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Thermal Regime of Harding Lake in the Interior Alaska

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Abstract

Thermal regimes of Harding Lake were investigated from the view point of being influenced by surrounding permafrost.

Temperature profiles obtained by thermometer chain showed particular changes below the thermocline. These changes cannot be explained by heat exchange from surface. There must be some advection from surrounding into hypolimnion.

Numerical estimation of the advective heat flux were made using the temperature profiles of each successive period. The obtained results confirmed the cold advection.

The quasi-stationary oscillation of temperature observed at thermocline could be explained quantitatively from internal seiche applied model of rectangular basin.

1. Introduction

Harding Lake is located at southwest of Fairbanks, Alaska. The shape of the lake is approximately circular and its diameter is about 3.7 km. The basin of the lake forms nearly symmetrical concave parabola and has a maximum depth of a little more than 40 m (Fig. 1). This maximum depth is relatively deep comparing with other lakes around this region. The lake has no drainage channel and also no inflow channel.

During summer season, surface temperature of the lake raises up above 20°C and warm surface layer is formed above remarkable thermocline but

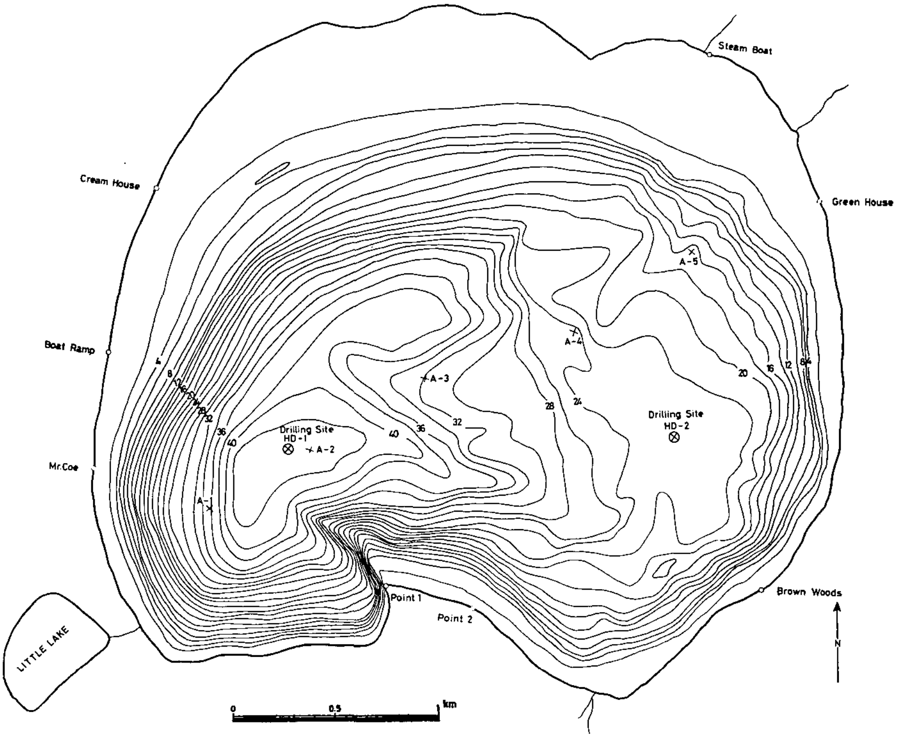

Fig. 1 Bathymetric map of Harding Lake. A-1, A-2, A-3, A-4, A-5 indicate the positions of measuring station.

hypolimnion remains stable at about 4°C below 15 m. In winter season, the surface of the lake is covered with ice of about 1 m thick but a little fall in temperature in the hypolimnion is observed.

Many investigations concerning the origin, geological characteristics and water balance of Harding Lake has been carried out but most of them are still under question and more investigations are needed to clarify these characteristics of Harding Lake.

In this paper, the thermal regime of the lake during heating period is investigated using temperature records obtained from verious depth of the lake, particularly in respecting to the influence from permafrost which might be existing around the lake. This work is also made as a one of the part of the joint project. The thermal budget and water balance of the lake is not only affected from the characteristics of climatological conditions of the region but has strong influence and impact to the environmental factors of neighboring area.

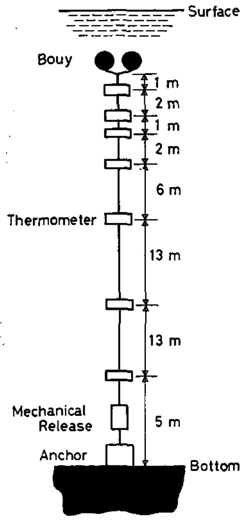

Fig. 2 Schematics of the thermometer chain.

2. Measurements

Temperature measurements of the lake were carried out from July 6 to July 24 at various depths of station A–2 which was shown in the bathymetric map (Fig. 1) using "Ryan" type recording thermometers. Each thermometer was fixed at a certain depth with wire cable which was sustained by buoys at upper end and anchor blocks through mechanical release at lower end. The arrangement of each thermometer with depth was shown schematicaly in Fig. 2.

Typical records obtained from surface layer at 2 m, from lower part of thermocline at 8 m and from hypolimnion at 22 m, were shown in Fig. 3a, b, c.

For replacement of recording paper of some thermometers, thermometer chain has to recover every 6 days and, by the difficulty of precise positioning, the chain could not be reset at exactly the same location. So that some temperature differences were occured due to depth change on each successive recording periods.

Other than successive measurements of the temperature by thermometer chain, viritical profiles of the temperature were taken using thermistor at each station shown on the bathymetric map (Fig. 1) and also before setting the chain at station A–2, virtical profiles of that were taken every 6 days.

Obtained temperature of each depth were shown in Table 1. In Figs. 4, 5, 6, 7, 8, 9, virtical profiles of temperature at station A–2 were shown by dual lines for each successive measurement and also, in Fig. 10, those of temperature at each station from A–1 to A–5 were shown.

3. Results and Discussions

3.1 *Quasi-stationary oscillation of the temperature in stratified layer.*

Remarkable temperature oscillation observed on the record obtained at 8 m depth where was lower part of well developed thermocline. The amplitude of temperature oscillation tends sometimes to more than 8°C. A part of temperature record obtained was shown in Fig. 3b.

It is well known that, when the layers of different density, if it is stratified, can oscillate relative to one another and this kind of oscillation is called internal seiche (Proudman, 1953). In thermally stratified lake like Harding Lake, such temperature oscillation might be existence in the layers around thermocline.

According to theoretical consideration, it can be shown that the period of the uninodal internal seiche is given, if some simple model of basin can be applied for the lake.

As the simplest case, the model of rectangular basin of uniform depth can be applied, then the period of that internal seiche, T, is given by following equation (Nakao et al. 1969);

$$T=2L\left\{\frac{\rho_h}{\rho_h-\rho_e}\cdot\frac{1}{g}\left(\frac{1}{Z_e}+\frac{1}{Z_h}\right)\right\}^{1/2}$$

when the length of the rectangular basin is L, the two layers have thickness Z_e and Z_h and densities ρ_e and ρ_h respectively. Since ρ_e and ρ_h are function of temperature, average temperature of each layer must be obtained. In Harding Lake, taking $Z_e=5$ m, $Z_h=35$ m, then the average temperatures of each layer bocome $T_e=19.6$°C and $T_h=5.9$°C, therefore, the densities of each layer become $\rho_e=0.99831$ and $\rho_h=0.99997$. And also length of rectangular basin assumes 3.7 km. Using above equation with these numerical values, then the period of the uninodal internal seiche is given by

$$Ti=2\times3.7\times10^5\left\{\frac{0.99997}{0.99997-0.99831}\cdot\frac{1}{980}\left(\frac{1}{5\times10^2}-\frac{1}{35\times10^2}\right)\right\}^{1/2}=6^h40^m$$

The observed period was nearly 6 hours as seen in Fig. 3~6, so that, as the

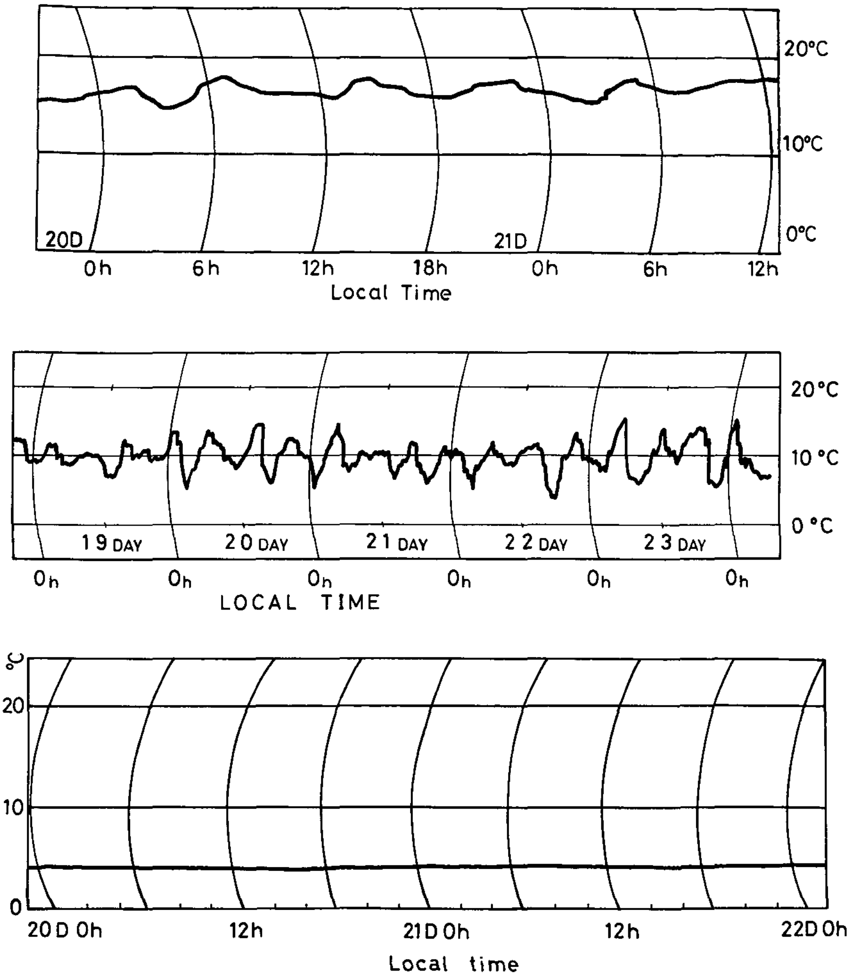

Fig. 3 Examples of the records obtained by thermometer chain.
a) 2 m depth of surface layer. b) 8 m depth of lower part of thermocline.
c) 22 m depth of hypolimnion.

first approximation, the order of the period of the internal seiche is fairly reasonable.

The quasi stationary oscillation of temperature observed at 8 m depth can be explained from internal seiche applied the simplest model of rectangular basin. More precise analysis of temperature oscillation might be needed for clarifying water movement and other mechanism of Harding Lake.

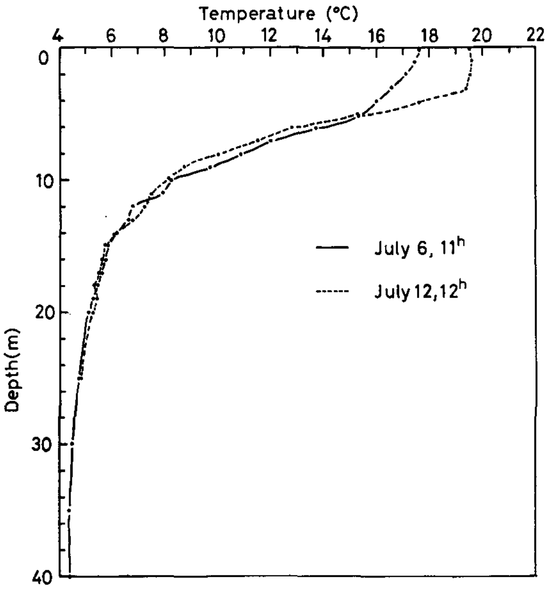

Fig. 4 Temperature profiles obtained at St. A–2

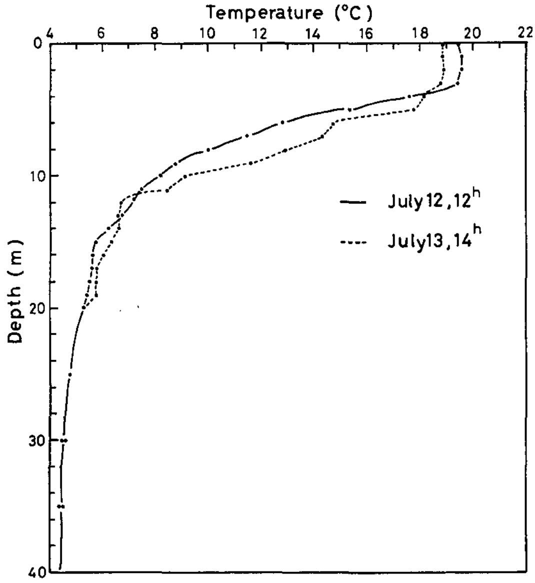

Fig. 5 Temperature profiles obtained at St. A–2

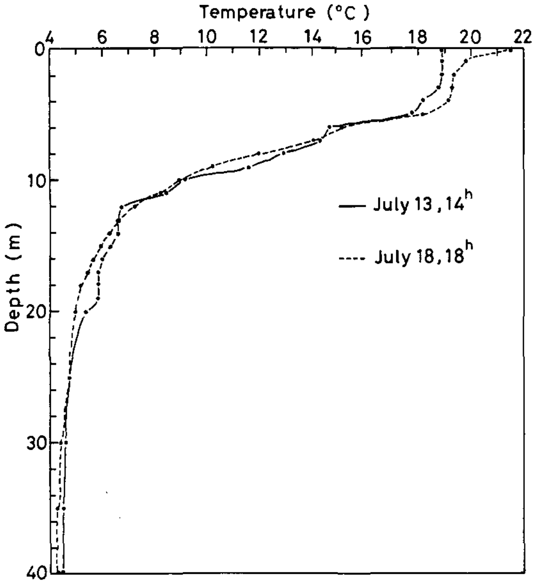

Fig. 6 Temperature profiles obtained at St. A–2

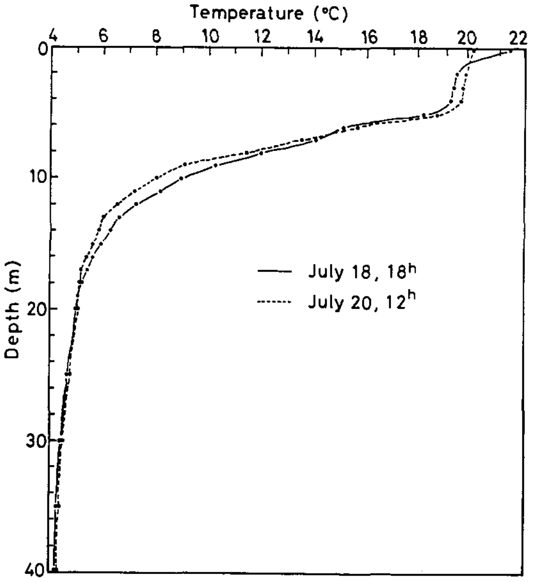

Fig. 7 Temprature profiles obtained at St. A–2

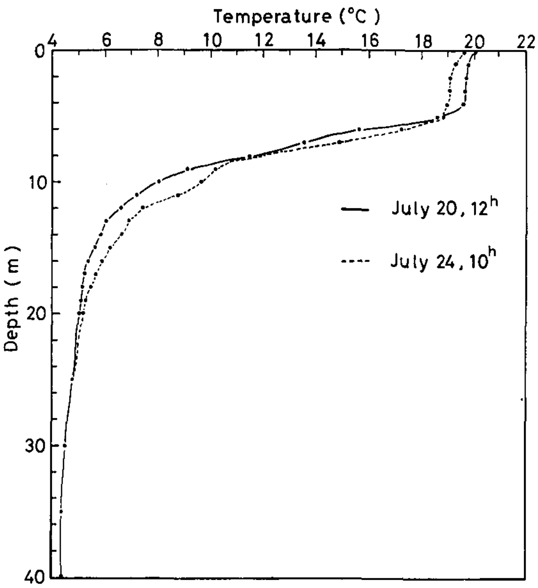

Fig. 8 Temperature profiles obtained at St. A–2

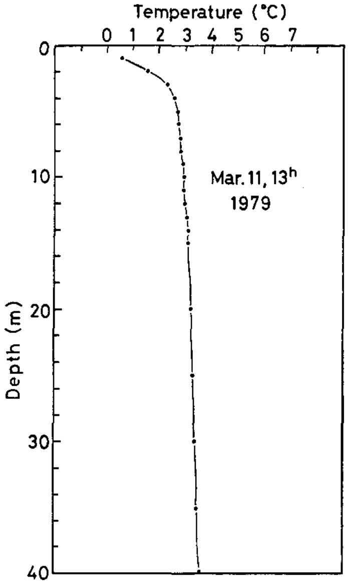

Fig. 9 Temperature profiles obtained at St. A–2

3.2 Advection into the hypolimnion.

In most lake in temperate region including Harding Lake, the entire body of water is in spring at a uniform low temperature or at slightly above 4°C. If such water were of uniform transparency and were quite undisturbed, radiation entering the water surface and being absorbed exponentially would heat the water at a rate falling exponentially from the surface and so would produce an exponential temperature profile. But evaporation from surface and wind stress on the water prevent such process being approached. As the results of such disturbances, by heating in spring and summer from a low temperature, the water tends to become divided into surface layer of more or less uniformly warm and fairly turbulent water, and hypolimnion of cold and relatively undisturbed region which are shown in Figs. 4~10. In case of Harding Lake, it is clear from the temperature profile shown in figures that, by absorbing solar radiation, heating of the surface layer proceeds with time during summer and at the same time, by some turbulent mixing, the temperature of the layer becomes nearly uniform as seen from Figs. 4~10. This means that the thermal behaviour of the surface layer is quite normal comparing with those of other temperate lakes.

On the other hand, behaviour of hypoliminion including thermocline, as seen from temperature profiles, is quite different from those of ordinary temperate lakes. That is, although the surface layer of the lake is heated and the temperature of that increases, in the underlying hypolimnion including thermcline of that, temperature of the layer is some or less decreasing as seen from Figs. 4~8. This phenomenon cannot be explained from heat transport mechanism by conduction which is commonly applied for ordinary temperate lake. There must be some advection from other source into hypoliminion for reducing the temperature of this layer.

As is mentioned before, Harding Lake has no drainage and inflow channels so that advection into the hypolimnion of the lake must be groundwater from surrounding region of the lake. The main source of groundwater of this region is not precipitation but melt water from permafrost which is distributing widely in this region. Temperature of the melt water from permafrost is considered to be fairly low, so that, if such water is supplied

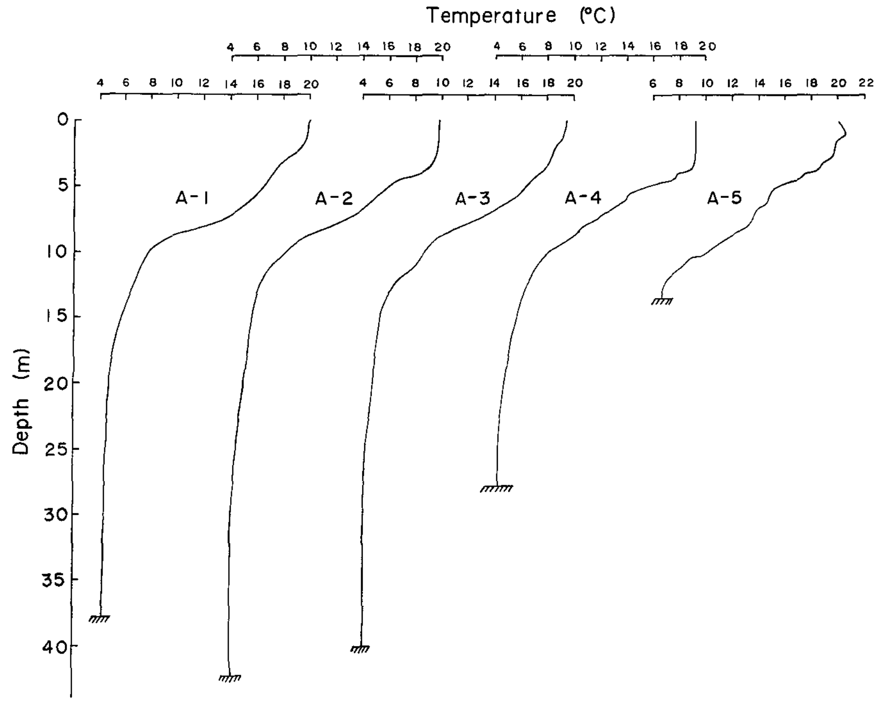

Fig. 10 Temperature profiles obtained at stations A-1 A-5 on July 15, 16.

Table 1 Temperature obtained at St. A-2.

Depth (m)	July 6 12^h °C	July 12 12^h °C	Huly 13 14^h °C	July 18 18^h °C	July 20 12^h °C	July 24 10^h °C	March 11 13^h °C
0	17.57	19.45	18.9	21.63	20.22	19.60	
1	17.43	19.55	〃	19.82	19.75	19.30	0.55
2	17.10	〃	〃	19.40	19.70	19.10	1.55
3	16.50	19.44	18.8	19.28	19.65	19.05	2.55
4	15.99	17.60	18.15	19.16	19.60	19.00	2.70
5	15.30	15.35	17.75	18.15	18.65	18.80	2.75
6	13.74	12.80	14.7	15.13	15.65	17.25	2.80
7	12.00	11.50	14.3	14.08	13.54	14.90	2.85
8	10.90	10.02	12.9	12.00	11.50	11.90	2.90
9	9.73	8.75	11.6	10.25	9.10	10.20	2.95
10	8.25	8.15	9.1	8.95	8.05	9.60	2.96
11	7.95	7.50	8.4	8.17	7.20	8.75	3.00
12	6.75	7.24	6.7	7025	6.60	7.45	3.05
13	6.60	6.72	6.6	6.62	6.05	6.90	3.10
14	6.15	6.20	6.6	6.28	5.85	6.65	3.10
15	5.85	5.72	6.3	5.97	5.65	6.20	3.20
16	5.70	5.60	6.0	5.63	5.39	5.90	
17	5.60	5.58	5.75	5.45	5.24	5.65	
18	5.45	5.50	5.75	5.20	5.15	5.50	
19	5.25	5.40	5.75	5.09	5.10	5.25	
20	5.10	5.30	5.3	5.02	5.05	5.20	3.20
25	4.71	4.75	4.75	4.70	4.80	4.80	3.30
30	4.50	4.45	4.60	4.45	4.58	4.60	3.40
35	4.45	4.32	4.50	4.30	4.44	4.40	3.45
40	4.30	4.30	4.45	4.28	4.38	4.35	3.60

into the hypolimnion of the lake, thermal regime of that is greatly influenced by that advection.

Step-like changes of the temperature which is observed in temperature profiles of A-2, A-4 and A-5, just below the thermocline is also confirmed the advection of cold water in these layers (Hutchinson 1957). As is well known, heat flux which is supplied through thermocline into the hypolimnion can be expressed as follows, if heat is transported only by conduction,

$$dQ/dt = -c\rho k \frac{d\theta_z}{dZ}$$

where Q is total heat that has passed through unit area of thermocline at depth Z and θ_z is the temperature at Z.

But, in case of Harding Lake, heat is transported not only by conduction but also by advection, then the advection term must be added above equation. So that total heat can be expressed as follows,

$$dQ/dt = -C \cdot \rho \cdot K d\theta z/dZ + A$$

where A is advection. Using the temperature profiles of each successive period, total heat in water column of unit area of hypolimnion can be estimated, if heat flux through the bottom be negligible. Whole period of observation can be divided into four, that is, from July 6 to July 12, 12 to 18, 18 to 20 and 20 to 24. From the temperature difference of each depth in the hyplimnion between two profiles, $\varDelta Q$ of each layer can be obtained and also average temperature gradient at the center of thermocline can be obtained. Then, following four equations of total heat can be obtained by integration from the top to the bottom through hypolimnion.

$$Q_{6-12} = -0.0221 = 2.15K_1 + A_1$$

$$Q_{13-18} = -0.0418 = 3.03K_2 + A_2$$

$$Q_{18-20} = -0.1273 = 3.01K_3 + A_3$$

$$Q_{20-24} = +0.0946 = 2.75K_4 + A_4$$

If we assume that the coefficient of eddy conductivity, K, is of the order of 10^{-2} and stayed nearly constant through the whole period (Arai et al. 1974), then, we can put a reasonable value for K above equations and estimate aprxoimate values of advection for each period.

As a first approximation, if we applied 0.05 (cm^2/sec) as for K, then, we can obtain A as follows,

$$A_1 = -0.1296 \ \text{cal} \cdot \text{cm}^2/\text{hour}$$

$$A_2 = -0.1933 \quad '' \quad ''$$

$$A_3 = -0.2778 \quad '' \quad ''$$

$$A_4 = -0.0284 \quad '' \quad ''$$

Although the estimation of the advection A is quite rough but the same tendency obtained from the results of the water budget which were examined by Nakao et al. (1981), during the period.

It might be possible to estimate more precise values of advection using the data of radiation, but, as a first approximation, the values of the advection might be reasonable.

From this estimation, the advection from surrounding region which is considered mainly melt water supply from permafrost is clearly confirmed but the order of the volume of that is still under question.

The step-like changes of the temperature and the cooling of the hypolimnion are clear evidences of the advection and calculation of the heat flux also confirmed that advection numerically.

4. Conclusion

Thermal regimes of Harding Lake were investigated from the view point that those of the lake must be influenced by the effect of surrounding permafrost.

From the obtained temperature profiles, it might be considered that the melt water from surrounding permafrost advected into the lake and is cooling the hypolimnion during summer. By that cooling, particular changes of the temperature profiles below the thermocline were observed.

More precise analysis must be needed to clarify these particular thermal regime of Harding Lake.

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