PALEONTOLOGICAL RESEARCH INSTITUTION

Sea Grant New York

NYC STEM Summer Institute: Climate To Go!

Photosynthesis drives change in atmospheric CO2

Standards

NGSS LS2B: Cycles of Matter & Energy Transfer in Ecosystems

NGSS ESS3D: Global Climate Change

Equipment

Carbon dioxide meter

Graph paper

Why?

Photosynthesis removes 120 Pg (120 billion metric tons) of carbon every year from Earth's atmosphere and turns it into the carbohydrates that make up living plants. Respiration and decay within ecosystems returns that same amount of carbon to the atmosphere every year. Photosynthesis is driven by sunlight, thus there are large variations in atmospheric CO_2 from day to night. Even though plants don't appear – to our eyes – to be doing much, they are busy changing the composition of the global atmosphere every day.

What?

The movement of carbon dioxide from the atmosphere into biomass is also part of the global carbon cycle (Figure 1). On very long timescales (thousands to millions of years) the geologic carbon cycle moves carbon from the Earth's mantle and crustal rocks into the atmosphere through volcanic eruptions. Carbon is removed from the atmosphere by chemical reactions that weather and decompose rocks. On shorter timescales carbon moves from biomass to the atmosphere and back via photosynthesis and respiration. In the ocean carbon also cycles to the atmosphere and back through exchange with sea water. Each of these three parts of the carbon cycle runs in a steady state, with all the inputs and outputs in balance. The fluxes can be very large, but as long as they are all balanced there is no overall accumulation in any one place.

Carbon is the building block of living organisms. Photosynthesis turns energy from sunlight into chemical energy stored as carbohydrates in plant tissue. The carbohydrates are synthesized from carbon dioxide and water (hence the two parts of the name carbo- and –hydrate). Oxygen is released as a byproduct of the chemical reaction:

$$6H_2O + 6CO_2 = C6H_{12}O_6 + 6O_2$$

The net result of photosynthesis is that plants consume carbon dioxide, release oxygen, and create food for themselves and almost all other living organisms.

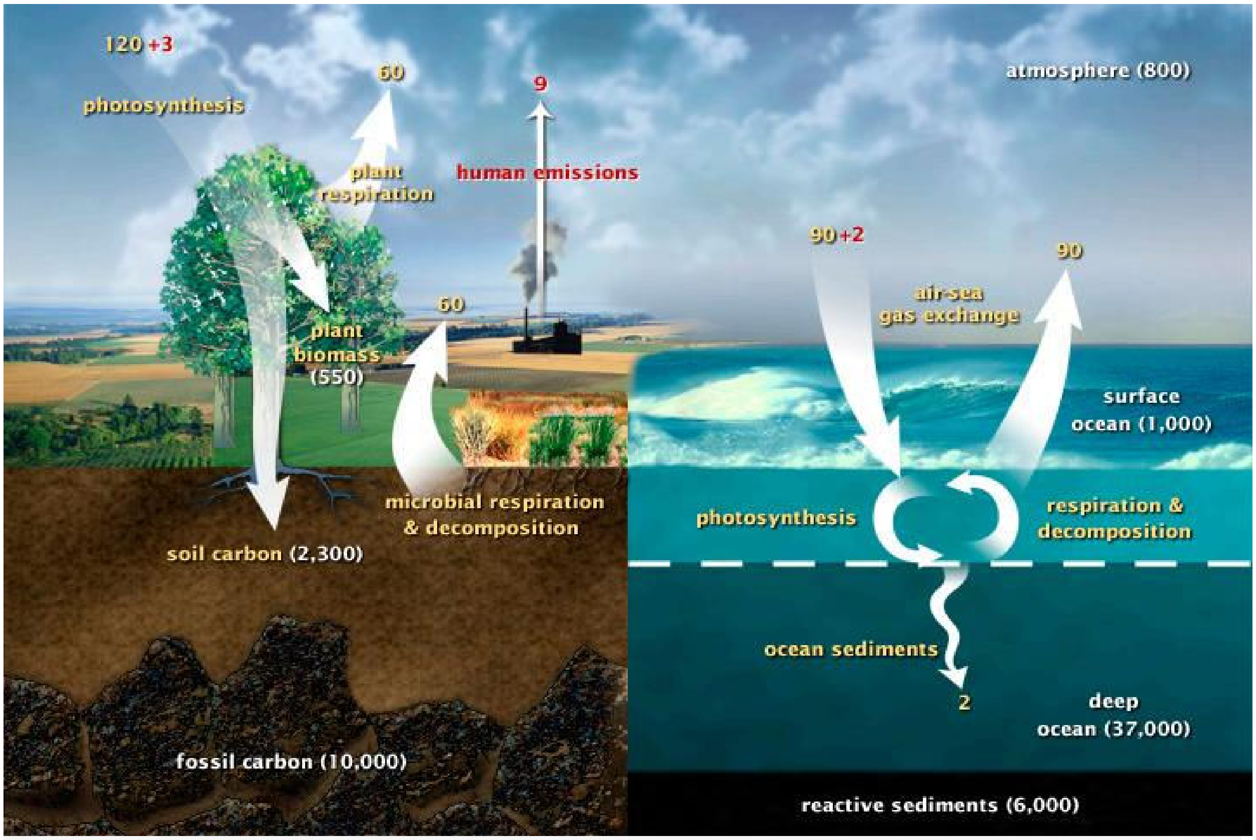

Figure 1: This diagram of the fast (non-geologic) carbon cycle shows the movement of carbon between land, atmosphere, and oceans. Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon per year. White numbers indicate stored carbon.
https://earthobservatory.nasa.gov/Features/CarbonCycle/images/carbon_cycle.jpg

How?
As photosynthesis is powered by sunlight the uptake and release of CO_2 corresponds to the daily flux of solar energy. The CO_2 flux is sufficiently large that a tabletop CO_2 sensor (or a field probe) can quantify the change from day to night. CO_2 is measured in parts per million (ppm). A measurement of 400 ppm means that in one million air molecules, 400 molecules will be CO_2. 400 ppm is equal to 0.04%.

Many CO_2 sensors are equipped with data loggers that will record CO_2 measurements at regular intervals set by the user. A sensor without a logger can be used with some creativity (or dedication); arranging a time lapse camera to photograph the data display will allow data to be recorded even when there is no observer present. The times of sunrise and sunset for any location in the US – and many locations worldwide – are made available by the US Naval Observatory (http://aa.usno.navy.mil/data/docs/RS_OneYear.php).

Set up the CO_2 sensor to record data for a period of 48 hours. Select a measurement interval that will allow students to graph the data by hand, ex: once per hour. A shorter interval will make a smoother graph, especially if students can graph the data with a computer.

Plot a time series of CO_2 measurements over the 48 hour period (X-axis=time, Y-axis=CO_2). Look up the times of sunrise and sunset and mark these on the X-axis of the graph.

Discussion

In any environment with abundant plant life – a forest, meadow, even a plant-filled back yard – the daily change in CO_2 will be approximately 100ppm. This is very large, compared with the average abundance of CO_2 in the atmosphere (currently appx. 410ppm). At sunrise when plants begin photosynthesis CO_2 begins to decrease. At sunset respiration becomes dominant and CO_2 rises again. CO_2 is the plant's "food," and carbon will eventually comprise 50% of the mass of the plant. Not only does an invisible atmospheric gas contribute significantly to the mass of plants, but storing CO_2 as biomass in trees is a very effective method of removing it from the atmosphere.

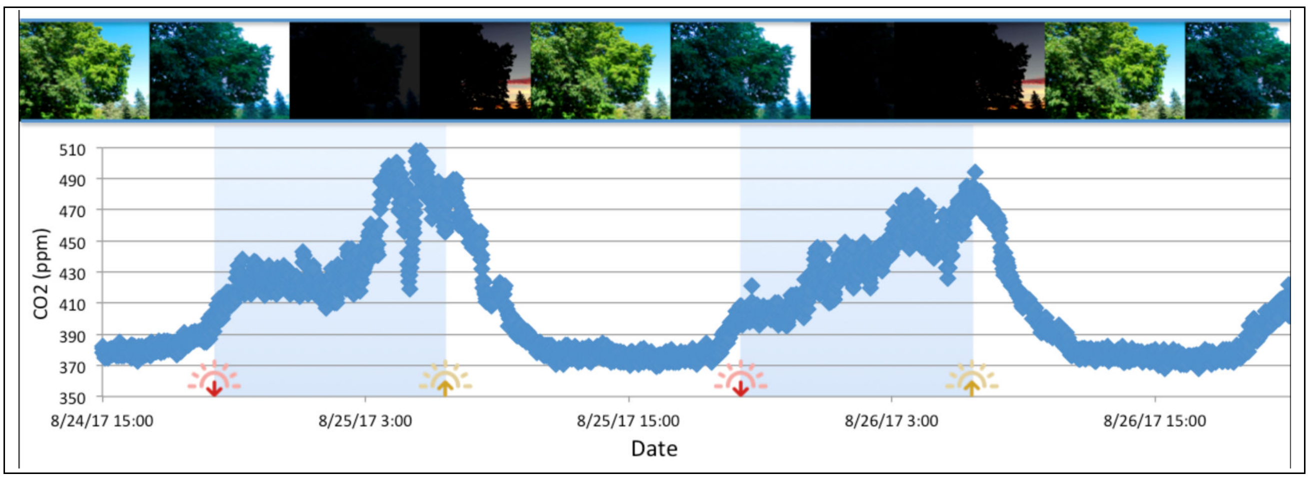

Figure 2: Daily variation in atmospheric CO2 in a temperate forest over a two day period. Times for sunrise and sunset are marked. Note that the amplitude of the variation is >100ppm.

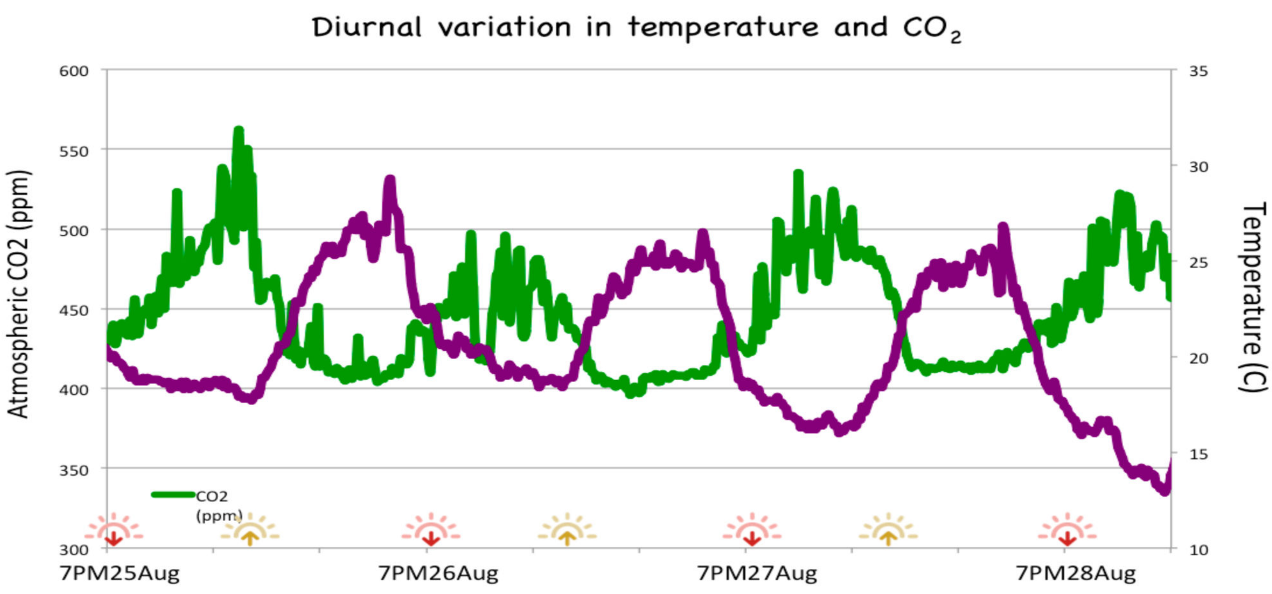

Figure 3: Comparison of daily variation in CO2 and temperature over four days in August.