## Dataset Title

Macrosystems EDDIE Module 2: Cross-Scale Interactions

## Short name or nickname you use to refer to this dataset:

Macrosystems EDDIE Module 2

## Abstract

Environmental phenomena are often driven by multiple factors that interact across different spatial and temporal scales. In freshwater lakes and reservoirs worldwide, phytoplankton blooms are increasing in frequency and severity due to cross-scale interactions between local, regional, and continental drivers, including land use (local) and climate change (regional) drivers. Because it is difficult to predict how lakes will respond to interacting processes operating at multiple scales, many researchers are using models to manipulate climate and land use scenarios and see how lakes respond. Lake simulation models provide a powerful tool for exploring how phytoplankton blooms respond to multiple drivers via cross-scale interactions.  
  
In this module, students will learn how to set up a lake model and "force" the model with climate and land use scenarios to test hypotheses about how local and regional drivers interact to promote or suppress phytoplankton blooms in different lakes.

The overarching goal of this module is for students to explore new modeling and computing tools while learning fundamental concepts about how lake phytoplankton blooms occur through cross-scale interactions. The A-B-C structure of this module makes it flexible and adaptable to a range of student levels and course structures.

This dataset contains instructional materials and the files necessary to run the complete module. Readers are referred to the GLM science manual (Hipsey et al. 2014) for further details on model configuration.

## Investigators

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| First Name | Middle Initial | Last Name | Organization | e-mail address | ORCID ID (optional) |
| Cayelan | C. | Carey | Virginia Tech | Cayelan@vt.edu | [0000-0001-8835-4476](http://orcid.org/0000-0001-8835-4476) |
| Kaitlin | J. | Farrell | Virginia Tech | farrellk@vt.edu | [0000-0002-4709-7749](https://orcid.org/0000-0002-4709-7749) |

## Other personnel names and roles

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| First Name | Middle Initial | Last Name | Organization | e-mail address | ORCID ID (optional) | Role in project |
|  |  |  |  |  |  |  |

## Keywords

Carey Lab, Virginia Tech, modeling, lakes, climate, land use, chlorophyll-a, teaching

## Funding of this work:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| PI First Name | PI Middle Initial | PI Last Name | PI ORCID ID (optional) | Title of Grant | Funding Agency | Funding Identification Number |
| Cayelan | C. | Carey | [0000-0001-8835-4476](http://orcid.org/0000-0001-8835-4476) | A macrosystems science training program: developing undergraduates' simulation modeling, distributed computing, and collaborative skills | National Science Foundation | EF 1702506 |

## Timeframe

* Begin date: 2017-08-13 (Module “birthday”)
* End date: 2019-03-19 (Module publication date)
* Data collection ongoing/completed: Completed

## Geographic location

* Verbal description: The Department of Biological Sciences at Virginia Tech is located in Blacksburg, Virginia, USA
* North bounding coordinates (decimals): 37.229596
* South bounding coordinates (decimals): 37.228545
* East bounding coordinates (decimals): -80.424863
* West bounding coordinates (decimals): -80.426228

## Taxonomic species or groups

N/A

## Methods

**Module development and testing**

Module teaching materials were developed by C.C. Carey and K.J. Farrell to provide instructors of undergraduate ecology courses with a ready-to-use, adaptable module that could be implemented in a 3-4 hour time period.

As the second module within the suite of Macrosystems EDDIE ([www.macrosystemseddie.org](http://www.macrosystemseddie.org)) teaching materials, this module was developed to teach students fundamental concepts about macrosystems ecology, and how a macrosystems approach can be used to understand how lakes are affected by drivers that operate on multiple, interconnected temporal and spatial scales. As a secondary goal, Macrosystems EDDIE modules introduce students to advanced computational tools as a way to manage, analyze, visualize, and interpret high-frequency and long-term ecological data sets.

The specific student learning goals for this module are that by the end of the module, students will be able to:

- Understand the concepts of macrosystems ecology and cross-scale interactions, and how different ecological processes can interact at local, regional, and continental scales.

- Simulate phytoplankton blooms in multiple lakes using ecosystem models of lake water quality set up with publicly-available high-frequency sensor datasets (Activity A).

- Test the effects of a climate scenario on the different lake models, and examine how the timing and intensity of phytoplankton blooms change with climate warming (Activity B).

- Examine the effects of both local nutrient loading and regional climate forcing to determine how factors acting at different scales interact to affect the intensity and timing of phytoplankton blooms (Activity C).

- Predict how lake phytoplankton blooms may respond globally to changing climate and land use.

The module was assessed by volunteer faculty testers during the 2017-2018 and 2018-2019 academic years. Faculty testers provided feedback that was used to update and optimize teaching materials. Carey and Farrell also used student pre- and post-module assessment questions to gauge effectiveness of teaching materials for achieving module learning goals. Pedagogical specialists with the Science Education Resource Center at Carleton College assisted with assessment development and implementation.

**Underlying model data**

The module uses the General Lake Model (GLM; Hipsey et al. 2014), an open-source hydrodynamic simulation model, to simulate lake temperatures and other physical limnology metrics over the model time period. The GLM model is paired with the Aquatic Ecodynamics library (AED; Hipsey et al. 2013) to simulate chemical and biological dynamics in the lake. GLM-AED in this module (version 2.2.0rc5) uses the ‘GLMr’ and ‘glmtools’ packages (Read and Winslow 2016, Winslow and Read 2016), which allow the GLM model to be run and output analyzed through the R statistical environment. The module includes datasets for two lakes that are part of the Global Lakes Ecological Observatory Network (GLEON; <http://gleon.org/>), Lake Mendota (Wisconsin, USA) and Lake Sunapee (New Hampshire, USA). The model representation of each lake has been simplified in multiple ways for the purpose of teaching this module: for example, while both Lake Mendota and Lake Sunapee have multiple surface inflows, they have been simplified to one inflow in the model.

Within the module, lake configuration files (glm2.nml, aed2.nml, aed2\_phyto\_pars.nml, aed2\_zoop\_pars.nml) have been coarsely calibrated for each lake. Meteorological driver data (met\_hourly.csv) for each lake were compiled at an hourly time step from the North American Land Data Assimilation System (NLDAS-2; Cosgrove et al. 2003) and include air temperature, short and long wave radiation, relative humidity, wind speed, and precipitation (rain and snow). Variations of the met\_hourly.csv file were created to simulate different air temperature warming scenarios; files appended with "\_plus2", "\_plus4", and "\_plus6" have air temperatures 2, 4, or 6 degrees Celsius warmer, respectively, than the observed air temperature for each hour included in met\_hourly.csv. Simplified surface water inflow files (inflow.csv) for each lake were based on existing GLM model calibrations for Lake Mendota and Lake Sunapee, and include discharge volume, water temperature, and nitrogen and phosphorus concentrations at a daily timestep. Variations of the inflow.csv file were created to simulate different land use change scenarios, as represented by changes in the concentration of filterable reactive phosphorus (PHS\_frp); files appended with “twoP”, “fourP”, and “sixP” and PHS\_frp concentrations that are 2, 4, or 6 times the concentration in the baseline model. Each lake model also includes a surface outflow file (outflow.csv) that is based on existing GLM model calibrations for Lake Mendota and Lake Sunapee.

For more information, we refer users to the website and publications listed below.

**Website & publications**

Carey, C.C., and K.J. Farrell. 13 August 2017. Macrosystems EDDIE: Cross-Scale Interactions. Macrosystems EDDIE Module 2, Version 2. <http://module2.macrosystemseddie.org>.

Farrell, K.J., & C.C. Carey. 2018. Power, pitfalls, and potential for integrating computational literacy into undergraduate ecology courses. *Ecology and Evolution* 8: 7744-7751. DOI: [10.1002/ece3.4363](http://doi.org/10.1002/ece3.4363)

Carey, C. C. and Gougis, R. D. 2017. Simulation modeling of lakes in undergraduate and graduate classrooms increases comprehension of climate change concepts and interest in computational tools. *Journal of Science Education and Technology* 26: 1–11. DOI: [10.1007/s10956-016-9644-2](http://doi.org/10.1007/s10956-016-9644-2)

**Notes and Comments**

Cosgrove, B. A., Lohmann, D., Mitchell, K. E., Houser, P. R., Wood, E. F., Schaake, J. C., Robock A., Marshall, C., Sheffield, J., Duan, Q., Luo, L., Higgins, R. W., Pinker, R. T., Tarpley, J. D., & Meng, J. (2003). Real‐time and retrospective forcing in the North American Land Data Assimilation System (NLDAS) project. Journal of Geophysical Research: Atmospheres, 108(D22).

Hipsey, M. R., L.C. Bruce, and D.P. Hamilton. 2013. Aquatic Ecodynamics (AED) model library and science manual. Draft v4, The University of Western Australia, Perth, Australia. 34 pp. Available: http://aed.see.uwa.edu.au/research/models/aed/Download/AED\_ScienceManual\_v4\_draft.pdf

Hipsey, M. R., L.C. Bruce, and D.P. Hamilton. 2014. GLM- General Lake Model: Model overview and user information. AED Report #26, The University of Western Australia, Perth, Australia. 42 pp. Available: <http://aed.see.uwa.edu.au/research/models/GLM/>

Read, J.S., and L.A. Winslow. 2016. glmtools R package v.0.14.6. Available: <https://github.com/USGS-R/glmtools>

Winslow, L.A., and J.S. Read. 2016. GLMr R package v.3.1.15 and GLMr R package default files. GLMr: A General Lake Model (GLM) base package. DOI: [10.5281/zenodo.595574](http://doi.org/10.5281/zenodo.595574)

## 

## **Data** **Entities** (this table goes into the instructional materials README)

# instructor\_materials.zip Contents

## File Types and Descriptions

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Entity Type** | **Externally Defined Format** | **Description** |
| instructor\_manual.pdf | image/pdf | image/pdf | Instructor guidelines and troubleshooting for the module. Includes answer key to student handout and discussion questions. |
| instructor\_powerpoint.pdf | image/pdf | image/pdf | Presentation to introduce core concepts and module activities at the beginning of module instruction. While this version has been archived as a pdf file, we refer interested readers to <http://www.module2.macrosystemseddie.org/> for editable powerpoint files. We note that some changes may be made to the files on the website as they are updated over time. |
| getting\_started\_mod2.pdf | image/pdf | image/pdf | Additional powerpoint slides that walk through module setup step-by-step and provide troubleshooting tips for common challenges students experience in the classroom. While this version has been archived as a pdf file, we refer interested readers to <http://www.module2.macrosystemseddie.org/> for editable powerpoint files. We note that some changes may be made to the files on the website as they are updated over time. |
| ready\_set\_eddie.pdf | image/pdf | image/pdf | Instructor introduction to R and the General Lake Model (GLM). |
| r\_you\_ready\_for\_eddie\_mod2.pdf | image/pdf | image/pdf | Step-by-step guide to download R, RStudio, and module files. |
| student\_handout.pdf | image/pdf | image/pdf | Handout for students to work through while completing the module. While this version has been archived as a pdf file, we refer interested readers to <http://www.module2.macrosystemseddie.org/> for editable Microsoft Word files. We note that some changes may be made to the files on the website as they are updated over time. |

## Data Entities within cross\_scale\_interactions.zip (this table goes into the cross\_scale\_interactions README)

# cross\_scale\_interactions.zip Contents

## File Types and Descriptions

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Entity Type** | **Externally Defined Format** | **Description** |
| CSI\_R\_Script.R | text/x-rsrc | application/R | Script that outlines the Activity A, B, and C steps that students complete as part of the module. |
| Mendota folder |  |  |  |
| glm2.nml |  | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for the Lake Mendota General Lake Model (GLM). Save as .nml to run. |
| aed2.nml |  | application/GLM | File to configure lake biogeochemical parameters for Aquatic Ecodynamics (AED) to simulate oxygen, carbon, phosphorus, and nitrogen dynamics, among others for Lake Mendota. Save as .nml to run. |
| aed2\_phyto\_pars.nml |  | application/GLM | File to configure lake phytoplankton parameters for AED for Lake Mendota. Save as .nml to run. |
| aed2\_zoop\_pars.nml |  | application/GLM | File to configure lake zooplankton parameters for AED for Lake Mendota. Save as .nml to run. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data for Lake Mendota. |
| met\_hourly\_plus2.csv |  |  | Meteorological GLM driver data for a year-round +2°C climate scenario for Lake Mendota. |
| met\_hourly\_plus4.csv |  |  | Meteorological GLM driver data for a year-round +4°C climate scenario for Lake Mendota. |
| met\_hourly\_plus6.csv |  |  | Meteorological GLM driver data for a year-round +6°C climate scenario for Lake Mendota. |
| inflow.csv |  |  | Surface inflow GLM driver data for a baseline simulation based on observed data for Lake Mendota. |
| inflow\_twoP.csv |  |  | Surface inflow GLM driver data for a 2× filterable reactive phosphorus (PHS\_frp) land use change scenario for Lake Mendota. |
| inflow\_fourP.csv |  |  | Surface inflow GLM driver data for a 4× filterable reactive phosphorus (PHS\_frp) land use change scenario for Lake Mendota. |
| inflow\_sixP.csv |  |  | Surface inflow GLM driver data for a 6× filterable reactive phosphorus (PHS\_frp) land use change scenario for Lake Mendota. |
| outflow.csv |  |  | Surface outflow GLM driver data based on observed data for Lake Mendota. |
| Sunapee folder |  |  |  |
| glm2.nml |  | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for the Lake Sunapee General Lake Model (GLM). Save as .nml to run. |
| aed2.nml |  | application/GLM | File to configure lake biogeochemical parameters for Aquatic Ecodynamics (AED) to simulate oxygen, carbon, phosphorus, and nitrogen dynamics, among others for Lake Sunapee. Save as .nml to run. |
| aed2\_phyto\_pars.nml |  | application/GLM | File to configure lake phytoplankton parameters for AED for Lake Sunapee. Save as .nml to run. |
| aed2\_zoop\_pars.nml |  | application/GLM | File to configure lake zooplankton parameters for AED for Lake Sunapee. Save as .nml to run. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data for Lake Sunapee. |
| met\_hourly\_plus2.csv |  |  | Meteorological GLM driver data for a year-round +2°C climate scenario for Lake Sunapee. |
| met\_hourly\_plus4.csv |  |  | Meteorological GLM driver data for a year-round +4°C climate scenario for Lake Sunapee. |
| met\_hourly\_plus6.csv |  |  | Meteorological GLM driver data for a year-round +6°C climate scenario for Lake Sunapee. |
| inflow.csv |  |  | Surface inflow GLM driver data for a baseline simulation based on observed data for Lake Sunapee. |
| inflow\_twoP.csv |  |  | Surface inflow GLM driver data for a 2× filterable reactive phosphorus (PHS\_frp) land use change scenario for Lake Sunapee. |
| inflow\_fourP.csv |  |  | Surface inflow GLM driver data for a 4× filterable reactive phosphorus (PHS\_frp) land use change scenario for Lake Sunapee. |
| inflow\_sixP.csv |  |  | Surface inflow GLM driver data for a 6× filterable reactive phosphorus (PHS\_frp) land use change scenario for Lake Sunapee. |
| outflow.csv |  |  | Surface outflow GLM driver data based on observed data for Lake Sunapee. |

## Data Table Structure (these tables go into the cross\_scale\_interactions README)

**met\_hourly.csv, met\_hourly\_plus2.csv, met\_hourly\_plus4.csv, met\_hourly\_plus6.csv**

|  |  |  |  |
| --- | --- | --- | --- |
| Column name | Description | Unit or  code explanation or date format | Empty value code |
| time | Date and time of sampling | YYYY-MM-DD HH:MM:SS | NA |
| ShortWave | Short wave radiation | wattsPerSquareMeter | NA |
| LongWave | Long wave radiation | wattsPerSquareMeter | NA |
| AirTemp | Air temperature | celsius | NA |
| RelHum | Relative humidity in percent | dimensionless | NA |
| WindSpeed | Wind speed | metersPerSecond | NA |
| Rain | Hourly rain accumulation | metersPerDay | NA |
| Snow | Hourly snow accumulation | metersPerDay | NA |

**inflow.csv, inflow\_twoP.csv, inflow\_fourP.csv, inflow\_sixP.csv**

|  |  |  |  |
| --- | --- | --- | --- |
| Column name | Description | Unit or  code explanation or date format | Empty value code |
| time | Date and time of sampling | YYYY-MM-DD HH:MM:SS | NA |
| FLOW | Stream inflow rate | cubicMetersPerSecond | NA |
| SALT | Inflow stream salinity | milligramsPerLiter | NA |
| TEMP | Inflow water temperature | celsius | NA |
| OGM\_don | Inflow dissolved organic nitrogen concentration | millimolesPerCubicMeter | NA |
| NIT\_nit | Inflow nitrate concentration | millimolesPerCubicMeter | NA |
| NIT\_amm | Inflow ammonium concentration | millimolesPerCubicMeter | NA |
| PHS\_frp | Inflow filterable reactive phosphorus concentration | millimolesPerCubicMeter | NA |

**outflow.csv**

|  |  |  |  |
| --- | --- | --- | --- |
| Column name | Description | Unit or  code explanation or date format | Empty value code |
| time | Date and time of sampling | YYYY-MM-DD HH:MM:SS | NA |
| FLOW | Lake outflow rate | cubicMetersPerSecond | NA |