   

**Project EDDIE: SOIL RESPIRATION**

**Student Handout**

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.

Learning Objectives:

* Explore a prepared soil respiration dataset from a long term C cycle research site and:
  + Recognize that soil respiration rates at a location vary across time scales, e.g., from days to seasons
  + Analyze relationships between soil respiration and its potential drivers
  + Make predictions for how changes in drivers will affect soil respiration rates
* Obtain and interpret global soil respiration maps from an online archive
  + Recognize and describe ways in which soil respiration varies across space, e.g., different ecosystems or biomes; develop explanations for these differences
  + Recognize that interannual variation in soil respiration 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

Why this matters: Soil respiration is one of most important transfers of C between the terrestrial biosphere and the atmosphere- whether in terms of individual ecosystems, whole continents, or the global C (Carbon) cycle. Because soils hold more C than any other part of the terrestrial biosphere, their net C exchange with the atmosphere is especially important. The net C balance between soil and atmosphere is often a very small difference between large amounts of C moving in (e.g., through leaf litterfall, root exudates) and large amounts moving out (through respiration by roots and also heterotrophic organisms doing decomposition). Thus a small change in either flux (inputs or outputs) can have a dramatic effect on the C balance of the soil, and hence the broader C cycle.

Outline:

1. Discussion of papers read for class and quick PowerPoint introduction
2. Activity A: Create climate variable and high-resolution graphs and calculate total efflux
3. Activity B: Explore global patterns data and answer application questions

Required pre-class readings:

* Carbon cycle overview: <http://earthobservatory.nasa.gov/Features/CarbonCycle/>
* Soil respiration paper by M. Kirschbaum (1995; cited nearly 1500 times!):
  + <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.
* C cycle research site: <http://flux.org.ohio-state.edu/site-description-umbs>

**Activity A:** Create climate variable and high-resolution graphs and calculate total efflux

For Activity A, our data come from a long-term forest C cycle research site in northern Michigan, at the University of Michigan Biological Station (UMBS). Researchers have been working at the site continuously since 1997 to measure and understand the total C cycle at this representative northern temperate forest. The University of Michigan Biological Station’s C cycle research site is one of the longest continuously-operating sites in the AmeriFlux Network, a network of over 200 C cycle research sites located throughout the U.S. and Canada. AmeriFlux interfaces with other continental-scale C cycle research networks throughout the world, which collectively inform the state of the science on the global C cycle, inform IPCC reports, and provide the scientific basis for policy decisions relating to the C cycle.

This data comes from sensor-based measurements of soil respiration and climate variables taken during the 2005-2006 measurement year at University of Michigan Biological Station. The data are from the large, central 1.1-ha plot in the control forest. The plot is in a 100-year-old mixed deciduous-conifer forest growing on ca.12,000-year-old glacial drift deposits. Northern Michigan has a continental climate with long, cold winters and warm summers.

1. Check out this page describing the site: <http://umbs.lsa.umich.edu/research/fest/faset> (Respond to the following questions with short answers (1-2 sentences).
   1. What is the FASET experiment?
   2. Do we have to worry about the FASET treatment for this dataset? Why or why not?
   3. Before you leave the site, click the “Methodology” link to see the automated soil respiration measurement chamber.
2. Soil respiration measurement methods: 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.

Ecosystem carbon exchange can also be measured by large “eddy flux” towers bristling with wind speed sensors and IRGAs, and indeed there is one such tower at our study site. This eddy flux data is beyond the scope of our class today.

1. Explore our dataset
   1. Open up the spreadsheet with Microsoft Excel, and look at the “data for annual timeseries” tab. In this dataset, multiple measurements during the day have been averaged to give a single daily value. The variables are:

|  |  |
| --- | --- |
| **Variable name** | **Description** |
| Day of year | January 1 is 1, December 31 is 365 |
| Hour of day | Hour (24-hour time) of the day of the year |
| Decimal day | Used for plotting a continuous time course of data; the combination of day of year and hour of day |
| Soil respiration | The rate of CO2 emission, given in terms of the number of micromoles of CO2 released per second per square meter of soil surface |
| Number of CO2 chambers | The number of automated chambers measuring the soil respiration. The chambers are located in a large plot. |
| Soil temperature | The temperature measured by a sensor at a depth of 7.5 cm below the soil surface |
| Soil moisture | The percentage of moisture measured by an electronic probe in the top 20 cm of the soil, given in terms of the percentage of soil volume occupied by water |
| Soil heat flux | The exchange of heat (longwave energy) between the soil and the atmosphere. Negative values indicate movement of heat towards the soil surface (warming); positive values indicate that the soil surface is losing heat to the atmosphere (cooling). Magnitude describes the instantaneous rate (intensity) of heat exchange. |
| Hourly rainfall | The amount of rain that fell during the hour of observation |
| Was it raining? | Yes or no at the time of observation |
| Shaded air temperature | The air temperature in the shade at a height of 2m above the ground |

* 1. Scroll to the bottom of the dataset. How many rows are there? Why do you think is it less than 365?

1. Graphing soil respiration
2. There is too much data here to see all at once in a table. It is far easier to make a plot.
3. Select columns A and B by clicking on the column letter A and dragging across to B.
4. In the green bar, select Chart, and choose Scatter > Straight Lined Scatter.
5. Right-click in the white space inside your chart and select “Move Chart” from the menu. Put the chart in a new sheet and call at “Annual plot” (without the quotes).
6. You can click on the series label and delete it, since the title explains it well enough.
7. Respond to the following questions with short answers after reviewing the chart (1-2 sentences):
   1. What is the approximate minimum value of the dataset? What about the maximum? As a percent or a factor, how much higher is the maximum than the minimum?
   2. Describe the general pattern of C efflux throughout the year. When is it highest and lowest?
   3. Based on your previous answer, what do you hypothesize is the main driver of C efflux?
8. Now add the rest of the variables.
9. Repeat the process of making a plot like you just did, but this time, select columns A through D to plot them all at once. Don't delete the legend this time, and answer the following:
   1. How would you describe the relationship between soil respiration and temperature? Soil respiration and soil moisture?
10. If we think there is a relationship between two variables, we can examine them separately in a scatterplot.
11. By default, when you make a scatterplot in Excel, the first column becomes the X (independent) variable, and subsequent columns become the Y (dependent) variables. You can manually switch columns later, but I find it much easier just to reorder the columns.
12. Select column B (Soil Respiration). Use cut and paste to move it to the last column of your data.
13. Delete the empty column. Soil Respiration should now be column D.
14. Select columns B and D (Temperature and Soil Respiration). You can control-click (Command-click on a Mac) to select multiple non-adjacent columns.
15. Now make a scatterplot (Marked Scatter), moving it to a separate sheet as before. Don't use a line; it won't make any sense because the X axis points are not in order.
16. Right-click on a point from one of your data series, and select “Add trendline.” In the dialog box that pops up, make sure that you have selected a linear trendline and that you show the equation and R-squared on the screen.

Note: You can think of the “R-squared” as the fraction of the variance in the Y-axis that can be explained by the X variable. For example, an R-squared of 0.20 means that, given certain assumptions about the data, 20% of the variance in soil respiration can be explained by the variable on the X axis. The other 80% of the variance in R-squared would be due to other factors.

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1. Another number called the “p-value” (unfortunately, not shown by default in Excel), represents the probability that the relationship we observe could have simply occurred by chance, given the known variability in our data. Answer the following:
2. What do you think about our linear trend line --- should we have chosen a different curve to describe the relationship? Which one?
3. What fraction of the variance in soil respiration can be explained by temperature in our simple linear model?
4. Explore daily changes
5. Go to the other dataset tab called “growing season.” This data is for the same plot and year, but is in greater detail, showing multiple measurements per day. This time, make a plot of Decimal Day against Soil Respiration (a simple straight line plot works best).
6. Describe the daily fluctuations in soil respiration. When is respiration highest and lowest (UTC)?
7. There seems to be another relationship we cannot explain just with diurnal variations. Let's add in our other predictors (temperature and moisture) to see how they might be affecting our data. Make another plot showing this, like before.
8. It rained on two days during these measurements. Which ones?
9. Temperature and moisture seem to affect respiration on different timescales. Think about the respiration data as two curves superimposed on one another: a daily wiggle and a multi-day increasing trend. Which seems to be driven by temperature, and which by moisture?
10. Total fluxes: How much CO2 are we talking about here? How much carbon moves from soil to the atmosphere in a day? A month? A year? To answer this, we can use Excel to make a quick calculation for us.
11. Return to the “data for annual timeseries” tab. Notice that there is an entry for each day. However, the flux is per second, not “per day.” Therefore, to get the flux per day, we need to multiply by the number of seconds in a day, then sum the days to find the yearly total.
12. In an empty column, say Column E, type the heading “micromol CO2 per m2 per day” in the top row.
13. In the next row (Row 2) of your new column, type “=D2\*60\*60\*24” in the cell (don’t include the quotes). The equals sign tells Excel that it is going to calculate a formula. The D2 refers to the contents of the cell in Column D, Row 2. (If your soil respiration data is not in column D, please adjust this formula accordingly.) Hit Return to see the calculation.
14. Stop and make sure you understand what you just did, and what the “60\*60\*24” means.
15. Now click on the cell with the calculation to select it. Use the slider bar on the right of the window to scroll down to the last cell. Shift-click on it and the whole range of cells should be selected. Now use the command Ctrl-d to fill the equation down into all of the other cells. (If you have never done this before, congratulations! You just experienced the single most useful thing that a spreadsheet program can do for you!
16. Now you have all the daily data. To get the respiration for the whole year, you need to sum up all the daily data.
17. Below the last cell of the daily soil respiration data, click the cell to select it; then click the sigma (∑) button. A sum formula should automatically appear. It will say something like “=SUM(E2:E302)” (assuming that you are summing the calculations in Column E). You can also just type the formula if you can’t find the Sum button.
18. Click return to see the calculation.
19. If you did this correctly, you should now have a pretty big number (more than 85 million) in the cell, showing the total CO2 efflux for the year. If you have something very different, stop and fix the problem before you move on.
20. There is a problem with our calculation – there are days of missing data. We are going to ignore this relatively small problem in this activity. But what would you do if you wanted to fix the problem?
21. Now let’s compare this number with some fossil fuel data. The first thing we need to do is to convert from micromoles of CO2 to kg of CO2, as most global statistics record CO2 in kg. If you are rusty at unit conversion, now is a good time to get some practice. For this task, you need to know that a mole of CO2 is 44 grams.

**13**. Answer the following questions:

1. Before you start, use your intuition. We are taking a number in micromoles and converting it to kilograms. Will our number get bigger or smaller? This will allow you to “reality-check” your answer.
2. Calculate kg CO2 per square meter per year. How many kg of CO2 was emitted by this square meter of soil over the entire year? Check with your instructor to make sure your calculation is correct.
3. Michigan has an area of 2.5 x 1011 square meters. Assuming this forest plot is roughly representative of Michigan, how much CO2 is that? (Include units.)
4. What is this number in millions of metric tons? A metric ton is 1000 kg.
5. According to the Environmental Protection Agency, Michigan emitted 180 million metric tons of fossil fuel CO2 over the same time period. How much larger was our estimate of soil flux?
6. Given the relationship between respiration and temperature that you observed, do you expect that greenhouse gas warming will increase or decrease the emissions of CO2 from the soil?

**Activity B:** Explore global patterns data of soil respiration and carbon dioxide emissions

For the second part of this module, we will be further exploring soil respiration and emission patterns, but this time on a global scale. The data for consideration will be from an online data repository called the Center for Carbon Dioxide Information Analysis Center, managed by the U.S. Department of Energy’s Oak Ridge National Lab. The repository archives and publishes data products that have been developed from raw data, such as that generated by the University of Michigan Biological Station, in forms useful for larger-scale C cycle research and policy applications.

1. We will go to the online data repository and explore two global carbon cycle data products related to soil respiration. Read the abstracts and supporting information for the two data products (maps), and work through the questions that follow.

* Global Patterns of Carbon Dioxide Emissions from Soils on a 0.5 Degree Grid Cell Basis.

<https://cdiac.ess-dive.lbl.gov/epubs/db/db1015/db1015.html>

* [Interannual Variability in Global Soil Respiration on a 0.5 Degree Grid Cell Basis](http://cdiac.ornl.gov/epubs/ndp/ndp081/ndp081.html). <https://cdiac.ess-dive.lbl.gov/epubs/ndp/ndp081/ndp081.html>

1. 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)*.*
   1. What regions have high CO2 emissions from soil, and which have low emissions?
   2. What is the range of values for soil CO2 emissions?

* 1. Given what you know about global climate, biome distributions, etc., what are some plausible mechanisms for these patterns of spatial variation?

1. 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) and answer the following questions.
   1. What is interannual variability in soil CO2 emissions?
   2. What regions have high interannual variability?
   3. In comparing to the previous map (#1), do some regions have high rates and high variability, or low rates and high variability, etc.?
   4. 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?
2. 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 and answer the following questions.
   1. How were these maps made, in terms of measurements, statistical modeling, and spatial extrapolation?
   2. What sources of uncertainty or variation arise at each of these steps in the production of a global map?
   3. How do these sources of uncertainty and variation limit the inferences that can be drawn from the map?
   4. Conversely, how do these global maps extend the inferences drawn from more local measurements, as in Activity A?