   

**Project EDDIE: LAKE ICE PHENOLOGY**

**Instructor’s Manual**

This module was initially developed by Carey, C.C., J.L. Klug, and D.C. Richardson. 1 Oct 2015. Project EDDIE: Lake Ice Phenology. Project EDDIE Module 1, Version 1. <http://cemast.illinoisstate.edu/data-for-students/modules/ice-phenology.shtml>. Module development was supported by NSF DEB 1245707.

Overall description: Lakes are changing worldwide due to altered climate. Many lakes that were historically frozen in the winter are now experiencing fewer days of ice cover and earlier ice-off dates. In this module, students will explore long-term ice-off datasets from several lakes and use linear regression to make predictions about ice-off dates in the future.

Pedagogical connections:

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| **Phase** | **Functions** | **Examples from this module** |
| Engagement | Introduce topic, gauge students’ preconceptions, call up students’ schemata | Pre-class readings, reflection questions, short introductory lecture, in-class discussions of readings |
| Exploration | Engage students in inquiry, scientific discourse, evidence-based reasoning | In-class analysis of ice-off records, first analysis is more guided than subsequent analyses |
| Explanation | Engage students in scientific discourse, evidence-based reasoning | In-class discussion, homework |
| Expansion | Broaden students’ schemata to account for more observations | Application questions in the homework |
| Evaluation | Assess students’ understanding, formatively and summatively | Suggested questions to ask during discussions |

Learning objectives:

* Understand how global climate change impacts local aquatic ecosystems
* Analyze a long-term ice-off dataset with understanding of statistical differences, biological relevance, and sources of variation
* Predict future scenarios of ice-off using linear models
* Develop rudimentary skills using excel for graphing and statistics
* Calculate lake heat budgets, and understand the interactions between lake ice-off date and heat storage

How to use this module:

This entire module can be completed in one 2-3 hour lab period or two 50 minute lecture periods for introductory or intermediate level students. Activities A and B could be completed with upper level students in one 50-60 minute lecture period. Students will need 1-2 hours outside of class to prepare for the exercise and complete the homework activities.

## Quick overview of the activities in this module

* *Activity A*: Interannual variation in ice-off dates, introduction to regression, change over time, comparison of rates across lakes, prediction
* *Activity B*: Examination of potential breakpoints doing segmented regressions and how the length of record can impact the magnitude of change
* *Activity C*: Calculating heat budgets, impacts of changes in ice cover on lakes

Workflow of this module:

1. Assign pre-class readings
2. Give students their handout when they arrive to class
3. Discussion of pre-class readings
4. Instructor gives brief PowerPoint presentation on ice-off and intro to linear regression (PowerPoint can be edited as desired).
5. As part of the presentation, the instructor gives a demo on how to create a regression line for the ice-off date of Lake Sunapee, New Hampshire, USA
6. After the presentation, the students divide into teams to construct a regression line for different lakes (using the entire dataset) and predict future ice-off dates (*Activity A*)
7. Students then use a set break-point at 1970 to conduct two regression lines and predict future ice-off dates (*Activity B*)
8. Students then calculate an annual heat budget for Mirror Lake, New Hampshire, USA for two years with an early and late ice-off date (*Activity C*).

Suggested pre-class readings:

* Seidl, A. 2009. “Water,” Pages 69-87 in *Early Spring* (Beacon Press, Boston).
* Magnuson, J.J. et al. 2000. Historical Trends in Lake and River Ice Cover in the Northern Hemisphere. *Science* 289: 1743-1746.
* Winder, M. and D.E. Schindler. 2004. Climate change uncouples trophic interactions in an aquatic ecosystem. *Ecology*. 85: 2100-2106.

Data providers citation:

* Benson, B. and J. Magnuson. 2000, updated 2012. Global Lake and River Ice Phenology Database, Version 1. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. <http://dx.doi.org/10.7265/N5W66HP8>
* Wetzel, R.G., and G.E. Likens. 2000. Limnological Analyses, 3rd edition. Springer Science and Business Media, Inc. New York.
* Likens, G.E., and T.C. Winter. 2010. Mirror Lake Thermal Profiles (1981-present). Durham, NH. Hubbard Brook Data Archive [Database]. http://hubbardbrook.org/data/dataset.php?id=83

Discussion of the pre-class readings prior to starting the instructor’s presentation:

Potential questions you could ask your students in class:

* *What does the word phenology mean?* [answer: the study of cyclic and seasonal natural phenomena, esp. in relation to climate and plant and animal life]
* Amy Seidl (2009) observes changes in nature associated with climate change in her backyard. *How have you potentially observed climate change in your life?*
* Both Magnuson et al. (2000) and Winder & Schindler (2004) papers use long-term datasets to examine changes in nature over time. *Why are long-term datasets important? What are other examples of indicators used to track climate change?* [e.g., altered bird migrations, Mauna Loa/Keeling curve, crop phenology]
* *What are the challenges of collecting long-term data?*
* *What is ice-out, anyway?* (TRANSITION TO INSTRUCTORS’ PRESENTATION)

**Presentation**

The notes below apply to slides within the PowerPoint presentation and act as things for the instructor to think through in advance or use as prompts for discussion during the presentation. Instructors can pick and choose from the PowerPoint as needed for their classroom.

* How exactly does ice melt?
  + During the period of ice cover, snow on the ice both reflects sunlight and insulates the lake. With a thick snow layer, the lake neither gains nor loses heat to the atmosphere. The sediment at the bottom of the lake can actually be a small heat source to the water column over the winter, from stored heat over the summer.
  + In the early spring, as the air warms and solar radiation increases, the snow melts, allowing light to penetrate the ice. The ice can act like glass in a greenhouse, allowing the lake water to warm. As a result, the ice begins to melt from the bottom, not the top.
  + When the ice erodes to a layer between 4 and 12 inches (10-30 cm) thick, it transforms into long vertical crystals called "candles." These candles transmit light very well, so the ice starts to look black.
  + Warming continues, promoting melting of the ice from below because the light energy is being transferred to the water below the ice as heat. Meltwater fills in between the crystals, which begin breaking apart. The surface of the ice begins to appear grey.
  + Finally, the ice thickness decreases further, allowing strong winds to break the surface of the ice apart. The candles will often collect on one side of the lake, making a tinkling sound as they pile up on the shore.
* [Magnuson Figure 1] What are the colored lines describing in Figure 1 of the Magnuson paper?
* [Magnuson Figure 1] What factors most strongly control ice-off/on dates? [Ice phenologies integrate change over an 8-month window (October through May). Ice freeze and breakup dates correlate most strongly with air temperatures in the month or two before the event (Magnuson paper, p. 1744, last paragraph)]
* [Magnuson Figure 1] Why is ice-off/ice-on such a good indicator of changing climate? [Ice data’s strengths as a climate proxy include the broad spatial distribution of sites, the annual resolution of the data, a longer record than other direct measures such as air temperature, and the relative ease and precision of measuring freeze and breakup dates both directly and by satellite, Magnuson paper, last paragraph; Also- Lakes as integrators, sentinels (Williamson 2008 *Frontiers* paper)]
* [Magnuson Figure 1] How does climate change affect variability in ice phenology? [For 184 lakes and rivers around the Northern Hemisphere, variability was 12% greater for freeze dates and 5% greater for breakup dates from 1971 to 1990 than during the period from 1951 to 1970. At Lake Mendota, the two earliest breakup events occurred in 1983 and 1997 during intense El Nino – Southern Oscillation events (Magnuson paper p. 1745, leftmost column).
* Why are changes in ice-off dates important ecologically (see Winder & Schindler paper)?
  + Clearwater phase mismatch (SEE PPT FIGURE): earlier ice-off dates mean that spring diatom bloom is happening earlier (diatoms respond to temperature); yet *Daphnia* peak is happening at the same time every year (photoperiod is a more important cue to emergence from ephippia). Hence, the diatom bloom crashes before *Daphnia* are able to multiply; the diatom bloom is the most important nutrition for *Daphnia* during the year- this is leading to long-term declines in *Daphnia* in northern lakes (bad for fish that eat *Daphnia*!)🡪Uncoupling of key limnological phenomenon
  + Warmer water 🡪 less dissolved oxygen 🡪 Bad for cold-water fish that need cold temps and lots of oxygen (e.g., trout and freshwater salmon species)
  + Less dissolved oxygen and anoxia 🡪 Increase in P and reduced metals cycling from the sediment
  + Warmer water 🡪Increased primary productivity (as described in the Seidl paper)

**Activity A\*:** Interannual variation, change over time, comparison of rates across lakes, prediction

Some example questions to lead discussion with the students, and step-by-step info on what to do as you talk through the PowerPoint and independent data activity:

* *What exactly does ice-off mean? How does one collect these data?*
* *What does day-of-year mean?*
* Step through excel graphing (depending on students’ skill level) for Sunapee dataset. Afterwards, send all of the students the ice-off datasets.
* Regression overview - talk through the basics: what is a linear equation, what does the slope mean, what is R2, what is a p value? (depending on skill level of students and the amount of time allotted to the class period, it may make sense to skip this, and just look at how the ice-off date varies over time- e.g., *what is the typical ice-off date at the beginning and end of dataset?*)
* *Talk about variation among years. If appropriate, discuss corrections for ENSO, NAO, and other climate patterns*.
* Have student pairs/groups choose a lake and create a regression line, and calculate the average ice-off day of year at the beginning and end of dataset.
* Once everyone is done, initiate a class discussion with the students.
  + Potential discussion questions- w*hat are the trends observed in each lake’s dataset? How did the trends differ among lakes? What would happen if you only examined a few years at a time vs. the entire dataset? Why is there so much variability in these data? Others? Why do different lakes have different patterns (size, location, local weather, northern vs. southern hemisphere, etc.)?*
  + Refer to the lake metadata (below, and as a slide in the PowerPoint and in the student handout). *Have the students to discuss the characteristics of each lake, and how those attributes may have affected the ice-off patterns.*

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| **Lake Name** | **Location** | **Latitude** | **Lake area (km2)** | **Trophic status** |
| Baikal | Siberia, Russia | 53 oN | 31,722 | Oligotrophic |
| Cazenovia | Near Syracuse, NY, USA | 42 oN | 4.5 | Eutrophic |
| Mendota | Madison, WI, USA | 43 oN | 39 | Eutrophic |
| Monona | Madison, WI, USA | 43 oN | 13 | Eutrophic |
| Oneida | Near Syracuse, NY, USA | 43 oN | 207 | Mesotrophic |
| Sunapee | Central NH, USA | 43 oN | 17 | Oligotrophic |
| Wingra | Madison, WI, USA | 43 oN | 1 | Eutrophic |

* Now that you have the predictive regression line, show the students how to fill in future date to guess the ice-off day that year or in the future.

\*Note to instructor: some of these datasets have missing values, which won’t affect regression lines and R2 calculations in Excel but will make calculating p-values in Excel more difficult. This is an opportunity to talk through the challenges and value of maintaining long-term datasets, as well as data variability. Depending on your Excel version- if you want to calculate p-values in Excel, instruct the students to remove the spreadsheet rows with missing data.

\*Data acknowledgement: At this point in the lesson, it would be good to mention the data providers who collected these long-term records, as well as acknowledge the limnologists that made these data accessible for this activity.

\*Available datasets: there are many additional ice-off datasets available at the National Snow & Ice Data Center (NSIDC; nsidc.org) Global Lake and River Ice Phenology database (<http://nsidc.org/data/lake_river_ice/index.html>), which contains ice-off records for 865 lakes and rivers in the northern hemisphere (542 water bodies have records >19 years). It might be useful to include a local or regional example for your students (or to have students go chose their down data).

**Activity B:** Rates of change can vary depending upon time period and length of record; segmented regression and prediction

* Explore the use of multiple regression lines- use a set breakpoint at 1970 and discuss how to graph subsets of the dataset individually.
  + Discuss why 1970 may or may not be a good breakpoint.
* Experiment with other breakpoints, if appropriate.
* Have students look at the data and see if natural breakpoints are visible.

**Activity C:** Temperature and heat budgets, impacts of changes in ice cover

Note: This could be used as in-class activity or homework exercise for advanced students

This activity is an adaptation of Exercise 4 in Wetzel and Likens 2000 *Limnological Analyses* and uses data from Wetzel and Likens (2000) and the Hubbard Brook LTER (Likens and Winter 2010).

* What is the relationship between temperature and heat?
  + [Temperature is a metric of the **intensity** of heat stored in a volume of water, not a metric of the **amount** of heat stored in that water. The units of heat are calories and are a function of the mass of the substance in grams, temperature in oC, and the specific heat in calories / (g × oC). Heat = mass × temperature × specific heat]
  + Talk through the example in which a pool of water filled with water at 0.1oC has a much greater heat content than does a glass filled with water at a temperature of 30oC, because the volume of the pool is much greater than the glass.
* The general heat budget of a lake is: Heat storage capacity = Net radiation + Change in heat storage (i.e., loss of heat to sediments or atmosphere). Energy added is positive, and energy lost is negative.
* We are interested in examining the relationship between ice-off date and heat storage capacity. *How does higher heat storage at the beginning of the year influence the ice off date? How does an earlier ice off date influence the lake’s heat storage later in the year?* This is directly related to Activities A and B in that we’re now trying to see what the effects of early vs. late ice-off may be on the lake year-round.
  + We are going to use actual data from a small lake in New Hampshire, USA to examine the implications of earlier vs. later ice-off.
* Mirror Lake is a very important lake in New Hampshire that has been used to examine the effects of acid rain in watersheds since the 1960s. Scientists have been measuring thermal profiles in the lake for several decades, and we can compare a thermal profile of the lake from a year that had a late ice-out date with a year that had an early ice-out date to see how the heat storage capacity will change. Here, we are using real data to compare the heat budget in 1970 (ice out date 116, April 26) vs. 2005 (ice out date 92, April 2)🡪 a 24 day difference!
* Walk students through homework handout (SEE NOTES IN INSTRUCTOR’S PRESENTATION) and encourage them to use an Excel spreadsheet to ease the calculations (or they can use a calculator). The answers are available in the Instructor’s Excel spreadsheet. Note: the May 18, 2005 thermal profile was interpolated from April and June 2005 sampling dates.
* Ask if they have any questions on the homework before ending class.