## Dataset Title

Macrosystems EDDIE Module 4: Macro-scale Feedbacks

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

Macrosystems EDDIE Module 4

## Abstract

Environmental phenomena are often driven by multiple factors that interact across space and over time. In freshwater lakes and reservoirs worldwide, carbon cycling and subsequent carbon dioxide (CO2) and methane (CH4) fluxes are changing due to local, regional, and continental drivers. In this module, students will learn how to set up a lake model and "force" the model with climate scenarios to test hypotheses about how local and global drivers will interact to promote or suppress greenhouse gas fluxes 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 non-linear macrosystem-level phenomena (e.g., lake greenhouse gas fluxes) can occur through macro-scale feedbacks. 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; 2019) for further details on model configuration.

## Investigators

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
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## Keywords

Carey Lab, Virginia Tech, Lake, lakes, modeling, models, water temperature, climate change, teaching,

macrosystems, GLEON, General Lake Model, GLM, macroscale feedbacks, Mendota, Sunapee, Falling Creek, Toolik, NEON, National Ecological Observatory Network, greenhouse gases, fluxes, carbon dioxide, methane, dissolved oxygen

## 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: 2019-04-01 (Module “birthday”)
* End date: 2020-04-15 (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, K.J. Farrell, and A.G. Hounshell 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 fourth 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 macro-scale feedbacks, and how different ecological processes can interact at local, regional, and continental scales.

- Simulate greenhouse gas fluxes in multiple lakes using ecosystem models of lake water chemistry 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 magnitude of greenhouse gas fluxes change with climate warming (Activity B).

- Examine how local conditions may alter the timing and magnitude of greenhouse gas fluxes from lakes to affect global climate change (Activity C).

- Predict how lake greenhouse gas fluxes may both respond to and amplify changing climate.

- The module was assessed by volunteer faculty testers during the 2018-2019 academic year. Faculty testers provided feedback that was used to update and optimize teaching materials. Carey, Farrell, and Hounshell 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. GLM 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. Calibrated models were set up for four lakes that are part of either the United States National Ecological Observatory Network (NEON; [www.neonscience.org](http://www.neonscience.org)) or the Global Lakes Ecological Observatory Network (GLEON; [http://gleon.org](http://gleon.org/)). The four lakes are Falling Creek Reservoir (Virginia, USA), Lake Mendota (Wisconsin, USA), Lake Sunapee (New Hampshire, USA), and Toolik Lake (Alaska, USA), which encompass a range of geographic location, trophic state, mixing regime, and watershed land use. The model representation of each lake has been simplified in multiple ways for the purpose of teaching this module: for example, lakes with multiple surface inflows were simplified to one inflow in the model.

Within the module, lake configuration files (glm2.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). For lakes that include a substantial surface inflow, an inflow file (inflow.csv) is included, which includes discharge volume, water temperature, and inflow salt concentration at a daily timestep. For lakes with a surface outflow, each lake model also includes a surface outflow file (outflow.csv) that is estimated based on inflows to maintain lake volume. Climate scenarios simulated +2oC, +4oC, and +6oC warming scenarios by increasing observed surface air temperature from 2013-2014 by +2oC (met\_hourly\_plus2.csv), +4oC (met\_hourly\_plus4.csv), and +6oC (met\_hourly\_plus6.csv), respectively for each of the 4 lakes.

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

**Website & publications**

Carey, C.C., K.J. Farrell, and A.G. Hounshell. 15 April 2020. Macrosystems EDDIE: Macro-scale feedbacks. Macrosystems EDDIE Module 4, Version 1. <http://module4.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. 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/>

Hipsey, M.R., Bruce, L.C., Boon, C., Busch, B., Carey, C.C., Hamilton, D.P., Hanson, P.C., Read, J.S., De Sousa, E., Weber, M., Winslow, L.A., 2019. A General Lake Model (GLM 3.0) for linking with high-frequency sensor data from the Global Lake Ecological Observatory Network (GLEON). Geosci. Model Dev. 12, 473–523. https://doi.org/10.5194/gmd-12-473-2019

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** |
| InstructorManual\_20200415.pdf | image/pdf | image/pdf | Instructor guidelines and troubleshooting for the module. Includes answer key to student handout and discussion questions. |
| InstructorPowerpoint\_20200415.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.module4.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\_mod4\_20200415.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.module4.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. |
| ReadySetEDDIE\_Instructor\_20200415.pdf | image/pdf | image/pdf | Instructor introduction to R and the General Lake Model (GLM). |
| R\_You\_Ready\_for\_EDDIE\_20200415.pdf | image/pdf | image/pdf | Step-by-step guide to download R, RStudio, and module files. |
| StudentHandout\_20200415.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.module4.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 macroscale\_feedbacks.zip (this table goes into the teleconnections README)

# Macroscale\_feedbacks.zip Contents

## File Types and Descriptions

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Entity Type** | **Externally Defined Format** | **Description** |
| MSF\_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. |
| Lake\_Characteristics |  | application/vnd.ms-excel | File with site information and physical characteristics of each lake. Tabs for each lake include long-term annual climate data used in the module. Save as .xlsx to run in script. |
| Variable\_Name\_Metadata |  | application/vnd.ms-excel | File which includes information about the variables, units, and formats for each of the data files used during the module. |
| Lakes/FallingCreek folder |  |  |  |
| aed2.nml | text/x-rsrc | application/GLM | File to configure lake biogeochemical parameters for Aquatic Ecodynamics (AED) to simulate oxygen, carbon, phosphorus, and nitrogen dynamics, among others for Falling Creek Reservoir. Save as .nml to run. |
| aed2\_phyto\_pars.nml | text/x-rsrc | application/GLM | File to configure lake phytoplankton parameters for AED for Falling Creek Reservoir. Save as .nml to run. |
| aed2\_zoop\_pars.nml | text/x-rsrc | application/GLM | File to configure lake zooplankton parameters for AED for Falling Creek Reservoir. Save as .nml to run. |
| glm2.nml | text/x-rsrc | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for the Falling Creek Reservoir General Lake Model (GLM). Save as .nml to run. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data for Falling Creek Reservoir. |
| met\_hourly\_plus2.csv |  |  | Meteorological GLM driver data for a year-round +2°C climate scenario for Falling Creek Reservoir. |
| met\_hourly\_plus4.csv |  |  | Meteorological GLM driver data for a year-round +4°C climate scenario for Falling Creek Reservoir. |
| met\_hourly\_plus6.csv |  |  | Meteorological GLM driver data for a year-round +6°C climate scenario for Falling Creek Reservoir. |
| inflow.csv |  |  | Surface inflow GLM driver data for a baseline simulation based on observed data for Falling Creek Reservoir. |
| outflow.csv |  |  | Surface outflow GLM driver data based on observed data for Falling Creek Reservoir. |
| Lakes/Mendota folder |  |  |  |
| aed2.nml | text/x-rsrc | 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 | text/x-rsrc | application/GLM | File to configure lake phytoplankton parameters for AED for Lake Mendota. Save as .nml to run. |
| aed2\_zoop\_pars.nml | text/x-rsrc | application/GLM | File to configure lake zooplankton parameters for AED for Lake Mendota. Save as .nml to run. |
| glm2.nml | text/x-rsrc | 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. |
| 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. |
| outflow.csv |  |  | Surface outflow GLM driver data based on observed data for Lake Mendota. |
| Lakes/Sunapee folder |  |  |  |
| aed2.nml | text/x-rsrc | 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 | text/x-rsrc | application/GLM | File to configure lake phytoplankton parameters for AED for Lake Sunapee. Save as .nml to run. |
| aed2\_zoop\_pars.nml | text/x-rsrc | application/GLM | File to configure lake zooplankton parameters for AED for Lake Sunapee. Save as .nml to run. |
| glm2.nml | text/x-rsrc | 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. |
| 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. |
| outflow.csv |  |  | Surface outflow GLM driver data based on observed data for Lake Sunapee. |
| Lakes/Toolik folder |  |  |  |
| aed2.nml | text/x-rsrc | application/GLM | File to configure lake biogeochemical parameters for Aquatic Ecodynamics (AED) to simulate oxygen, carbon, phosphorus, and nitrogen dynamics, among others for Toolik Lake. Save as .nml to run. |
| aed2\_phyto\_pars.nml | text/x-rsrc | application/GLM | File to configure lake phytoplankton parameters for AED for Toolik Lake. Save as .nml to run. |
| aed2\_zoop\_pars.nml | text/x-rsrc | application/GLM | File to configure lake zooplankton parameters for AED for Toolik Lake. Save as .nml to run. |
| glm2.nml | text/x-rsrc | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for the Toolik Lake General Lake Model (GLM). Save as .nml to run. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data for Toolik Lake. |
| met\_hourly\_plus2.csv |  |  | Meteorological GLM driver data for a year-round +2°C climate scenario for Toolik Lake. |
| met\_hourly\_plus4.csv |  |  | Meteorological GLM driver data for a year-round +4°C climate scenario for Toolik Lake. |
| met\_hourly\_plus6.csv |  |  | Meteorological GLM driver data for a year-round +6°C climate scenario for Toolik Lake. |
| inflow.csv |  |  | Surface inflow GLM driver data for a baseline simulation based on observed data for Toolik Lake. |
| outflow.csv |  |  | Surface outflow GLM driver data based on observed data for Toolik Lake. |

## Data Table Structure (these tables go into the macroscale\_feedbacks\_README)

**met\_hourly.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 |  |

**met\_hourly\_plus2.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 |  |

**met\_hourly\_plus4.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 |  |

**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 |  |

**inflow.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 |

**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 |

## 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/>

Hipsey, M.R., Bruce, L.C., Boon, C., Busch, B., Carey, C.C., Hamilton, D.P., Hanson, P.C., Read, J.S., De Sousa, E., Weber, M., Winslow, L.A., 2019. A General Lake Model (GLM 3.0) for linking with high-frequency sensor data from the Global Lake Ecological Observatory Network (GLEON). Geosci. Model Dev. 12, 473–523. https://doi.org/10.5194/gmd-12-473-2019

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)