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A NOTE ON THE WATER EXCHANGE BETWEEN THE SOUTH AND THE NORTH BASINS OF LAKE BIWA

By

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Abstract

An estimation on the water exchange between the south and the north basins of Lake Biwa, due to the water movement induced by the wind, was given by a numerical calculation. The model is two dimensional and a wind of 6 m/sec was simulated for 10 hours. Drift currents caused by the wind seem to be the most effective for the water exchange. During 20 hours, 2.93% of the total volume of water of the south basin is transported to the north basin, while 7.31% of the total volume of water of the south basin is transported from the north to the south basin. The mixing area of the waters of these two basins is spread to a width of 6 km.

1. Introduction

It is well known that the north and the south basins of Lake Biwa have considerably different properties of water. In view of the water resources, it is an important problem to clarify the process and the mechanism of water exchange between these two basins. The Seta River is the only effluent river of Lake Biwa. Therefore, the Seta brings about the southward current in the south basin, and the water from the north basin incessantly flows into the south basin. And, when we consider the water exchange between these two basins, the Seta River plays the most important role, if we don't take the evaporation into account. But there are some possibilities of water flow from the south to the north basin. The first is the oscillatory water flow of the surface seiches, but it may be unable to yield a large amount of water exchange between these two basins due to a short periods of flow of the surface seiches. The second is a density current in winter which is the water flow above the bottom slope of the basin (Okamoto*) and which is thought to happen intermittently. And the last is the water flow induced by the south wind and the internal seiches. Fig. 1 shows the records of the water temperature taken at site **A** shown in the map of Lake Biwa (Fig. 2) by Okamoto (1969), and wind speed taken at Mano (site **B** in Fig. 2) simultaneously. It is found from Fig. 1 that the sharp descent of the water temperature was caused on Aug. 9 by a strong south wind. Okamoto (1969) pointed out that the warm water in the upper layer was driven to the north, while the cold water in the lower layer of the north basin creeps

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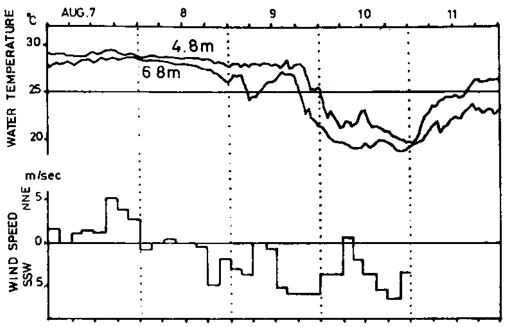

Fig. 1. The record of water temperature at site A, and of wind speed (NNE-SSW component) at site B (Mano) in August, 1967 (after Okamoto).

up above the sloping bottom of the lake, and he estimated that the volume transport of water from the south basin to the north was 15% of the total volume of the south basin, and that the volume transport from the north basin to the south was 20%. This last phenomenon is a very interesting and important one for the problem of the water exchange between the south and the north basins, and thus we made some numerical experiments to examine this problem.

2. Design of the model

For simplicity, we consider only the water motion in a two dimensional section along the longitudinal main axis, which is shown by a thick line in Fig. 2; i.e. we assume that all physical quantities do not vary according to the direction perpendicular to this section. The bottom profile of the section is shown by the broken line in Fig. 3, where the calculated area and the arrangement of the non-uniform grids are also shown by the solid lines.

We assume the hydrostatic balance in the vertical direction and we neglect the effect of the rotation of the earth. Therefore, the equations which govern the water motion are written as follows,

$$\frac{\partial u}{\partial t} + \frac{\partial}{\partial x}(u^2) + \frac{\partial}{\partial z}(u \cdot w) = -\frac{1}{\rho_0}\frac{\partial p}{\partial x} + \nu_h \frac{\partial^2 u}{\partial x^2} + \frac{\partial}{\partial z}\left(\nu_v \frac{\partial u}{\partial z}\right), \quad (1)$$

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0, \quad (2)$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(u \cdot \rho) + \frac{\partial}{\partial z}(w \cdot \rho) = \kappa_h \frac{\partial^2 \rho}{\partial x^2} + \kappa_v \frac{\partial^2 \rho}{\partial z^2}, \quad (3)$$

$$\frac{\partial p}{\partial z} = -\rho \cdot g, \quad (4)$$

where t is the time, the x-axis is chosen horizontally northwards and parallel to the

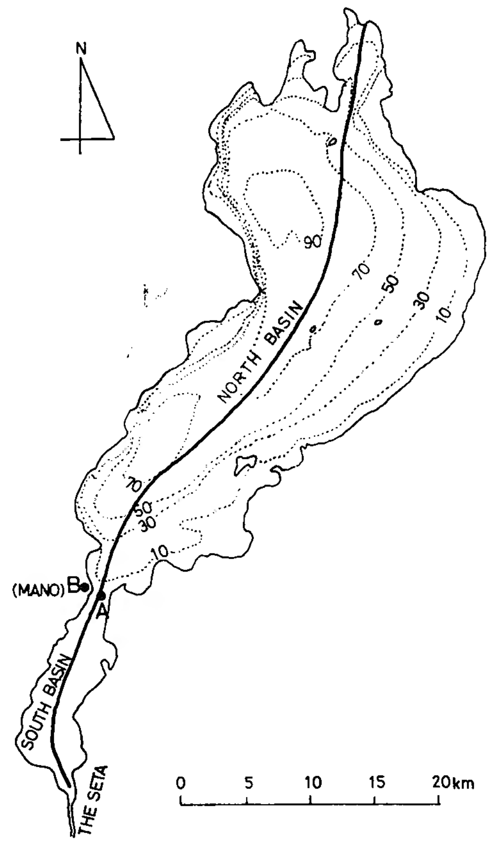

Fig. 2. Map of Lake Biwa. The thick line shows the longitudinal main axis.

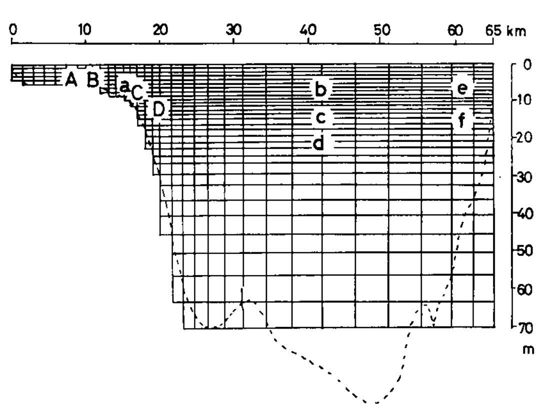

Fig. 3. The two-dimensional section along the main axis in Fig. 2. The broken line shows the bottom profile. The solid line shows the area of calculation and the arrangement of the non-uniform grids.

main axis of the lake, and the z-axis vertically upward, and u and w are the velocity components of x and z directions, respectively. ρ is the water density which is the function of the water temperature, and ρ_0 is the mean density of the entire lake. p is the hydrostatic pressure, and g (=980 cm sec^{-2}) the acceleration due to gravity. ν and κ are the eddy viscosity and the eddy diffusivity, respectively, and the suffixies h and v represent the horizontal and vertical components, respectively.

The boundary conditions are as follows,

$$\frac{\partial \zeta}{\partial t} = w, \quad p = \rho g \zeta, \quad and \quad \nu_v \frac{\partial u}{\partial z} = \tau, \quad at \quad z = 0, \tag{5}$$

$$\nu_v \frac{\partial u}{\partial z} = -\gamma_b^2 u|u|, \quad and \quad w = 0 \quad at\ the\ bottom, \tag{6}$$

where ζ is the elevation of the free surface measured from $z=0$, γ_b^2 the friction coefficient and τ the wind stress. We also assume that there is no heat flux through the bottom boundary and that there is water discharge through the Seta River with the speed of 3.22 cm/sec.

We assume that the lake water is at rest initially, and that the field of water temperature or water density is horizontally uniform in the basin, and the initial vertical profile of the water temperature is the typical distribution in Lake Biwa in summer as shown in Fig. 4.

We set ν_h and κ_h as 10^4 cm^2 sec^{-1} and κ_v as 0.1 cm^2 sec^{-1}. We assume that ν_v has the vertical distribution as shown in Fig. 4. The bottom friction coefficient γ_b is set as 2.6×10^{-3} after Hansen [1956]. Numerical integration was performed according to the well-known procedure.

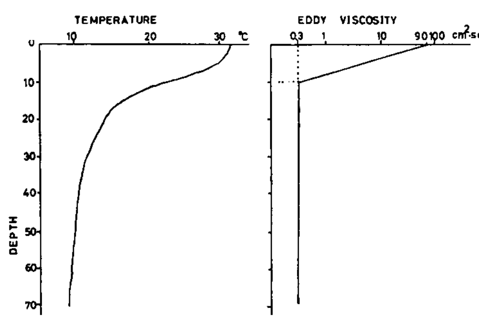

Fig. 4. The vertical profiles of the initial temperature (the left) and of the vertical eddy viscosity (the right).

3. Results and discussion

The numerical calculation was made under the following conditions; that the south wind of 6 m/sec began to blow abruptly at t=0 and stopped at t=10 hours, The integration was continued until $t=270$ hours. When the wind begins to blow, the warm water in the upper layer of the basin is driven to the north and thus the surface and internal seiches are induced in the basin.

Fig. 5 shows the time change of the water temperature at some representative points, which are shown in Fig. 3 by the letters, *a*, *b*, *c*, *d*, *e* and *f*. These water temperature fluctuations in this figure are induced by the internal seiches, and we can see that the fundamental mode of the internal seiche has a period of about 70 hours, while the first harmonic has a period of about 35 hours. Fig. 5(*a*), which corresponds to site A in Fig. 2, shows that the water temperature falls by 7.5°C between $t=0$ and $t=14$ hours. The magnitude of this temperature descent is found to be the same as that of Okamoto's observed value. After the wind stopped, the

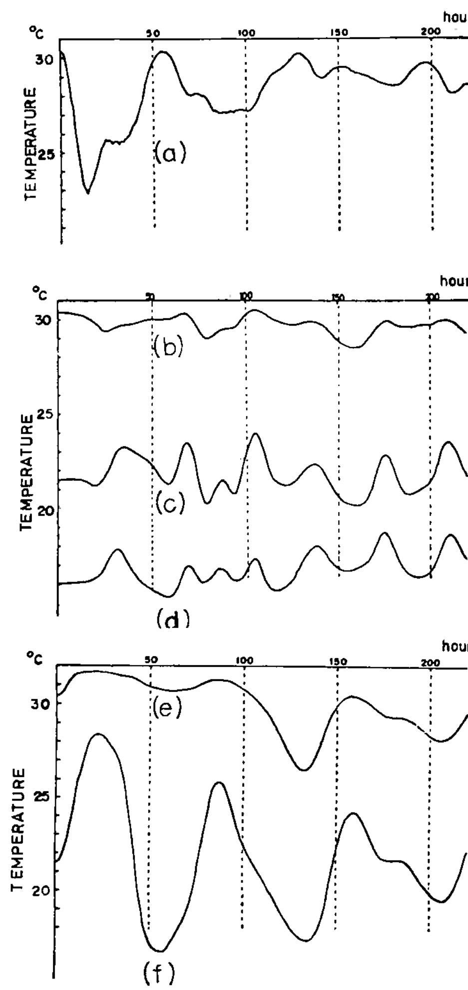

Fig. 5. The time change of the water temperature at some representative points shown in Fig. 3.

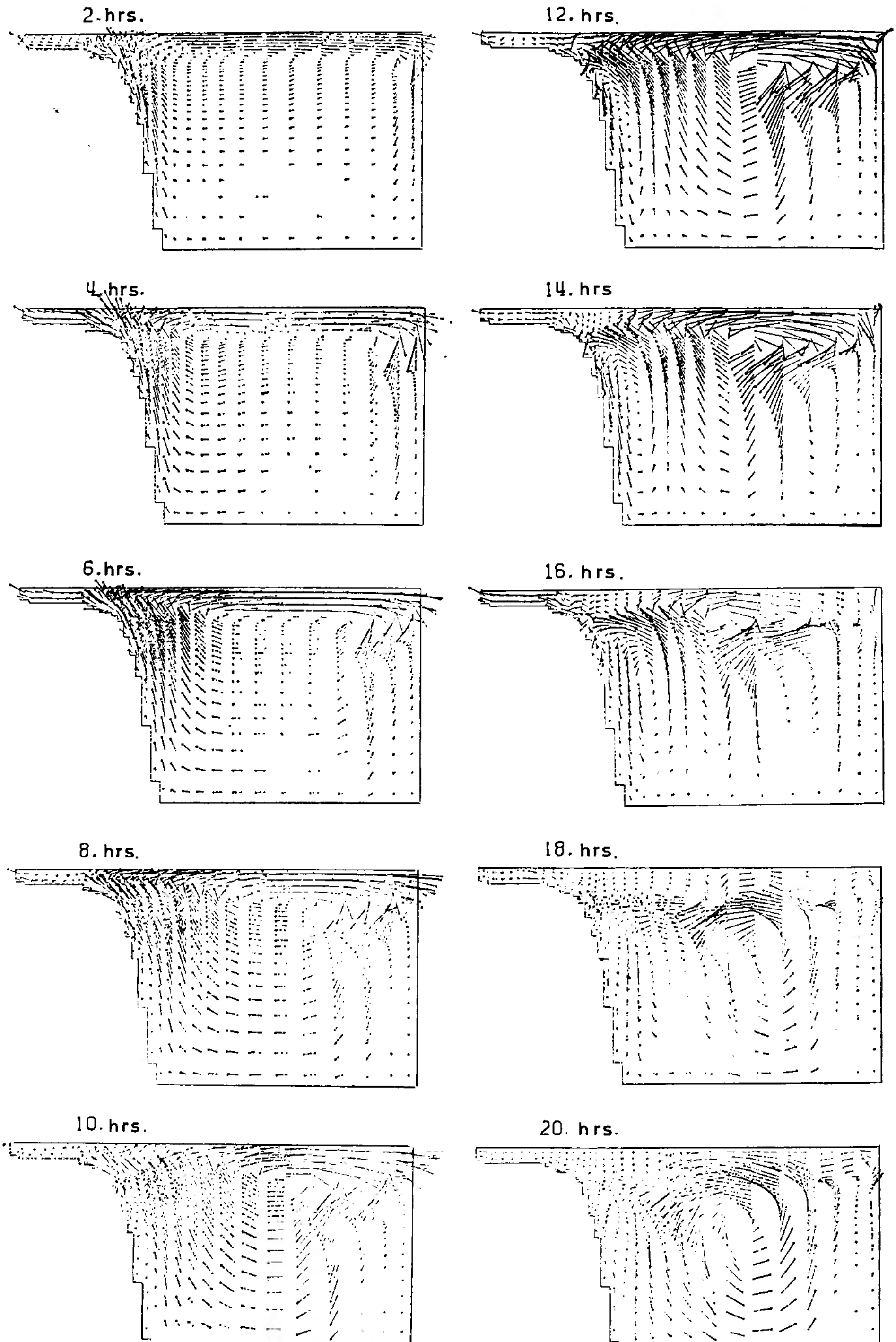

Fig. 6. The velocity distributions illustrated every two hours between $t=0$ and $t=20$ hours.

water temperature fluctuates with the period of 70 hours, the period of the fundamental internal seiche in this basin, but such a large temperature variation as 7.5 °C does not appear at this stage.

Fig. 6 shows the velocity distributions illustrated every two hours between $t=0$ and $t=20$ hours. It is shown that, at the intermediate region between the north and south basins, the water creeps up the sloping bottom while the wind blows, changes its direction at the head of the slope, and returns to the north basin through the upper part of the basin. It is evident that the sharp descent of the water temperature is caused by this 'creeping up' of the lower, cold water.

In the intermediate region between the south and the north basins, surface seiches bring about the water movement. Fig. 7 shows the time change of the horizontal velocity at some representative points which are plotted in Fig. 3. It is found that the horizontal velocity is oscillating with a period of 145 minutes. This oscillation is attributed to the uni-nodal surface seiche, but its calculated period is rather smaller than the observed period of 250 minutes in Lake Biwa (Imasato [1971]). This disagreement may be attributed to the assumption of the constant width of the basin along the main axis. Fig. 7 (*C*) and (*D*) show the 'creeping up' velocity, which becomes as large as 5 cm/sec, caused by the wind used in this experiment. Of course the 'creeping up' velocity is acompanied by small fluctuations due to the surface seiche.

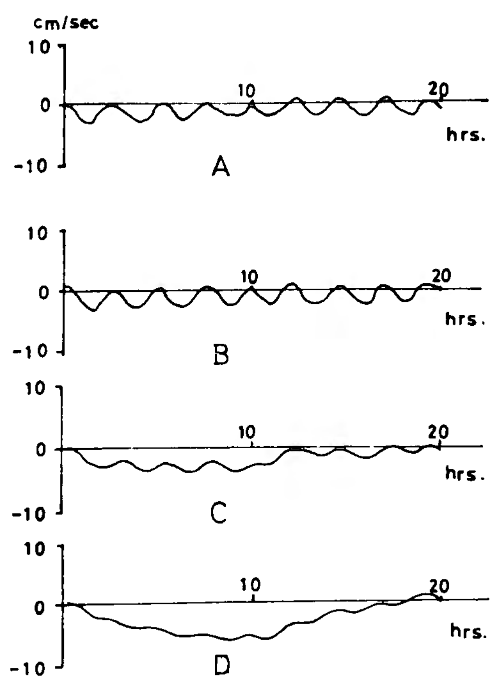

Fig. 7. The time change of horizontal velocity at some representative points shown in Fig. 3.

Now we will estimate the order of the water exchange between the south and the north basins. Supposing that the lake waters of these two basins are initially separated from each other at $x=14.5$ km, indicated by the broken line (line **D**) in Fig. 8, and that we give the indicator 1 to the water which is initially in the south basin (which shall be called the "south water"), and the indicator 0 to the water which is initially in the north basin (the "north water"), then, the water in any grid of the model basin has an indicator from 1 to 0 and this indicator expresses the rate of the volume of the south water to that of the total water in the grid. Fig. 8 shows the distribution of the indicator at $t=20$ hours. The south water goes into the north basin by the wind drag through the upper layer of the basin, and the north water into the south basin through the lower. The interface **D** is diffused and grows to about 5 km in width. The water volume transported from the south to the north basin across the interface **D** during 20 hours is 2.93 % of the total volume of the south basin, and the one from the north to the south is 7.31 % of the total volume of the south basin. Because of the water discharge from the Seta River, the interface **D** should move by 0.50 km to the south in this time interval. In the case of no water discharge, the volume transport from the south to the north and also the volume transport from the north to the south will be 5.12% of the total volume of the south basin.

The calculated volume transport to the north basin seems to be small, but it must be noted that the region containing the south water is spread to about 4 km to the north during 20 hours due to the effects of the wind drag, the diffusion and the mixing.

The surface seiche may only take a role as a diffusing force for the interface **D**. In the present calculation, it is impossible to evaluate the role of the internal seiche

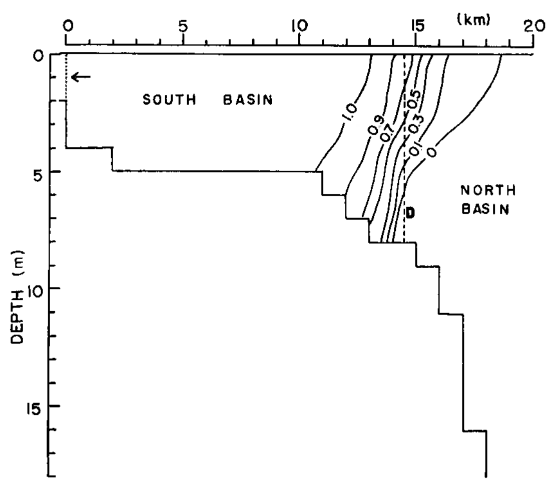

Fig. 8. The distribution of the "indicator" at $t=20$ hours. The broken line **D** denotes the initial interface between the south and the north waters.

in the volume transport from the south to the north basin, but it may not be very effective, considering the water temperature oscillation due to the internal seiche in Fig. 5(*a*), as well as the velocity distribution at $t=20$ hours in Fig. 6. Of course, in order to confirm the present results, we must deal with the three-dimensional model, and clarify the velocity field and the distribution of the water property after a great deal of observations.

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