## Dataset Title

Macrosystems EDDIE Module 3: Teleconnections

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

Macrosystems EDDIE Module 3

## Abstract

Ecosystems can be influenced by teleconnections, in which meteorological, societal, and/or ecological phenomenon link remote regions via cause and effect relationships. Because it is difficult to predict how ecosystems will respond to drivers from remote regions, many researchers are using models to simulate different teleconnection scenarios and see how ecosystems respond. For example, lake simulation models provide a powerful tool for exploring how lake thermal structure and ice cover respond to climate teleconnections such as the El Niño/Southern Oscillation (ENSO).  
  
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 far-away drivers interact with local lake characteristics to affect lake temperatures and ice cover 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 teleconnections affect lake temperatures and ice cover. 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, teleconnections, ENSO, Mendota, Sunapee, Falling Creek, Toolik, Barco, Crampton, Prairie Pothole, Suggs, NEON, National Ecological Observatory Network

## 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: 2018-05-18 (Module “birthday”)
* End date: 2019-05-10 (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 K.J. Farrell and C.C. Carey 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 third 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 teleconnections, and how different ecological processes can interact at local, regional, and global scales.

- Set up and run ecosystem models to simulate lake temperatures and ice cover in multiple lakes (Activity A).

- Test the effects of teleconnected climate scenarios on the different lake models, and examine how local characteristics modify global-scale climate forcing effects on lake temperatures and ice cover (Activity B).

- Compare the role of teleconnections in driving lake temperatures and ice cover across multiple lakes in different regions (Activity C). Predict how lake temperatures and ice cover may respond to changes in the timing and intensity of global-scale meteorological phenomena (Activity C).

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. Farrell and Carey 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 eight 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 eight lakes are Barco Lake (Florida, USA), Crampton Lake (Wisconsin, USA), Falling Creek Reservoir (Virginia, USA), Lake Mendota (Wisconsin, USA), Lake Sunapee (New Hampshire, USA), Prairie Pothole (North Dakota, USA), Suggs Lake (Florida, 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.

El Niño scenarios are estimated in the module based on long-term climate data. For each lake, historical climate data (annual mean, minimum, and maximum air temperatures; total annual rain and snow) were aggregated from the National Oceanic and Atmospheric Administration National Climatic Data Center (NOAA NCDC) station nearest the lake, except for Toolik Lake, where data (annual mean air temperature) were obtained from the Toolik Environmental Data Center. Each year within the long-term data record was assigned as either El Niño, La Niña, or neutral years based on the Multivariate ENSO Index (MEI; available <https://www.esrl.noaa.gov/psd/enso/mei/>).

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

**Website & publications**

Carey, C.C., and K.J. Farrell. 18 May 2019. Macrosystems EDDIE: Teleconnections. Macrosystems EDDIE Module 3, Version 1. <http://module3.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** |
| 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.module3.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\_mod3.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.module3.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\_mod3.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.module3.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 teleconnections.zip (this table goes into the teleconnections README)

# teleconnections.zip Contents

## File Types and Descriptions

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Entity Type** | **Externally Defined Format** | **Description** |
| Teleconnections\_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. |
| Lakes/Barco folder |  |  |  |
| glm2.nml | text/x-rsrc | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for the Barco Lake General Lake Model (GLM). Save as .nml to run. |
| 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. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data for Barco Lake. |
| Lakes/Crampton folder |  |  |  |
| glm2.nml | text/x-rsrc | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for the Crapmton Lake General Lake Model (GLM). Save as .nml to run. |
| 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. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data for Crampton Lake. |
| Lakes/Falling Creek folder |  |  |  |
| 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. |
| 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. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data 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 |  |  |  |
| 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. |
| 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. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data 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/Prairie Pothole folder |  |  |  |
| glm2.nml | text/x-rsrc | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for the Prairie Pothole General Lake Model (GLM). Save as .nml to run. |
| 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. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data for Prairie Pothole. |
| Lakes/Suggs folder |  |  |  |
| glm2.nml | text/x-rsrc | application/GLM | File to configure lake characteristics, meteorological driver data, and physical response variables for the Suggs Lake General Lake Model (GLM). Save as .nml to run. |
| 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. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data for Suggs Lake. |
| Lakes/Sunapee folder |  |  |  |
| 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. |
| 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. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data 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 |  |  |  |
| 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. |
| 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. |
| met\_hourly.csv |  |  | Meteorological GLM driver data for a baseline simulation based on observed data 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 teleconnections\_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 |  |

**inflow.csv (if applicable)**

|  |  |  |  |
| --- | --- | --- | --- |
| 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/>

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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)