Development of biogeochemical model coupled with hydrodynamic model of Lake Shumarinai

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To study an environmental impact such as a forest logging, especially impact on a lake ecosystem, it is necessary to develop a model of biogeochemical model coupled with hydrodynamic model. Here the results of application of hydrodynamic model to Lake Syumarinai are shown as an interim report.

Since a level of water surface fluctuate largely, a hydrodynamic structure in such system has been often modeled by 2D cross section model. But in the case of Lake Syumarinai the fluctuation of water surface level is not so large except in winter freezing period, and thus 3D leveled model can be applied to this system as done in estuarine system. The fundamental equation of 3D leveled model is described as follows:

Equation of continuity

$$\nabla \cdot \vec{\mathbf{v}} + \frac{\partial w}{\partial z} = 0$$

$$\nabla = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y} \right), \vec{\mathbf{v}} = (u, v)$$

Equation of momentum

$$\frac{\partial u}{\partial t} + \vec{\mathbf{v}} \cdot \nabla u + w \frac{\partial u}{\partial z} - fv = -\frac{1}{\rho_0} \frac{\partial p}{\partial x} + \frac{\partial}{\partial z} \left(K_M \frac{\partial u}{\partial z} \right) + F_X$$

$$\frac{\partial v}{\partial t} + \vec{\mathbf{v}} \cdot \nabla v + w \frac{\partial v}{\partial z} + fu = -\frac{1}{\rho_0} \frac{\partial p}{\partial y} + \frac{\partial}{\partial z} \left(K_M \frac{\partial v}{\partial z} \right) + F_Y$$

$$\rho g = -\frac{\partial p}{\partial z}$$

Equation of heat conservation

$$\frac{\partial\theta}{\partial t}+\vec{v}\cdot\nabla\theta+w\frac{\partial\theta}{\partial z}=\frac{\partial}{\partial z}\left(K_H\frac{\partial\theta}{\partial z}\right)+F_\theta$$

Where

x, y, z : coordinate system、 upward direction is positive in vertical direction

u, v, w: Current velocity component in x , y and z direction, respectively.

p : pressure, θ : temperature

f : Coliori's parameter, ρ_0 : representative density of water

ρ : water density

K_M : vertical eddy viscosity, K_H : vertical eddy diffusivity

A_M : horizontal eddy viscosity, A_H : horizontal eddy diffusivity

g : Gravity acceleration, t : time

The current velocity field in this lake is driven by inflow from watershed, an out flow from this lake, wind and a temperature gradient caused by the heat budget between water and atmosphere. Inflow, out flow and wind conditions are given as boundary conditions of model. As for the water temperature, parameters such as temperature of inflow water, solar radiation, infrared radiation from water surface, and atmospheric humidity, atmospheric temperature and turbulent heat transfer which control the heat budget between water and atmosphere are also given as boundary conditions of model. Provided that these parameters are given as a time dependent boundary conditions, the model can simulate the time evolution of physical processes in the lake. If anthropogenic impact would happen in the watershed, the model could predict the change of physical processes in the lake in response to this impact.

In the model, Lake Syumarinai is idealized by using 100 ×100m grid system. The area covers 8km×15km. In vertical direction, 8 levels (level thickness is 2m until 10 meter depth, and then level thickness is set to be 5m in deeper zone) system is employed in this study. The hindcast of physical processes by the model has been attempted in the case of year 2004. The observed fluctuation of water level is shown in Fig.1. The boundary conditions to the model such as water temperature of river water and meteorological parameters are given as a daily base. The parameter tuning in terms of vertical diffusivity was attempted, and found to be 0.01cm^2/s near thermocline (Fig. 2). The best-fit case was that the vertical diffusivity was assumed to be a function of

Richardson number. The comparison between the time series observed data and model results was also attempted. The reasonable agreement in the surface layer was obtained, whereas a distinct discrepancy was found in deeper layer (Fig. 3). Especially on September 9 when typhoon passed this area, the temperature in deeper layer rose rapidly in observed data due to strong mixing, but such tendency is not found in the model results. The model used daily average wind data, but typhoon passed within a few hours. We need hourly averaged data for model input at least.

The hydrodynamic model (Fig. 4) has completed except the period when typhoon was passing through the area under consideration.

In near future, we develop the biogeochemical model coupled with the hydrodynamic model.

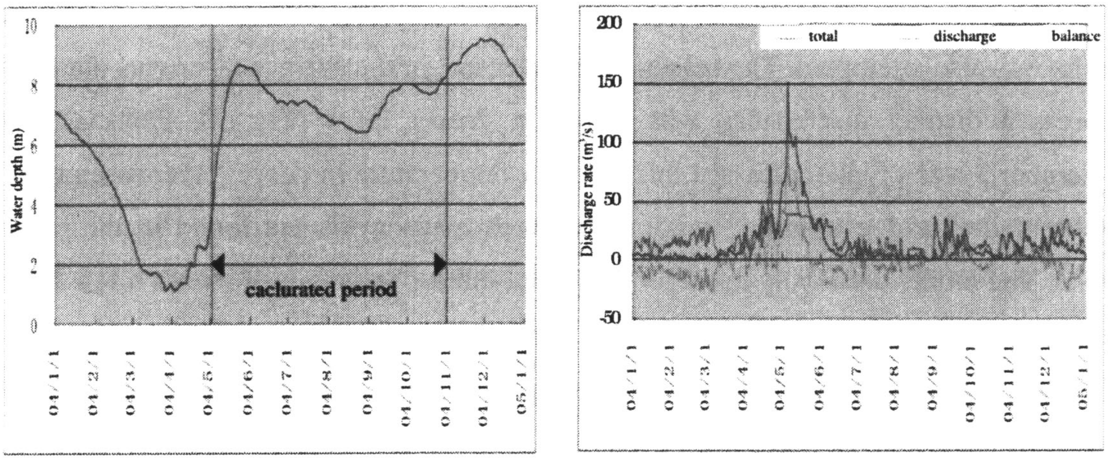
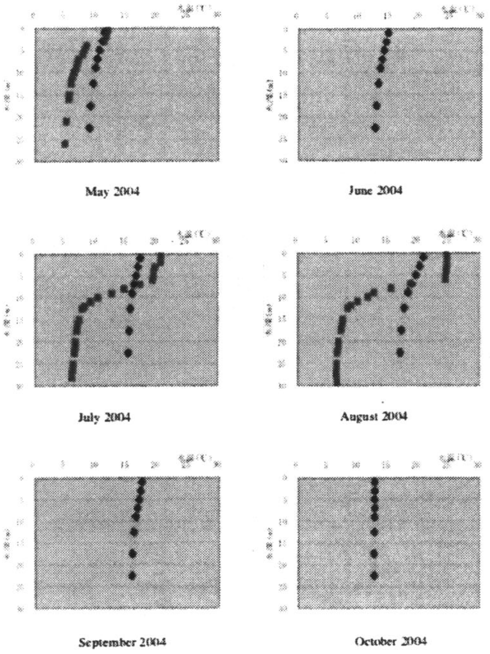
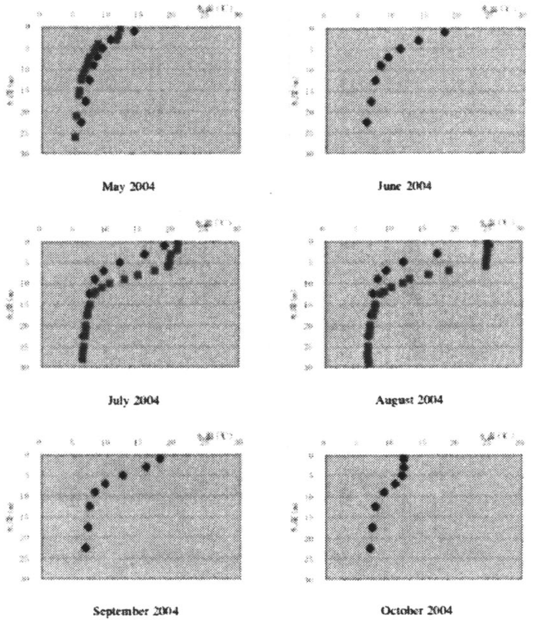


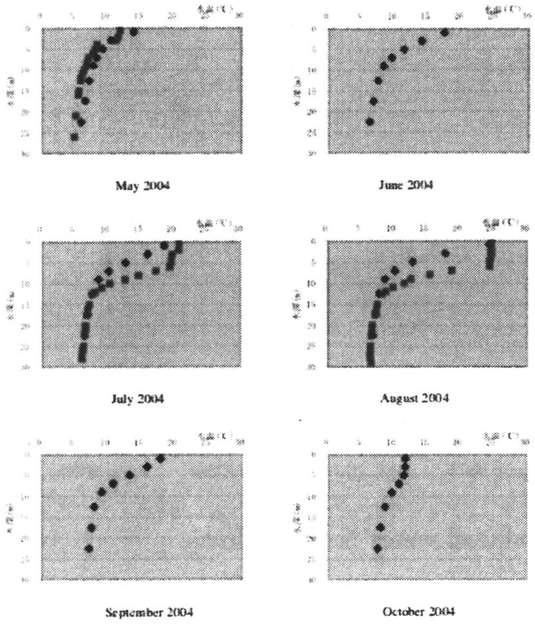
Fig. 1. The observed fluctuations of water level (left panel) and discharge rate (right panel) in 2004.



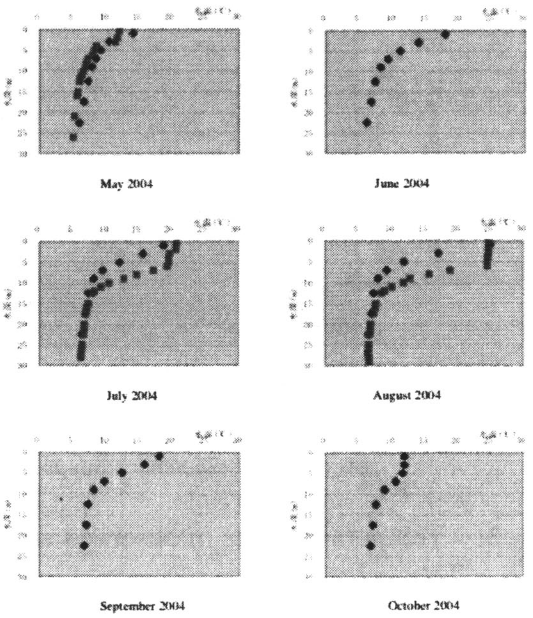
Vertical diffusivity = 1 cm^2/s



Vertical diffusivity = 0.0001 cm^2/s



Vertical diffusivity = 0.01 cm^2/s



Vertical diffusivity = assumed to be a function of Richardson number.

Fig. 2. Parameter tuning in terms of vertical diffusivity.

Observed (■) and calculated (◆) vertical profiles of water temperature were compared.

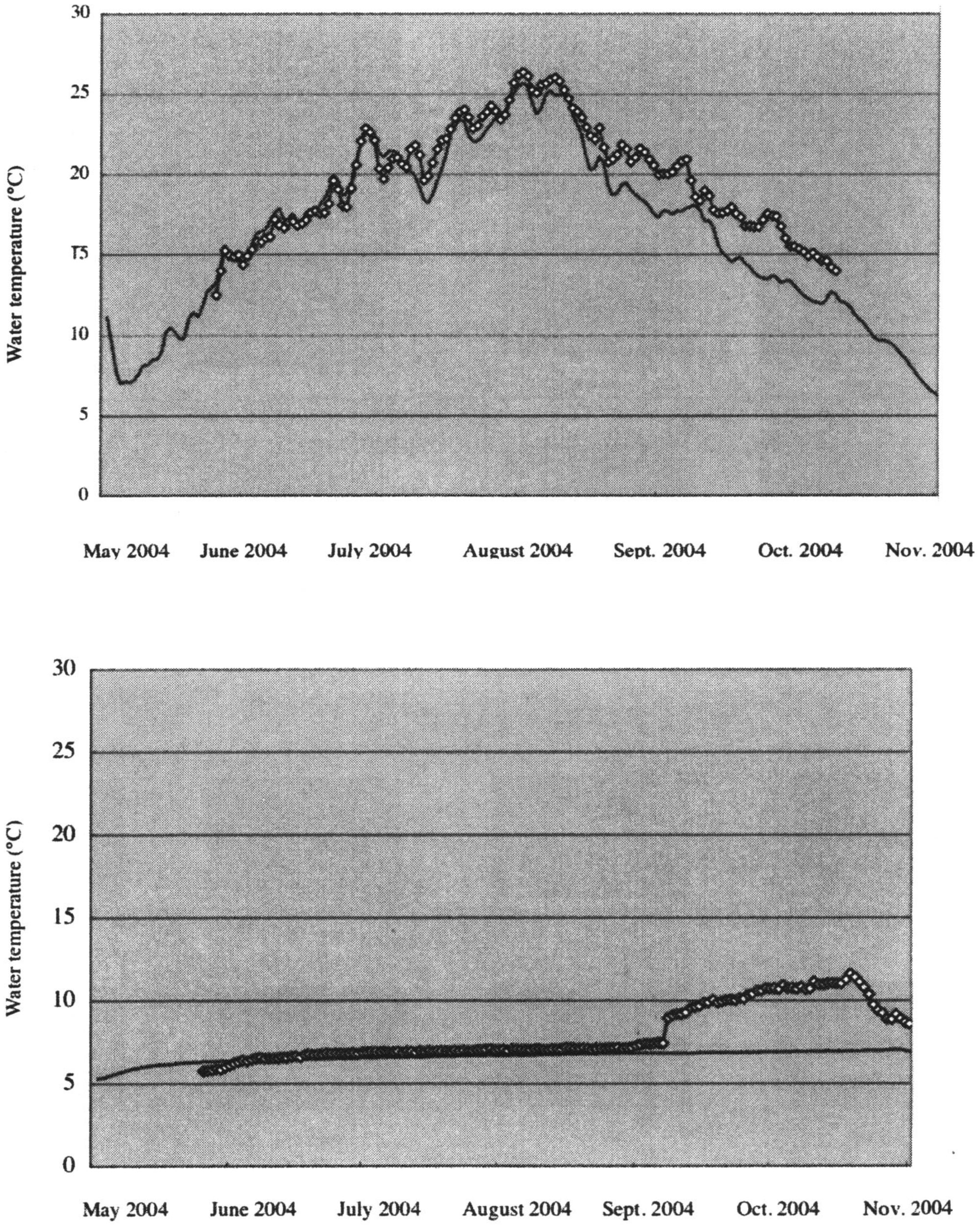


Fig. 3. Temporal change in observed and calculated water temperature.
(upper panel: surface layer; lower panel: 20m depth).
diamond: observation; solid line: calculation.

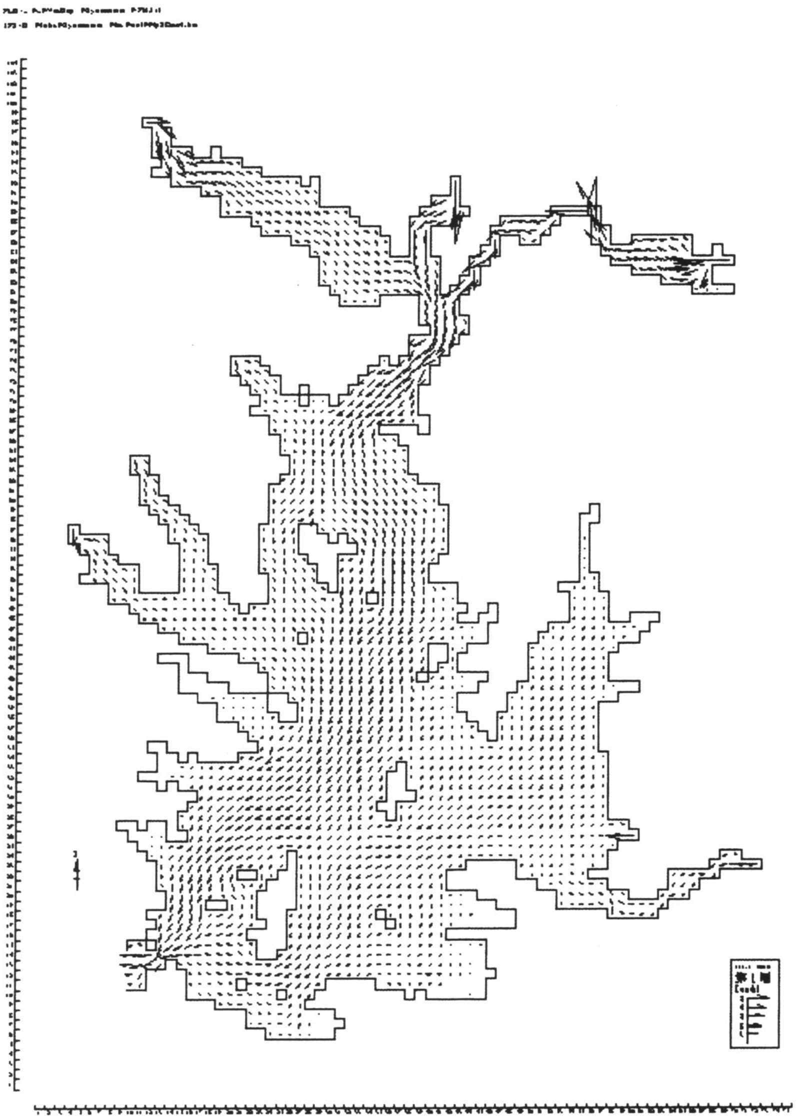


Fig. 4. Pattern of lake water flow simulated by the hydrodynamic model in Lake Shumarinai (average in August).