DATA Nugget

Are forests helping in the fight against climate change? A balancing act
Eddy flux tower investigations

Featured scientist: Bill Munger from Harvard University

Research Background:

As humans drive cars and produce electricity, we release carbon dioxide (CO_2) into the air. Because CO_2 helps to trap heat near the surface of the earth, it is known as a "greenhouse gas". However, CO_2 is also an important piece of natural systems. When plants photosynthesize they remove CO_2 from the air and make the sugars they need both for food and to make their stems, roots, and leaves. Some of that carbon gets used up rapidly and is returned to the atmosphere via respiration, but the carbon that ends up in wood stays there for a long time, keeping that CO_2 out of the atmosphere. When trees drop their leaves, lose branches in storms, or die, the carbon that has been stored in those tissues begin to break down, and some of that stored carbon returns to the atmosphere. The rest accumulates over time as soil. Therefore we can think of forests as a balancing act between carbon accumulation in wood and soil, and CO_2 emitted by the decomposition and plant metabolism. When the accumulation of carbon is greater, the site is a "carbon sink", as on the whole the forest is removing CO_2 from the atmosphere. When the sum of decomposition and respiration is greater, the site is a 'carbon source', as the forest is adding carbon back into the atmosphere. Uptake and emission could both be large, but in perfect balance and have no impact on CO_2 in the atmosphere. In order to figure out whether an entire forest is a source, sink or neutral we need consider the growth we can see and the CO_2 release from decomposition that we can't see.

For a long time, scientists tried to figure out if an entire forest removed (carbon sink) or added (carbon source) CO_2 to the air by trying to measure all of the individual pieces, but it was really easy to miss important sources or sinks of CO_2. Scientists discovered that they could build a tower to help them measure the "breath" of the entire forest. Using this "eddy flux tower", with sensors that measure the wind speed and direction, we can determine whether each puff of air (also called an "eddy") is moving up into the atmosphere from the forest, or moving down from the atmosphere into the forest. If we also measure how much CO_2 is in each of these eddies and add them all up, we can determine if the whole forest is releasing CO_2 to the atmosphere or taking it in over the course of an entire year. We call this number the "Net Ecosystem Exchange" (or "NEE" for short). When we talk about NEE, a *negative* number means that more carbon is moving down and being taken out of the air and stored in plants and soils, so the atmosphere is *losing* carbon. When NEE is a *positive* number, it means that carbon is being lost from the forest (because decomposition and metabolism are greater than photosynthesis) and the atmosphere is *gaining* carbon. NEE has a daily cycle with positive values at night and negative values when the sun is shining. In temperate forests where leaves drop and trees stop growing in winter, NEE has an annual cycle with negative numbers during daytime in summer and positive values in winter. If we add up all the hours we get the balance that defines if the site is a source or sink for the year.

Initially, scientists thought that forests would tend to be carbon sinks when they were young and growing rapidly, but eventually be carbon neutral as they aged. Disturbances such as hurricanes or invasive species are also likely to change the carbon balance of a forest: if trees die, there will be less photosynthesis and more decomposition and respiration. On the other hand, changes in climate, the length of the growing season, or CO_2 concentration in the atmosphere might boost photosynthesis relative to decomposition and respiration. Scientists from a Long Term Ecological Research Site affiliated with Harvard University called Harvard Forest, decided to investigate this further by measuring the NEE of a temperate forest using an eddy flux tower. After measuring the CO_2 in the eddies at Harvard Forest for several years, scientists made a surprising discovery: each year, this forest is taking in more CO_2 than it is releasing, meaning that the forest is helping to slow the buildup of CO_2 in the atmosphere caused by humans! Scientists have continued to measure the CO_2 for over 20 years now. By looking at how the NEE changes over time, we can try to make predictions about the future: will forests continue to take up for CO_2 than they release?

<u>Scientific Question</u>:

How has net ecosystem exchange (NEE) at the Harvard Forest changed over time, and what does that tell us about how this forest is influencing carbon dioxide levels in the atmosphere?

<u>Scientific Data</u>:

Use the data below to answer the scientific question:

Year	NEE (grams C/m^2/year)
1992	-164
1993	-179
1994	-173
1995	-282
1996	-194

1997	-163
1998	-157
1999	-213
2000	-261
2001	-426
2002	-270
2003	-212
2004	-458
2005	-543
2006	-458
2007	-537
2008	-612
2009	-358
2010	-36
2011	-150
2012	-339
2013	-218
2014	-459
2015	-194

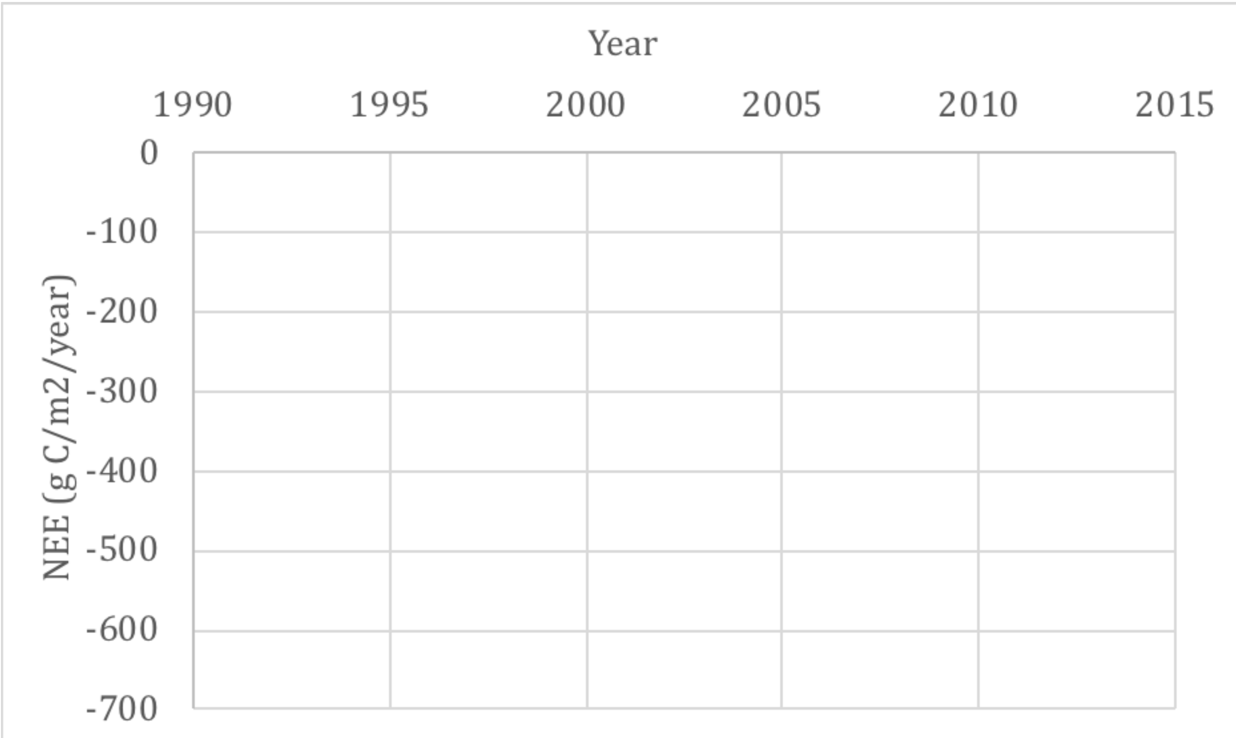
What data will you graph to answer the question?

Independent variable: Year___________________________________

Dependent variable: __NEE (grams of carbon/meters^2/year)

Draw your graph below: Identify any changes, trends, or differences you see in your graph. Draw arrows pointing out what you see, and write one sentence describing what you see next to each arrow.

Graphing Level	
A	Graph provided, axes labeled and data displayed
B	Axes labels provided, student must graph data
C	Graph not provided, student must label axes and graph data



Interpret the data:

Make a claim that answers the scientific question.

Net ecosystem exchange is negative every year, but highly variable. There seems to be a general decrease over time (NEE is becoming MORE negative), suggesting that the forest is removing more CO_2 from the atmosphere now than it used to.

What evidence was used to write your claim? Reference specific parts of the table or graph.

NEE has been negative at HF every year in the data series (1992-2015). This is strong evidence that suggests that the forest acts as a carbon "sink": each year, it removes more CO_2 from the air than it produces. Over the last 25 years, there has been a general pattern of NEE becoming more negative (although there is lots of variability, especially in more recent years!)

Explain your reasoning and why the evidence supports your claim. Connect the data back to what you learned about in the introduction.

The negative values of annual NEE show that this forest is a carbon sink, because more CO_2 is being removed from the atmosphere via photosynthesis than is returning via decomposition and respiration. This suggests that forests are helping to reduce the total CO_2 in the atmosphere.

Your next steps as a scientist:

Science is an ongoing process. What new question do you think should be investigated?

There are a number of possibilities for thoughtful answers to the following questions! One natural next step in this process has been to try and figure out: 1. Why is the forest a carbon sink? 2. Why is the forest storing gradually more carbon over time (ie NEE is becoming more negative)? These questions are currently under investigation by scientists at the Harvard Forest and elsewhere. One hypothesis is that as CO_2 concentrations increase in the atmosphere, trees can increase how quickly they photosynthesize and grow (because trees use the CO_2 to grow, this is similar to providing more "food" for the trees). Alternative hypotheses include other factors that might increase growth and photosynthesis, such as warmer and wetter weather, or changes to the amount of dead wood and its decay rate.

What future data should be collected to answer your question?

Independent variable(s): ____Temperature, precipitation. CO_2 concentration, etc

Dependent variable(s): ___________NEE ______________________________

For each variable, explain why you included it and how it could be measured.

Because we would like to isolate the *mechanism* driving the pattern we observed in the long-term data, we should try to follow a two- step process. First, we can look through the observational data for clues. For example: was there a general increase in CO_2 concentration over the same time period that the NEE was getting more negative? Were the years that had the most negative NEE the warmest, or the wettest? Once we find a likely suspect in our observational data, the next step is to design an experiment. Experiments help us to isolate individual factors in a way that help us understand which ones might be responsible for the response we see. For this type of question, scientists have set up large scale manipulations: large pieces of forest that get altered in some way. For example, there are several experimental forests where scientist have set up systems that increase the CO_2 levels in the air in a patch of forest. By comparing the tree growth in the parts of the forest receiving extra CO_2 to the parts that are not receiving any extra, we can determine if increased CO_2 levels in the air is (in part) responsible for the pattern we see in NEE!

What hypothesis are you testing in your experiment? A hypothesis is a proposed explanation for an observation, which can then be tested with experimentation or other types of studies.

Example hypothesis: Increasing CO_2 concentration causes trees to photosynthesize and grow more, which removes more carbon from the atmosphere. This helps explain the general pattern we see in NEE over time at the Harvard Forest.