest variation occurs at Haukivesi, 8.1 kJ

$cm^{-2}m^{-1}$. At all observation sites in southern and central Finland, the variation exceeds 4 kJ $cm^{-2}m^{-1}$, but at Inari and Kilpisjärvi it is only 3.0 and 3.3 kJ $cm^{-2}m^{-1}$, respectively.

The annual course of water temperature at different depths at Päijänne Linnansaari is shown in Fig. 5. After the ice break-up, the temperature of surface layers increases rapidly. It reaches its maximum at the end of July, but the deepest layers warm up until the end of September. The average temperature of the vertical water column at the freezing date is 2.1 °C. The minimum temperature is reached in January through all depths. Thereafter, a slight increase of water temperature occurs: in February the heat energy storage of the water column increases by 4.4 kJ cm^{-2}, in March by 5.9 kJ cm^{-2} and in April by 16.6 kJ cm^{-2}. In the upper half of the water column, the

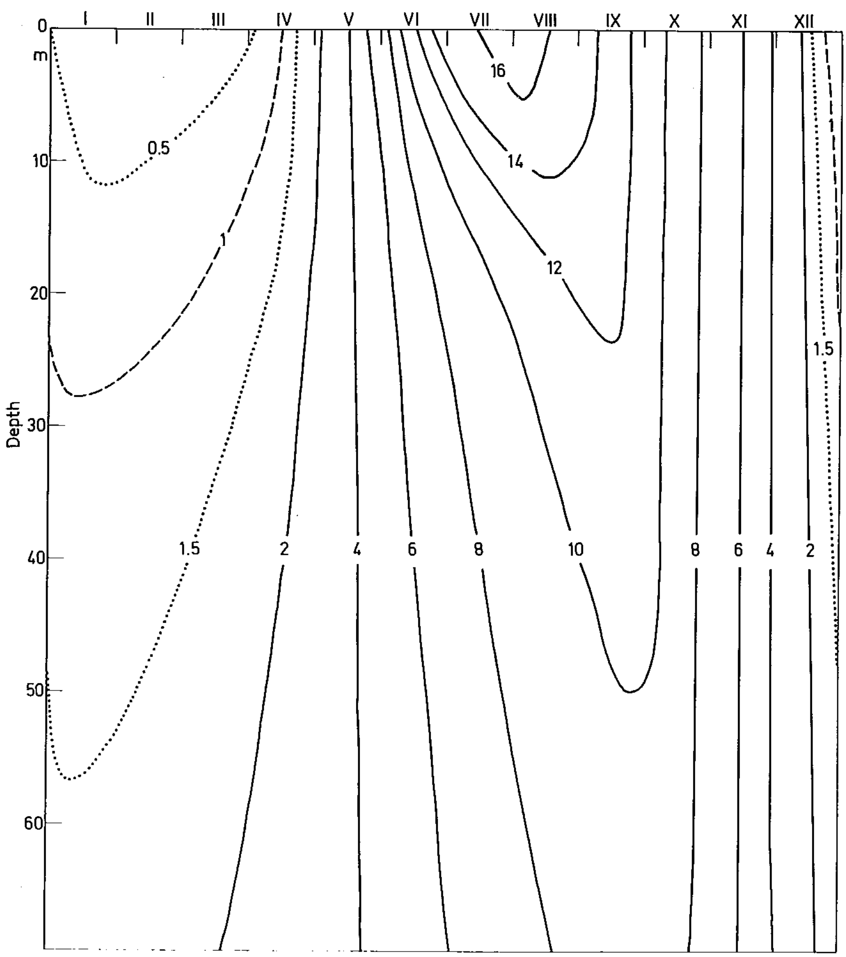

Fig. 5. The annual course of water temperature at different depths in Lake Päijänne at Linnansaari in 1961—75.

increase of heat energy storage in February to April is 30 per cent higher than in the lower half of the column.

4. *The representativity of the period 1961—75*

The longest water temperature observation series from Lake Saimaa at Lauritsala was used to study the representativity of the period 1961—75. The difference in the surface water temperature was largest in June: the monthly mean for the period 1916—60 was over 1 °C lower than for the period 1961—75. For the other months, the differences were smaller.

In Fig. 6, the mean temperatures of surface water at Lauritsala in July are shown for the whole period 1916—80. Also the highest moving average temperature of 10 days is shown. The best July for vacationeers — at least as to water temperatures — was in 1972, when the monthly mean exceeded

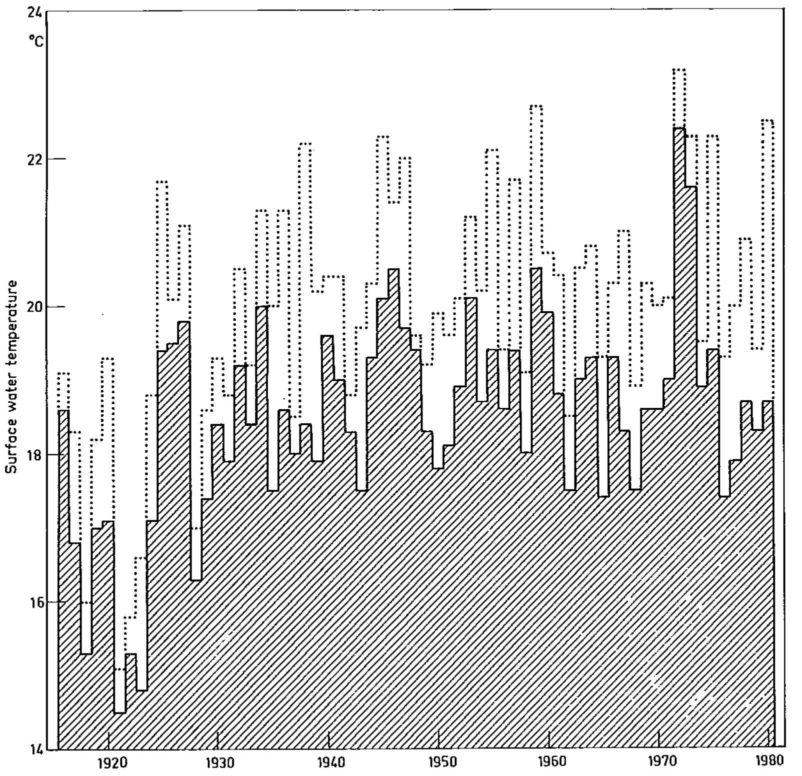

Fig. 6. The average temperature of surface water in Lake Saimaa at Lauritsala in July (solid line) and the maximum moving average temperature of 10 days (dashed line) in 1916—80.

22 °C. The same year can boast about the warmest 10 d period of surface water temperature: 23.2 °C. On the other hand, it was quite chilly to swim in July 1921: the monthly mean temperature did not exceed even 15 °C.

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