## Dataset Title

Macrosystems EDDIE Module 1: Climate Change Effects on Lake Temperatures

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

Macrosystems EDDIE Module 1

## Abstract

Climate change is modifying the thermal structure of lakes around the globe. Because it is difficult to predict how lakes will respond to the many different aspects of climate change (e.g., altered temperature, precipitation, wind, etc.), many researchers are using models to manipulate climate scenarios and simulate lake responses. Lake simulation models provide a powerful tool for exploring the sensitivity of lake thermal structure characteristics to weather.  
  
In this module, students will learn how to set up a lake model (General Lake Model; GLM) and "force" the model with climate scenarios of their own design to test hypotheses about how lakes may change in the future. Once students have mastered running one climate scenario for their lake, they will learn how to use distributed computing tools to scale up and run hundreds of different climate scenarios for their lakes.  
  
The overarching goal of this module is for students to explore new modeling and computing tools while learning fundamental concepts about how climate change will affect lakes. 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

|  |  |  |  |  |  |
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## Keywords

Carey Lab, Virginia Tech, modeling, lakes, water temperature, climate change, 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 |
| Cayelan | C. | Carey | [0000-0001-8835-4476](http://orcid.org/0000-0001-8835-4476) | The use of high-frequency data to engage students in quantitative reasoning and scientific discourse | National Science Foundation | TUES 1245707 |
| Cayelan | C. | Carey | [0000-0001-8835-4476](http://orcid.org/0000-0001-8835-4476) | SAVI: PRAGMA - Enabling Scientific Expeditions and Infrastructure Experimentation for Pacific Rim Institutions and Researchers | National Science Foundation | ACI 1234983 |

## Timeframe

* Begin date: 2017-06-30 (Module “birthday”)
* End date: 2018-12-19 (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 primarily 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. Parts of this module were originally developed for the Lake Modeling Module as part of the earlier Project EDDIE ([www.projecteddie.org](http://www.projecteddie.org)) suite of modules.

As the first 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:

- Set up and run the General Lake Model (GLM) in the R statistical environment to simulate lake thermal structure.

- Understand how GLM configuration files, driver data, and output files are organized and used.

- Modify the input meteorological data for one GLM model to simulate the effects of different climate scenarios on lake thermal structure.

- Interpret model output from GLM simulations to understand how changing climate will alter lake thermal characteristics.

- Use the GRAPLEr R package to set up hundreds of model simulations that vary input meteorological data, and run those simulations using distributed computing.

- Explore the application of distributed computing for modeling climate change effects on lakes.

The module was assessed by volunteer faculty testers during the 2017-2018 academic year. 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 model configuration for this module is based on the default dataset included in the ‘GLMr’ package (Winslow and Read 2016), which allows the GLM model to be run through the R statistical environment. The default dataset is for “Awesome Lake,” which is a simplified model conceptualization of Lake Kinneret, Israel. The representation of Lake Kinneret has been simplified in multiple ways for the purpose of teaching this module: for example, while Lake Kinneret includes multiple surface inflows and a surface outlet, those are not included in the Awesome Lake model.

The glm2.nml lake configuration file and the met\_hourly.csv meteorological driver data file used in this module are from the default lake model files included with the GLMr package for R (Winslow and Read 2016), which are a simplified version of the "warmlake" demonstration model setup for GLM version 2.1.8. 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. The field\_data.csv file consists of water temperature profiles from Lake Kinneret, and were obtained by the University of Western Australia Aquatic EcoDynamics research group (http://aed.see.uwa.edu.au/).

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

**Website & publications**

Carey, C.C., S. Aditya, K. Subratie, R. Figueiredo, and K.J. Farrell. 30 June 2017. Macrosystems EDDIE: Climate Change Effects on Lake Temperatures. Macrosystems EDDIE Module 1, Version 1. <http://www.module1.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)

## 

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

|  |  |  |  |
| --- | --- | --- | --- |
| **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.module1.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\_mod1.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.module1.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\_mod1.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.module1.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 lake\_climate\_change.zip (this table goes into the lake\_climate\_change README)

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Entity Type** | **Externally Defined Format** | **Description** |
| glm2.nml | text/x-rsrc | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for General Lake Model (GLM). Save as .nml to run. Located within lake\_climate\_change.zip folder |
| 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. Located within lake\_climate\_change.zip folder |
| field\_data.csv |  |  | Observational field data for Awesome Lake’s water temperatures. Located within lake\_climate\_change.zip folder |
| met\_hourly.csv |  |  | Meteorological driver data for Awesome Lake used in the General Lake Model (GLM). Located within lake\_climate\_change.zip folder |
| met\_hourly\_plus2.csv |  |  | Meteorological driver data used in the General Lake Model (GLM) for a year-round +2°C climate scenario for Awesome Lake. Located within lake\_climate\_change.zip folder |
| met\_hourly\_plus4.csv |  |  | Meteorological driver data used in the General Lake Model (GLM) for a year-round +4°C climate scenario for Awesome Lake. Located within lake\_climate\_change.zip folder |
| met\_hourly\_plus6.csv |  |  | Meteorological driver data used in the General Lake Model (GLM) for a year-round +6°C climate scenario for Awesome Lake. Located within lake\_climate\_change.zip folder |
| MyExpRoot folder |  |  |  |
| glm2.nml |  | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for General Lake Model (GLM). Save as .nml to run. |
| job\_desc.json |  | ??? | JavaScript Object Notation file that specifies the range of GLM model scenarios to run through the GRAPLEr package |
| met\_hourly.csv |  |  | Meteorological driver data used in the General Lake Model (GLM). |

## Data Tables (these tables go into the lake\_climate\_change README)

**field\_data.csv**

|  |  |  |  |
| --- | --- | --- | --- |
| Column name | Description | Unit or  code explanation or date format | Empty value code |
| DateTime | Date and time of sampling | YYYY-MM-DD HH:MM:SS |  |
| Depth | Water depth where the sensor reading was measured | meter |  |
| Temp | Water temperature | celsius |  |

**met\_hourly.csv, met\_hourly\_plu2.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 |  |
| ShortWave | Short wave radiation | wattsPerSquareMeter |  |
| LongWave | Long wave radiation | wattsPerSquareMeter |  |
| AirTemp | Air temperature | celsius |  |
| RelHum | Relative humidity in percent | dimensionless |  |
| WindSpeed | Wind speed | metersPerSecond |  |
| Rain | Hourly rain accumulation | metersPerDay |  |
| Snow | Hourly snow accumulation | metersPerDay |  |

## Notes and Comments

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>

Subratie, K., and R. Figueiredo. 2017. GRAPLEr R package v.3.1.0. Available: [www.graple.org](http://www.graple.org) or <https://github.com/GRAPLE/>

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)