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Towards better environmental software for spatio-temporal ecological models: Lessons from developing an intelligent system supporting phytoplankton prediction in lakes[☆]

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ABSTRACT

Implementing a case study using existing spatio-temporal ecological models could be time-consuming and error-prone. To alleviate this problem, several strategies, aiming to achieve a robust but easy-to-use environmental software, were used to develop an intelligent system supporting phytoplankton prediction in **Lakes** (iLake). This environmental software coupled three modules (a two-dimensional hydrodynamic module, a mass-transport module and a phytoplankton kinetics module) together to predict the time dynamics of phytoplankton distribution in a lake. A case study of phytoplankton prediction in Lake Taihu using iLake demonstrated its high potential, but low learning curve, for lake modeling.

1. Introduction

Spatio-temporal ecological models are valuable in describing spatial heterogeneity and time dynamics of complex ecosystems (Chen et al., 2011; Jørgensen, 2008). However, it is generally time-consuming and error-prone for users to implement a case study using many of the existing spatio-temporal ecological models. This is particularly true for the users with limited modeling skills (e.g., managers). The difficulties of using spatio-temporal ecological models mainly result from (1) large spatio-temporal data set required for model initialization, (2) limited tools for data processing and model calibration, and (3) different data formats from one model to another. To simplify the use of the existing spatio-temporal ecological models, many strategies have been proposed for developing environmental software (Argent et al., 2009; Craig, 2004; McIntosh et al., 2011). However, many of the existing environmental software still require a significant learning curve that could be difficult for primary users to follow.

In this study, an **i**ntelligent system supporting phytoplankton prediction in **Lakes** (iLake) was developed to simulate the time evolution of phytoplankton distribution in a lake. The ideas behind the software development were discussed to benefit the development of other environmental software for spatio-temporal ecological models. A case study of phytoplankton prediction in Lake Taihu (in China) was presented to show the practical use of Lake PPS.

2. iLake description

Algal blooms are severe environmental problems worldwide (Paerl and Huisman, 2008). Forecasting phytoplankton dynamics could help managers to identify algal blooms in lakes (Huang et al., 2012a). A spatial hydrodynamic–phytoplankton model has been developed by Huang et al. (2012a) to forecast time dynamics of phytoplankton distribution in Lake Taihu, a large shallow lake in China. To be of practical use in water management, an intelligent system supporting phytoplankton prediction in **Lakes** (iLake) was developed to run this spatio-temporal model by different user groups. iLake was originally developed for Lake Taihu with a name of Taihu PPS (Huang et al., 2012b). However, it was updated to use in any large eutrophic lake.

2.1. Modules in iLake

iLake integrated three modules, i.e., a two-dimensional hydrodynamic module, a mass-transport module and a phytoplankton kinetics module (Fig. 1). The hydrodynamic module simulated the vertically-averaged

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[☆] **Software availability**.
Name of software: an **i**ntelligent system supporting phytoplankton prediction in **Lakes** (iLake).
Developer: Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences.
Documentation: http://www.escience.cn/people/elake/index.html.
First available year: 2013.
Programming language: Python and FORTRAN.
Contact person: Junfeng Gao; Jiacong Huang E-mail: gaojunf@niglas.ac.cn; jchuang@niglas.ac.cn.

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1574-9541/

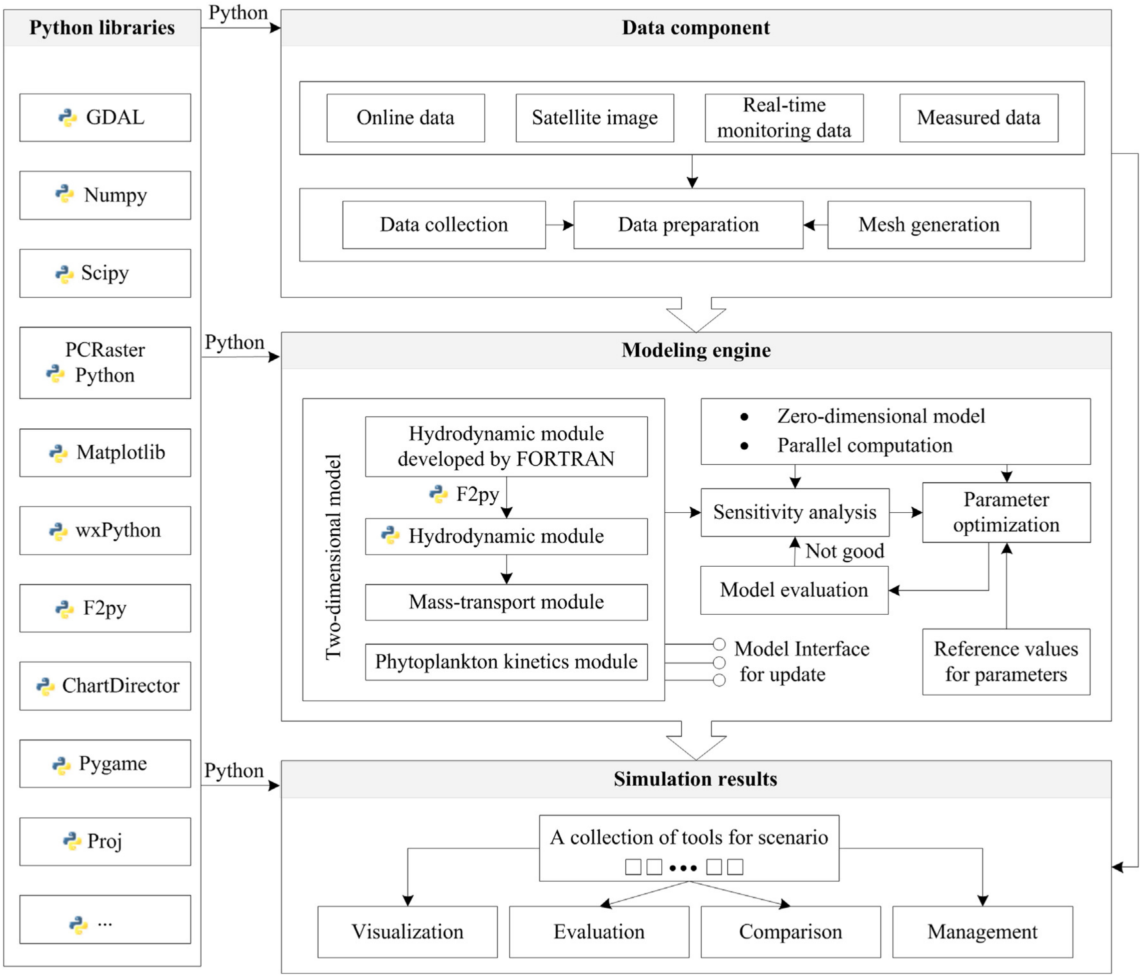

Fig. 1. Software architecture of iLake. The symbol represents the Python library.

water velocity of lakes with the following governing equations (Cheng et al., 2006; Huang et al., 2012a).

$$\frac{\partial h}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial z}{\partial x}=\frac{\tau_x^z-\tau_x^b}{h}+fv \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial z}{\partial y}=\frac{\tau_y^z-\tau_y^b}{h}-fu \tag{3}$$

where u and v are the vertically-averaged water velocity components in the horizontal x and y directions; t is the time; z and h are the water level and depth, respectively; τ_x^z and τ_y^z are the surface wind stress components in the x and y directions; τ_x^b and τ_y^b are the bottom stress components in the x and y directions; and f is the Coriolis parameter.

The mass-transport module calculated the horizontal transport of phytoplankton and nutrients in the water based on the simulation results from hydrodynamic module. The dissolved (e.g., nitrite, nitrate and ammonia) matter followed water movement simultaneously. However, phytoplankton biomass was assumed to remain at the water surface when wind velocity is less than 2 m/s (Huang et al., 2012a).

The phytoplankton kinetics model describes the biological and physical processes of phytoplankton using the following mass conservation equation,

$$\frac{dChl}{dt}=(U-RA-MA-SA-GA-EA)Chl \tag{4}$$

where Chl represents the phytoplankton biomass; and U, RA, MA, SA, GA and EA represent the phytoplankton growth, respiration, mortality, sinking, grazing and excretion rates respectively. More details of these three modules can be found in Huang et al. (2012a).

2.2. Software development

iLake was developed using Python programing language and its extensive libraries (Fig. 1). Numpy, Scipy and PCRaster Python were used for map and matrix algebra, and GDAL and Proj supported GIS data transformation. The user interfaces and data visualization were implemented with wxPython, Matplotlib, ChartDirector and Pygame. F2py compiled the hydrodynamic model programed with FORTRAN into a Python library. A data component was developed to generate the required inputs for models in iLake. A modeling engine implemented module communication, sensitivity analysis, parameter optimization and model evaluation. Scenario-based tools were developed to manage the simulation results.