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**Project EDDIE SOIL RESPIRATION**

**Instructor’s Manual**

This module was initially developed by Nave, L.E., N. Bader, and J.L. Klug. 25 June 2015. Project EDDIE: Soil Respiration. Project EDDIE Module 9, Version 1. <http://cemast.illinoisstate.edu/data-for-students/modules/soil-respiration.shtml>. Module development was supported by NSF DEB 1245707.

Overall description: Soils hold more carbon (C) than any other component of the terrestrial biosphere. Soils accumulate C through inputs from primary producers (e.g., leaf litter, root exudates), yet they also lose C through root respiration by the primary producers and decomposition of soil C by heterotrophic organisms. The net C balance of a soil is usually a very small difference between the very large inputs and outputs of C, and this exchange of C between soils and the atmosphere is one of the single biggest terms in the global C budget. In this module, students will explore high-frequency, sensor-based datasets documenting climate variables and the emissions of C (as CO2) from soils to the atmosphere, using these datasets to understand patterns and drivers of variation in soil CO2 emissions to the atmosphere (soil respiration).

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, introductory lecture, in-class discussion |
| Exploration | Engage students in inquiry, scientific discourse, evidence-based reasoning | Guided and independent analyses of soil respiration and climate datasets |
| Explanation | Engage students in scientific discourse, evidence-based reasoning | Independent interpretation of soil respiration and climate datasets |
| Expansion | Broaden students’ schemata to account for more observations | Independent exploration and analysis of global soil respiration maps |
| Evaluation | Assess students’ understanding, formatively and summatively | In-class discussions and student application activities (graphing and interpretation) |

Learning objectives:

* By analyzing a prepared soil respiration dataset from a long term C cycle research site:
  + Recognize that soil respiration rates at a location vary across time scales, e.g., from days to seasons
  + Analyze relationships between soil respiration rates and its potential drivers
  + Make predictions for how changes in drivers will affect soil respiration rates
* Download and interpret global soil respiration data products from an online archive
  + Recognize and describe ways in which soil CO2 emissions vary across space, e.g., different ecosystems or biomes; develop explanations for these differences
  + Recognize that interannual variation in soil CO2 emissions also varies across space and explain what may drive this variation
  + Appreciate how large-scale spatial data products are made, and how the methods of their creation affect the inferences that can be drawn from them

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. If the activity was introduced ahead of time and students have used Excel before, Activity A could be completed in a single 50-60-minute lecture period, but you may then want to budget additional time following class for students to complete Activity B.

Quick overview of the activities in this module

* *Activity A*: Students make one-year time-course graphs of climate variables and high-resolution [short-term] time course graphs of soil respiration and climate variables, and calculate total efflux.
* *Activity B*: Visually inspect the patterns of global spatial variation of carbon emissions and soil respiration, and complete readings.

Workflow of this module:

1. Assign pre-class readings
2. Disperse student handouts in class
3. Discussion of pre-class readings
4. Instructor gives brief PowerPoint presentation on soil respiration and the C cycle, and environmental implications.
5. At the end of the presentation, the instructor demonstrates how to plot a one-year time course graph of soil respiration rates. Also, discuss interpretation of variability and demonstrate the use of regression to attempt to explain variability.
6. Students complete Activity A.
7. Depending on time and comfort with the subject matter, the students then complete Activity B of the module by acquiring global soil respiration data products.
   1. [Global Patterns of Carbon Dioxide Emissions from Soils on a 0.5 Degree Grid Cell Basis](http://cdiac.ornl.gov/epubs/db/db1015/db1015.html); <http://cdiac.ornl.gov/epubs/db/db1015/db1015.html>
   2. [Interannual Variability in Global Soil Respiration on a 0.5 Degree Grid Cell Basis](http://cdiac.ornl.gov/epubs/ndp/ndp081/ndp081.html); <http://cdiac.ornl.gov/epubs/ndp/ndp081/ndp081.html>
8. Students interpret the patterns in the two data products in light of the analyses they have done.

Suggested pre-class readings:

* Carbon cycle overview: <http://earthobservatory.nasa.gov/Features/CarbonCycle/>
* University of Michigan Biological Station carbon (C) cycle research site: <http://flux.org.ohio-state.edu/site-description-umbs/>
* Kirschbaum (1995) Soil respiration paper:
  + <http://www.sciencedirect.com/science/article/pii/003807179400242S>
  + Kirschbaum, M. F. (2013). Seasonal variations in the availability of labile substrate confound the temperature dependence of organic matter decomposition. *Soil Biology & Biochemistry*, *57*568-576.

Data providers’ citations:

* Raich, J. W. and C. S. Potter. 1995. Global Patterns of Carbon Dioxide Emissions from Soils. Global Biogeochemical Cycles 9(1)23-36. doi: 10.3334/CDIAC/lue.db1015
* Raich, J. W., C. S. Potter, and D. Bhagawati. 2002. Interannual variability in global soil respiration, 1980-94. Global Change Biology 8:800-812. doi: 10.3334/CDIAC/lue.ndp081
* Vogel, C.S., C.M. Gough, and P.S. Curtis. Do continuous data improve estimates of annual soil respiration? The importance of measurements during rapid weather changes. Poster presentation from the Automated Soil Respiration Workshop – a Terrestrial Ecosystem Response to Atmospheric and Climate Change (TERACC) sponsored workshop, Durham, New Hampshire, USA, September 2007.

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

Potential questions you could ask your students in class:

* NASA C cycle webpage:
  + *How does the magnitude of the C flux in soil respiration compare to other natural and anthropogenic components of the global C cycle?* Soil respiration and other fluxes are small relative to the pools, soil respiration is on par with plant respiration and much bigger than human emissions
  + *What are the slow vs. fast C cycles, and which does soil respiration fit into?* Slow is geologic, inorganic C burial through sedimentation, fast is the stuff we tend to focus on (ecosystems, anthropogenic factors and climate change). Soil respiration is like a fingerprint for what is happening in soil, which is the interface between the fast (biosphere/atmosphere) and the slow (geologic) components of the C cycle.
* Kirschbaum paper:
  + *How does a change in temperature affect input and output fluxes of the C cycle? For example, NPP vs. soil respiration- what are the differences in sign and magnitude of temperature effects on these fluxes?* NPP has positive relationship with temperature, meaning more C going in to plant biomass; soil respiration has negative (and much stronger) relationship with temperature, meaning it is more sensitive and increases C losses to atmosphere more than the increase in NPP can counteract them.
  + *What type of curve describes the relationship between temperature and soil respiration? What does this mean for the influence of an increase in temperature on the global C cycle?* Curve is exponential not linear; this means that a small increase in temperature has a large influence on soil respiration. This is especially true in places with low temperatures; a small increase has an extremely large effect on soil respiration. This is worrisome because there is a LARGE amount of soil C stored in places where cold dominates (e.g., permafrost).
* Cross-readings (NASA and Kirschbaum): *How do we rectify the disconnect between the highly sensitive process of soil respiration, which has a flux rate that is very small compared to the amount of C held in the soil (60/2300=2.6%)? In terms of understanding and predicting the C cycle, which is better, to measure soil respiration well and detect changes there, or measure soil C stocks accurately and detect changes that way?* The answer is BOTH; science benefits from multiple complementary approaches, each with their own strengths and limitations.
* UMBS C Cycle Research website: *Describe the site where the soil respiration data for this module come from. Where is it located? What is the climate like there? What is the ecosystem and biome type? Are the studies conducted there relevant to other locations; if so where and why?* Site is in upper Great Lakes, climate is temperate continental meaning short warm growing seasons, long cold winters, and shoulder seasons (spring, fall) where observed changes in climate have been quite strong and have extremely important ecosystem impacts. Ecosystem is mixed deciduous/conifer forest at the tension zone between temperate deciduous and boreal conifer forests, thus site is a sentinel very sensitive to climate change. E.g., loss of cold-tolerant northern species, and replacement by warmer southern species, migration of forest pests. Site is generally representative of large areas of this tension zone in North America.

**Presentation**

The notes below apply to slides within the PowerPoint presentation and serve as a preparation tool for instructors, or to use as discussion prompts during the presentation. Instructors can pick and choose from the PowerPoint as needed for their classroom.

* What is soil respiration?
  + The emission of carbon dioxide (CO2) from the surface of the soil.
* What is happening in soil that produces CO2?
  + Aerobic respiration. Roots, microorganisms (e.g., fungal hyphae, bacterial cells), macro organisms (e.g., insects, salamanders) and other organisms break down C-containing compounds for energy and release CO2 during cellular respiration.
* Why does the soil emit CO2?
  + CO2 is a gas whose behavior is subject to laws of physical chemistry, and as such it diffuses from areas of high concentration (in soil pore spaces) to areas of relatively low concentration (the atmosphere).
* How is soil respiration measured?
  + CO2 absorbs infrared radiation (aka longwave; heat). This physical property is important globally because it drives the greenhouse effect- if not for the presence of CO2 and other greenhouse gases in Earth’s atmosphere, we would lose so much of our outgoing infrared radiation to space that ambient temperatures would be inhospitably cold to life as we know it.
  + At the same time, increasing the CO2 concentration of the atmosphere is increasing the retention of heat in Earth’s energy budget, which is causing climate change.
  + The fact that CO2 absorbs infrared energy is what is used to measure its concentration in an atmosphere of any size. To measure soil respiration, a container or lid of a known volume is placed on top of the soil. As the volume of air inside the container (called the “headspace”) fills up with CO2 over the course of several minutes, a pump is used to circulate the mixture of headspace gases through an infrared gas analyzer (IRGA).
  + The IRGA passes controlled pulses of longwave radiation through the headspace gas, and by measuring how much longwave radiation is absorbed, it measures the amount of CO2 in that mixture of headspace gases.
  + By measuring the concentration of CO2 in the headspace repeatedly, many times per second over several minutes, it is possible to calculate the amount of CO2 moving from the soil into the headspace per second, or per minute, per hour, etc.
* What factors control the rate at which CO2 is generated in the soil by the organisms inhabiting it?
  + The availability of C substrates for breakdown via aerobic respiration, the types and number of organisms present in the portion of soil being measured, the environmental factors that control the metabolic activity of organisms (e.g., temperature, water and nutrient availability).
* What factors control the rate at which CO2 moves from the soil to the atmosphere?
  + The porosity of the soil, the concentration gradient (difference in CO2 concentration) between the soil and the atmosphere.
* What factors might make it difficult to measure soil respiration, or might result in flawed or false readings of soil respiration?
  + Measuring soil respiration is difficult when the factors that limit organismal metabolism are highly constrained, resulting in very low rates of CO2 emission (which are difficult to measure against the background concentration of CO2 in the atmosphere). E.g., when soils are very cold, or dry, have few organisms, or lack nutrients that are required for metabolic processes.
  + Flawed and false respiration measurements can come from measuring only a few, small portions of the soil and failing to capture the spatial variation in soil respiration rates. For example, an animal burrow or a mushroom acts as a “CO2 chimney” by funneling CO2 from a large area into a small exit location, and similar “patchiness” in soil respiration rates can result from soil microtopography (e.g., moist patches vs. dry patches) or uneven heating (sun flecks).
* How can we be sure that our measurements are accurate- that they really represent reality and can tell us how much CO2 is being emitted from the soil per second, hour, or day?
  + Make many measurements across a study site, and verify that they are consistent- if variation among measurement locations is high, more samples are needed to constrain the true amount of CO2 being emitted by the soil.
  + Likewise, make frequent measurements over time and inspect the data to be alert for sudden changes. If there is a sudden change, or a change over time, ask whether that change might be correlated with some driver of soil respiration, like environmental conditions, or if it appears to be unrelated to any potential drivers (in which case it might indicate an electrical or physical problem with the measurement system).
* If we think some environmental changes are driving changes in soil respiration, how can we test the hypothesis that these drivers are indeed responsible for changing soil respiration?
  + Measure soil respiration repeatedly at a number of sites, and for every measurement of soil respiration make a co-located, contemporaneous measurement of the environmental factors that might be driving the changes in soil respiration over time.
  + Use statistical tests, such as correlation analysis or regression, comparison of averages or variances to identify whether factors hypothesized to be drivers of soil respiration are indeed related to variation in soil respiration.
  + Another approach is through experimentation. For example, if it is believed that the supply of C-containing compounds to roots (i.e., sugars from photosynthesis) is the main driver of soil respiration in a place, dig trenches or insert deep cores into the ground to sever the roots. Measure soil respiration over weeks to months as the roots die and determine whether separating the roots from the trees that feed them changes the soil respiration rate.
* Why is soil respiration important, in terms of the C cycle of a forest, or a region, or the entire globe?
  + The emission of CO2 from the soil accounts for roughly half of the total emissions of CO2 from terrestrial ecosystems. Factors that change the rate of CO2 emission from soil can change the C budget of a forest from being a C sink (net removal of CO2 from the atmosphere, counteracting the greenhouse effect and climate change) to a C source (net emission of CO2 from forest to the atmosphere and a positive feedback to atmospheric C pollution and climate change).

**Demonstration:** plotting an annual timeseries

Note: Some example questions to lead discussion with the students, and step-by-step info on what to do as you demonstrate the plotting of an annual timeseries in Excel or other software.

* *What is soil respiration? How is it measured?*
* *What does day-of-year mean? Why are there data for only 302 of the 365 days in the year?* (Think about the fact that this is a sensor-based dataset- the wild forest is not the natural home of sensitive electronics, and sometimes they break down!)
* Step through Excel graphing (depending on students’ skill level) for the data contained in the ‘data for annual timeseries’ tab. Plot Column B (soil CO2 emission) as a function of Column A (day of year).
* Interpreting variability- *What do you see in the annual timeseries of soil CO2 emissions?* Ups and downs from day to day, weekly to monthly or seasonal increases and declines. *When do the highest and lowest values of soil respiration occur?* *What could be driving this variability over all its timescales? Over-sensitive sensors? Real environmental drivers like daily or seasonal weather? How do we find out?*
* Demonstrate fitting a linear regression curve to the soil CO2 emission rate. Use % soil moisture (column D) as the independent (predictor) variable. Talk through the basics: *What is a linear equation? What does the slope mean? What is R2?What is a p value? What does it mean that there is a significant negative correlation between soil moisture and respiration rate?*
* Talk about statistical vs. biological significance- *Does it make sense that soil respiration decreases as moisture availability goes up?* (Not really- this was just for demo purposes and to get students thinking about how to analyze relationships between variables). At this point, the Engage portion of the activity should be complete, as well as some initial part of the Explore portion.

1. Divide the students into pairs and begin Activity A, which constitutes more Explore and Explain, and some initial part of the Expand portion of this module

**Activity A**: Graphing/analyzing climate variables and soil respiration

* Using data provided by their instructor (EDDIE\_SoilRespiration\_Data Excel file):
  + Students make one-year time-course graphs of climate variables in the ‘data for annual timeseries’ tab. They then qualitatively analyze the patterns of temporal variation in soil, temperature and moisture, and assess their similarity and difference to soil respiration.
  + Students make high-resolution [short-term] time course graphs of soil respiration and climate variables during the growing season [‘growing season’ tab]. Using this ‘zoomed in’ view of soil respiration, temperature and moisture, assess the similarity and difference.
  + Students utilize full yearlong data record to calculate total efflux.

Note: For the last part, students will be making calculations in Excel. For the calculations, students should arrive at 11.52 kg CO2 per square meter per year. The calculated flux from the entire state is 2.88 x 1012 kg for the year, which is 2880 million metric tons. This is 16 times the reported fossil fuel flux for the same year. This is a great opportunity to point out the enormous scale of short-term respiration, and the fact that it is balanced by photosynthesis.

**Activity B**: Exploring global spatial variation patterns, application questions:

Note: This portion of the module provides the ability to further Expand and Extend. Students may work in pairs or small groups, working through questions. Instructors may choose to cover questions below on carbon emissions, soil respiration, and background information as a group through whole-class discussion in order to better gauge student understanding.

* Inspect the patterns of global spatial variation in the data product called [Global Patterns of Carbon Dioxide Emissions from Soils on a 0.5 Degree Grid Cell Basis](http://cdiac.ornl.gov/epubs/db/db1015/db1015.html).
  + [*http://cdiac.ornl.gov/epubs/db/db1015/db1015.html*](http://cdiac.ornl.gov/epubs/db/db1015/db1015.html)
  + *What regions have high CO2 emissions from soil, and which have low emissions? What is the range of values for soil CO2 emission? Given what students know about global climate, biome distributions, etc., what is driving these patterns of spatial variation?*
* Inspect the patterns of global spatial variation in the data product called [Interannual Variability in Global Soil Respiration on a 0.5 Degree Grid Cell Basis](http://cdiac.ornl.gov/epubs/ndp/ndp081/ndp081.html).
  + [*http://cdiac.ornl.gov/epubs/ndp/ndp081/ndp081.html*](http://cdiac.ornl.gov/epubs/ndp/ndp081/ndp081.html)
  + *What is interannual variability in soil CO2 emissions?* *What regions have high interannual variability? In comparing to the previous map (#1), do some regions have high rates and high variability, or low rates and high variability, etc.? How does the magnitude of the units on this map compare to the magnitude of the units on map #1, and what does this ratio and the variability mean for the C balance of global soils?*
* Read the background information on the webpage for the [Global Patterns of Carbon Dioxide Emissions from Soils on a 0.5 Degree Grid Cell Basis](http://cdiac.ornl.gov/epubs/db/db1015/db1015.html) data product.
  + [*http://cdiac.ornl.gov/epubs/db/db1015/db1015.html*](http://cdiac.ornl.gov/epubs/db/db1015/db1015.html)
  + *How were these maps made, in terms of measurements, statistical modeling, and spatial extrapolation? What sources of uncertainty or variation arise at each of these steps in the production of a global map? How do these sources of uncertainty and variation limit the inferences that can be drawn from the map? Conversely, how do these global maps extend the inferences drawn from more local measurements, as in Activity A?*