Simulation of methane dynamics in a mid-latitude eutrophic lake with constraints using incubation data

Hiroki Iwata[*1], Wataru Nakano[1], Victor Stepanenko[2], Daiki Kobayashi[3], Tsukuru Taoka[1], Masayuki Ito[4], Yuuichi Miyabara[5], Ryuichi Hirata[6], and Yoshiyuki Takahashi[6]
1 Department of Environmental Science, Shinshu University, Matsumoto, Japan.
2 Research Computing Center, Moscow State University, Moscow, Russia.
3 XXX, Japan Meteorological Agency, XXX, Japan.
4 School of Human Science and Environment, University of Hyogo, Himeji, Japan.
5 Institute of Mountain Science, Shinshu University, Suwa, Japan.
6 National Institute for Environmental Studies, Tsukuba, Japan

Lake is an important source of methane (CH_4) contributing to approximately 10 % of total natural source. Developing a lake CH_4 emission model is one of the tasks for improving the accuracy of climate simulation. LAKE2.0 is a process-based lake simulation model which includes CH_4 dynamics module, and have been evaluated against CH_4 dynamics in boreal lakes. Further validations are called for to apply the model to lakes with different trophic level in different climate. We applied and validated this lake model to a mid-latitude eutrophic lake, Lake Suwa, in Japan where data of eddy covariance CH_4 flux, dissolved CH_4 concentration, and production and oxidation rate obtained by incubation experiments are available.

LAKE2.0 is a horizontally-integrated one-dimensional lake model which is composed of physical and process-based biogeochemical modules. The lake mixing and turbulent diffusion of dissolved gasses are calculated based on the k-e turbulence closure scheme. CH_4 production is modeled to increase with temperature with Q10 relationship and to decrease with sediment depth, with a parameter to determine the maximum CH_4 production rate at the sediment surface. CH_4 oxidation is modeled to increase with dissolved CH_4 and oxygen concentrations, with a parameter to determine the maximum CH_4 oxidation rate without CH_4 and oxygen limitation. We improved the accuracy of oxidation module by adding Q10 temperature dependence to the default module. Oxygen dynamics are also incorporated in the model.

Lake Suwa is a shallow eutrophic lake located in central Japan. In this lake, we have installed an observation mast at a pier on the southeast shore where meteorological conditions were monitored. These data were used to drive the model simulation. Lake water and sediment were periodically sampled, and incubated under different temperature conditions to determine CH_4 oxidation and production rates, respectively, and their temperature dependence.

Simulation of water temperature and sensible and latent heat fluxes into the atmosphere showed a reasonable agreement with observations, suggesting the physical module of the model is relatively sound. Whereas, simulated dissolved oxygen concentration was overestimated during winter, and consumption of oxygen in the bottom water layer in summer was not reproduced well. We adjusted sediment oxygen demand in the oxygen dynamics module and this improved the reproducibility of summer dissolved oxygen concentration. The overestimation in winter dissolved oxygen concentration remained, however the oxidation rate has less dependency on dissolved oxygen concentration in the oxygen level observed.

The parameters in the CH_4 production and oxidation modules were determined using production and oxidation rate data obtained from incubation experiments. By optimizing the parameters, the production module can explain 49 % of variation in observations. Similarly, the parameters for oxidation were determined, and the reproducibility of oxidation module was improved by taking the temperature dependence into account, explaining 40 % of variation in observations.

Simulated dissolved CH_4 concentration showed a reasonable agreement with the observations owing to the parameter optimization and by considering the temperature dependence in oxidation module. Resulting CH_4 emission simulated showed a reasonable seasonal variation with 25 % overestimation compared to the observations. Simulated diffusive emission contributed to, on average, 7 % of the total emission. This contribution was underestimated compared to partitioned eddy covariance diffusive CH_4 flux, suggesting a need to improve the module of emission pathways.

In conclusions, the structure of LAKE2.0 model is sound, and the use of appropriately determined parameters results in a reasonable simulation of CH_4 dynamics. Further efforts should be made to improve the biogeochemical module and to predict the variation of parameters among different lakes.