**Environmental Drivers of Ecosystem Carbon Fluxes from Minutes to Years**

**Background, and why you should care:** Carbon is the currency of ecosystem production, comprising half of the dry weight of plant tissues produced when atmospheric CO2 is fixed via photosynthesis and then used to build biomass. The rate at which new plant biomass accumulates or, put another way, the “flux” of carbon from the atmosphere to plant biomass is net primary production (NPP). A closely related term, net ecosystem production (NEP), is the balance between gross primary production (GPP, whole-canopy carbon fixation) and ecosystem respiration (Re, respiration from all organisms). Often, NEP is equated with “carbon sequestration”, a general term used to describe the quantity of carbon dioxide removed from the atmosphere, because it is a measure of the net balance between CO2 moving into the forest from photosynthetic carbon fixation and that which is released back to the atmosphere from respiration. This balance between whole-ecosystem carbon uptake (i.e., GPP) and loss (i.e., Re) changes over time as leaves grow and later fall, as shifting climate alters the balance between these two opposing fluxes of carbon, and as disturbances modify the number and physiology of primary producers. Spatially, variability in climate and disturbance regime may explain why ecosystems in different regions sequester carbon at different rates. Understanding how much carbon ecosystems sequester and why is therefore a question of fundamental importance to ecologists, and also to the management of terrestrial ecosystems for carbon sequestration.

Facilitating the quest to answer these questions, researchers are increasingly drawing from open research networks that provide high temporal resolution (usually half-hourly to hourly) estimates of NEP, GPP, and Re for different ecosystems all over the world. Among these networks, the National Ecological Observatory Network (NEON, <https://www.neonscience.org/>) and FLUXNET (<http://fluxnet.fluxdata.org/>) provide freely available carbon flux data. When combined with long-term environmental data from networks collecting meteorological information such as the National Oceanic and Atmospheric Administration (NOAA, <http://www.noaa.gov/>), it is possible to assess the sensitivity of carbon fluxes to ongoing and predicted climate change. This lab challenges participants to use open, long-term data from a variety of networks to ask: 1) How variable are carbon fluxes among sites and over time?; 2) Do temporal patterns of carbon flux differ at different timescales of minutes, days, and years?; and 3) Given historical climate trends, how will changes over time, should they continue, affect the future trajectory of carbon fluxes?

**Part 1: Site selection and hypothesis development**

1. *Select as a group a unique NEON eco-region to investigate (Figure 1)*. You can read about the different NEON eco-regions and how they were selected here: <https://www.neonscience.org/field-sites>.
2. *Within each NEON eco-region, identify a 5-yr+ operating carbon flux tower.* Carbon flux data from meteorological towers is currently collected by NEON sites and many others operating within FLUXNET. Information on sites, including those representing NEON, and data availability is found here: <http://ameriflux.lbl.gov/sites/site-list-and-pages/>. Use the site-specific climate and ecosystem information provided in the previous link to inform your hypotheses below.
3. *Develop hypotheses for your site as a group*. Specifically, consider the temporal patterns of NEP, gross primary production (GPP), and ecosystem respiration (Re) at the following temporal scales (or, depending on the available time, your instructor may focus on only one of these timescales):
   * + Daily
     + Monthly
     + Yearly

(Hint for your group: Consider how and why ecosystems in different eco-regions – nested within different climate and ecosystem functional type domains – may have different patterns over time. Figure 3 in the following may provide some food for thought: <https://www.nature.com/scitable/knowledge/library/terrestrial-primary-production-fuel-for-life-17567411>.) If you have access to a white or chalk board, consider having your group share your hypotheses visually with the entire class.

After hypothesizing temporal trends in these carbon fluxes, use the following data visualization tool to consider the relationship between your visual hypotheses and observations, and how this could inform your data analysis: <https://rampages.us/ecotechniques/data-visualization/>)



Figure 1. NEON eco-regions span a large gradient in climate, ecosystem type, and geography, all of which may affect carbon fluxes. Credit and see: <https://www.neonscience.org/sites/default/files/2017_NEONDomainOverview.jpg>.

**Part 2: Test your hypotheses using real data**

1. *Each group, download carbon flux (including NEP, GPP, Re) data for your site.* Alternatively, your instructor may have downloaded data for you prior to this exercise. NEON’s raw carbon flux data (<http://data.neonscience.org/>) are processed by Ameriflux (<http://ameriflux.lbl.gov/>) and freely available to the public for download via the FLUXNET2015 dataset following user registration. Details on the data acquisition process are here: <http://ameriflux.lbl.gov/data/how-to-uploaddownload-data/>. If you are instructed to download data yourself, only one representative from your group needs to register with Ameriflux to download data on the group’s behalf.
2. *Unzip and open the .csv, import the monthly times-step data into excel or google sheets (i.e., file with “FLUXNET2015\_SUBSET\_MM”).* Though we focus here on monthly data, you and/or your instructor may wish to evaluate temporal patterns on different data time-steps/frequencies, with hourly, daily, weekly, monthly, and yearly values provided in the zipped folder. Orient and familiarize yourself with the variable headers: <http://fluxnet.fluxdata.org/data/fluxnet2015-dataset/fullset-data-product/>.
3. *Given your hypotheses, consider how to organize and then plot your data in a spreadsheet program (e.g., Microsoft Excel or Google Sheets)*. For examining how carbon fluxes change from month-to-month, what is your x-axis? What about your y-axis? How do you organize your data? Once you’ve answered these questions, plot monthly data time-series for NEP, GPP, and Re.
4. *Were your hypotheses generally supported?* Share your results with the larger group, and discuss how you might quantitatively (and not just visually) evaluate support for your hypotheses. If you are feeling ambitious and have the time, consider using statistics to test your hypotheses.

**Part 3: Assess the environmental drivers of carbon fluxes and infer responses to climate change (Optional, suggested for more advanced classes).**

1. *Focusing on Re, or ecosystem respiration (CO2 emissions from all organisms), hypothesize and then use data to determine which climate variable most closely correlates with ecosystem respiration at your site.* (Hint: what is the primary environmental driver of respiration, from cellular to global scales?) To test your hypothesis, you’ll again need to plot your data but this time with a different x-axis. What is the explanatory variable or x axis? What is positioned on the y-axis? Is the trend linear or non-linear? Qualitatively, is the general trend supportive of your hypothesis concerning the relationship between climate and Re?
2. *Develop a simple statistical model (i.e., best-fit equation) using data.* Once your data are plotted, apply a linear or non-linear model that relates Re to the environmental parameter most strongly coupled with this carbon flux. Discuss the significance of a linear vs. non-linear trend in light of changing climate. Record the statistical model/equation in preparation for the next step.
3. *Using NOAA’s “Climate at a glance” (*[*https://www.ncdc.noaa.gov/cag/*](https://www.ncdc.noaa.gov/cag/)*), select the regional time series associated with your site and determine monthly rates of (warning, spoiler alert if you are reading ahead and haven’t yet completed #1 and 2 above) change in air temperature during the last 50 years, approximately the period during which global climate warming has occurred most rapidly.* Observational weather/climate data extend back over a century for most regions and provide quantitative insight into future temperature change. Record the annual rate of change in temperature. (Note Fahrenheit to Celsius conversion: *T*(°C) = (*T*(°F) - 32) × 5/9.)
4. *Returning to your site Re and air temperature data (from FLUXNET2015), isolate January and July monthly Re values, and forecast 50-yr air temperatures for those months.* First, you’ll need to calculate the average air temperatures during these months for your site and then predict future temperatures assuming a constant rate of increase, decrease, or no change based on historical climate data.
5. *Using forecasted monthly air temperatures for January and July, “drive” your Re-air temperature model and plot predicted changes over time in future monthly Re.* Driving the model means you’ll make predictions of January and July Re by plugging in predicted future air temperature data. This general approach to inferring future Re is similar to that used by climate scientists to predict changes in atmospheric CO2as the Earth warms. More on this topic can be found here in this open education resource: <https://www.nature.com/scitable/knowledge/library/studying-and-projecting-climate-change-with-earth-103087065>.
6. *Groups report out findings, evaluate which eco-region appears most sensitive/vulnerable to temperature shifts and which ones are more resistant to change.* With the rule-of-thumb knowledge that the average American emits 1 metric ton of CO2 annual from driving, assess as a group how much additional carbon will be emitted by the ecosystem you’ve investigated on a per hectare basis in 50 years. Is it comparable in magnitude to that which is emitted annually by the “average” driver?