

CLIMATE CHANGE TOOLKIT

The Carbon Cycle: Respiration

Equipment:

- Appropriate field site - a bare soil or grassy space works well
- One-liter soil flux chambers (1 or 2 per group)
- Duct tape (or similar, to make an opaque chamber)
- Lab CO₂ probes and necessary hardware/software for probes
- Soil thermometers (optional)

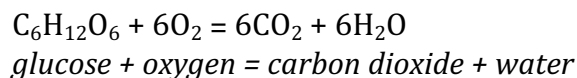


Introduction

Measure the flux of carbon dioxide from soil to the atmosphere using a lab CO₂ probe and home-made flux chambers, then graph the results.

Why?

Photosynthesis transfers carbon dioxide from the atmosphere to plants, releasing oxygen in the process. Respiration runs this reaction backwards, releasing CO₂ while consuming oxygen.



Globally, 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 return that *same amount* of carbon to the atmosphere every year. We can quantitatively measure this flux in any outdoor environment, and compare it with anthropogenic carbon fluxes. Global climate change - especially rising temperature - can perturb the carbon cycle in both the short and long term.

What?

The movement of carbon dioxide from the atmosphere into biomass is 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. In contrast, the human contribution to the carbon cycle is one-way: humans burn fossil fuels and biomass releasing CO₂ to the atmosphere. There is no equivalent return process, thus humans upset the natural balance.

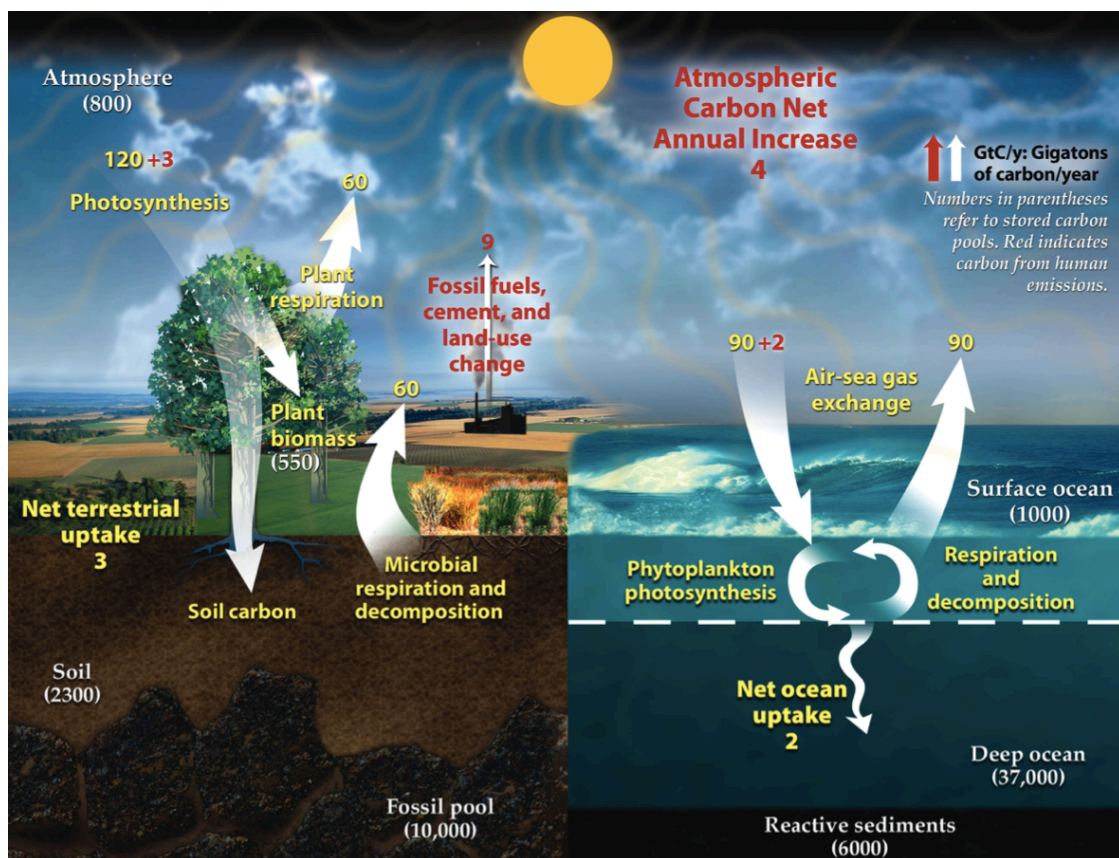


Figure 1: This diagram of the fast (non-geologic) carbon cycle shows the movement of carbon between land, atmosphere, and oceans. Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon per year. White numbers indicate stored carbon.
https://earthobservatory.nasa.gov/Features/CarbonCycle/images/carbon_cycle.jpg

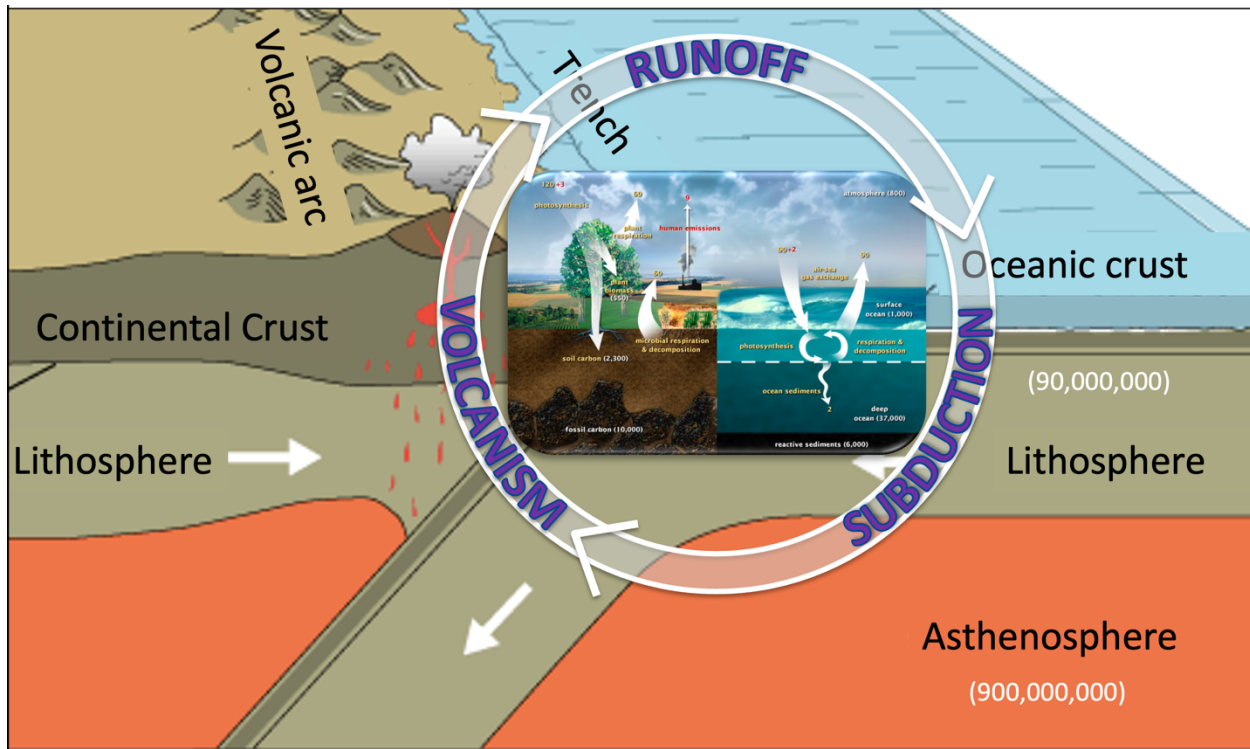


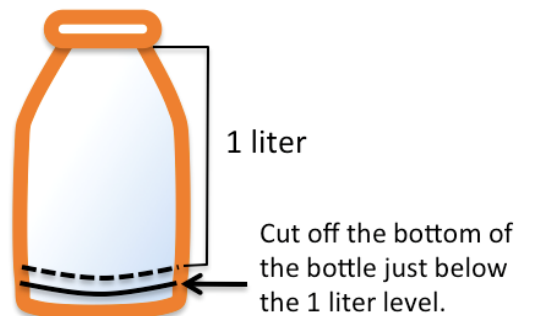
Figure 2: The geologic carbon cycle. The terrestrial and marine carbon cycles from Figure 1, above, are placed within the plate tectonic setting of the geologic carbon cycle. Geologic processes are slower, but move many more gigatons tons of carbon (units are the same as above).

How?

We will measure the respiration and decomposition flux from the soil using a CO₂ probe. From these data we can estimate the contribution of our local environment to the global carbon cycle.

PART 1 - BUILD THE EXPERIMENTAL COMPONENTS

Make a plastic juice bottle flux chamber. The flux chamber will control the movement of CO₂ gas between the soil and probe, and allow us to make quantitative measurements. Choose a 2-quart (or similar) plastic juice bottle with a wide enough mouth to fit the CO₂ probe. Pour in one liter of water (that you've pre-measured in a beaker or graduated cylinder). With the cap on, turn the bottle upside down and draw a line at the one liter mark. Discard the water and cut off the bottom of the juice bottle evenly, just below the one liter line.



This will allow us to push the flux chamber a little bit into the soil to give it some stability during our measurements. Measure the cross-sectional area of the opening at the bottom of the bottle (*length* x *width* for a rectangular bottle; or πr^2 for circular). Measure in *meters* and record the value (or measure in cm and convert to meters: 1 cm = 0.01 m). Finally, cover the bottle with duct tape (or paint, or any other opaque material so that light does not pass through the bottle).

PART 2 – SET UP AND RUN THE EXPERIMENT

Select a field site – any place with soil should work – a grassy field, forest, or park.

➤ If you are working in a grassy field you can run a side-by-side experiment with two flux chambers, one opaque and one clear (instructions on p.6).

Prep your CO₂ probe as you would for any experiment (set up computer interface, etc.). We will record CO₂ values at a time interval of 10 seconds over an experimental run of about 5-10 minutes.

- Remove the cap from the juice bottle flux chamber and insert the probe into the top of the bottle. The probe should fit loosely; make sure there is an air gap that will allow the CO₂ to flux through and out of the chamber. Allow a few minutes for the probe to equilibrate.
- Press the flux chamber into the soil so that the one-liter line is at ground level.
- Collect data for 5 – 15 minutes. Note that at the beginning of the experiment the CO₂ data may be noisy. If so, when analyzing the data ignore these first few minutes of measurements.

Important: protect the experiment from wind, as wind blowing across the top of the chamber disturbs the accumulation rate of CO₂.

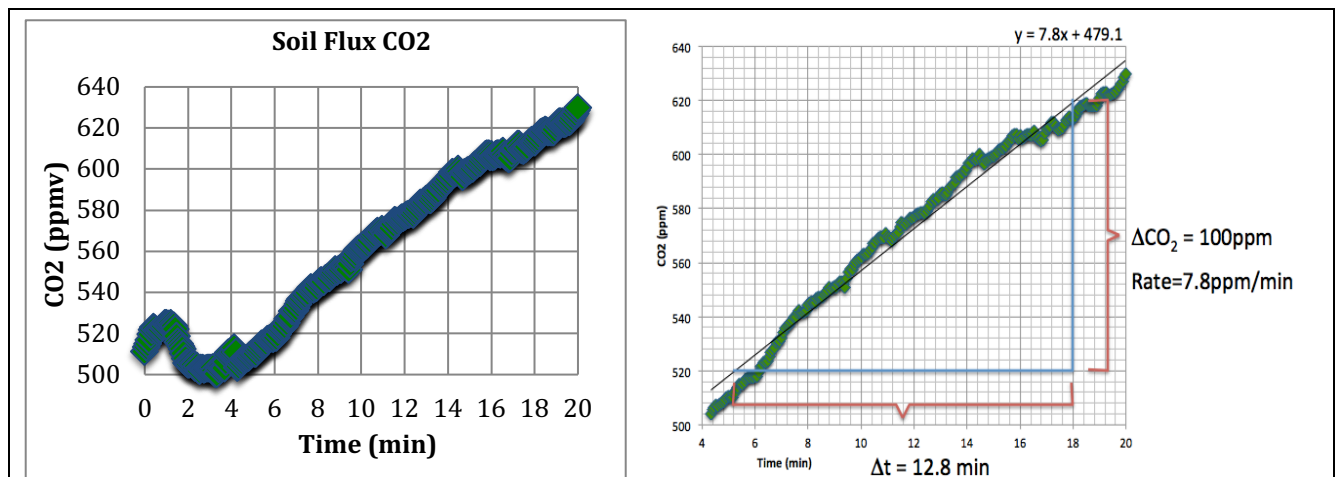


Figure 3: (Left) Sample data; a time series of carbon dioxide measurements. Note that data are noisy at the beginning of the experiment. For these data the slope is calculated only from 4-18 minutes. For any data set, look for a consistent increase early in the experiment; these will be the most characteristic data, unaffected by later CO₂ buildup in the chamber. (Right) Calculation of rate of change for CO₂ data.

PART 3 – ANALYZE THE DATA

The data collected by the CO₂ probe is in units of concentration – parts per million. We want to work in units of mass; grams, kilograms or metric tons of CO₂. For example, in Figure 1 the fluxes are given as gigatons of carbon per m² per year. In the chart below we will convert the measured concentration flux into a mass flux of CO₂ – the mass of CO₂ per unit volume per unit time. We will use metric (mks) units, so we should end up with kg/s (although in this case its OK to use minutes if the probe was set up that way).

- Graph the data: time (min or sec) on the X-axis, and CO₂ (ppmv) on the Y-axis. To calculate the flux we will find the rate of change of the CO₂ concentration in the one-liter flask measured over a fixed interval of time (Figure 2).
- Draw a line – or use a computer to fit a straight line – through your data and calculate the slope. This is the flux rate in units of ppmv/time.

UNIT CONVERSION FROM CONCENTRATION TO MASS FLUX OF CO₂

Steps in Unit Conversion	Result
1. Calculate the cross-sectional area of the flux chamber in units of square meters.	m ²
2. Recall that at standard temperature and pressure (STP) one mole of gas occupies a volume of 22.4 liters. Invert this quantity to find the number of moles in a single liter of gas (e.g. the size of our flux chamber).	mol
3. From the graphed data, calculate the rate of change of CO ₂ in the flask in ppmv/second.	ppmv/s
4. Convert this rate of change from ppmv to its decimal equivalent (to do this, divide the rate by 1,000,000). This allows us to use the rate to calculate mass.	
5. Multiply the rate from Step 4 by the number of moles from Step 2, then divide by the cross-sectional area of the flux chamber from Step 1. The result is the flux of CO ₂ in units of mol/m ² /s.	mol/m ² /s
6. The mass of CO ₂ is 44 g/mol (C=12, O=16). Multiply the result from Step 5 by 44 g/mol to convert the flux to units of g/m ² /s.	gCO ₂ /m ² /s
7. This result is what we were looking for: the mass flux of CO ₂ per unit area per unit time. In order to compare our result with published data, there are most likely more unit conversions to do – but simpler ones – converting g to kg or minutes to years. See below.	

Flux is an extensive property; one that changes with the size of the system. For example, the longer we observe, the more CO₂ moves through the flux chamber, or, the larger the chamber the more CO₂ will move through it. Therefore we need to normalize our measurement with respect to both time and the cross-sectional area of the flux chamber. The rate calculation already accounts for the time of observation. We still need to account for the basal area of the flux chamber.

OPTIONAL: A PAIRED RESPIRATION/PHOTOSYNTHESIS EXPERIMENT

On a grassy outdoor site both photosynthesis and respiration contribute to the CO₂ flux. Here we can set up a paired experiment with an opaque chamber and a clear chamber, and compare the results.

- Set up and run the experiment as before (see p.4), this time placing the clear and opaque chambers side-by side in the grass, pressing them down firmly so that the lower edges of the chambers are in contact with the soil, not just sitting loosely on the grass. Note: if there are not enough CO₂ probes to measure CO₂ simultaneously the experiments can be run sequentially.
- Compare the respiration rates measured in the two chambers.

PART 4 – PUTTING RESULTS IN CONTEXT

Compare the data we collected with the maps of global respiration CO₂ flux (Figure 4). These data are the average annual soil fluxes in units of megagrams of carbon (not CO₂) per square kilometer per year, so for direct comparison we will need to do additional unit conversion:

8. First change grams of CO ₂ to grams of carbon. The fraction of C in CO ₂ is 12/44 (mass of CO ₂ =44, mass of C=12). Multiply your result in Step 6 by (12/44).	gC/m ² /s
9. Convert the time from seconds to years. 1yr=(365days)(24hrs)(60min)(60sec).	gC/m ² /yr
10. Convert m ² to km ² (1km=1000m)	gC/km ² /yr
11. Convert g to Mg (1Mg=1,000,000g)	MgC/km ² /yr

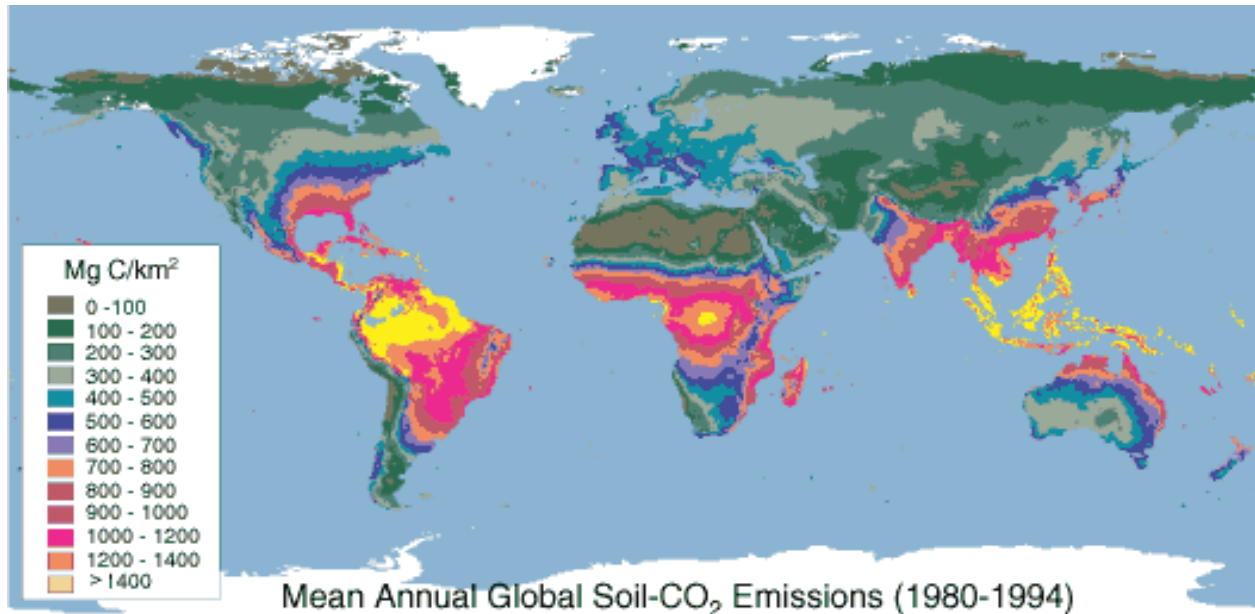


Figure 4: Global mean annual soil carbon flux (MgC/km²/yr), Raich et al., 2003 (https://cdiac.ess-dive.lbl.gov/epubs/ndp/ndp081/map_yrnmn.html)

Questions:

Locate the place you made your measurement on the map (approximately).

1. How does your result compare? Is it the same/higher/lower?
2. Since the map shows annual values, how might your result be different if you could make measurements all year long?
3. Examine the map. Where are C fluxes high (generally)? Where are they low?
4. What conclusions can you draw about how environmental conditions control the rates of soil respiration and decomposition?
5. If climate is warming globally, how might higher temperatures change this map pattern several decades into the future?
6. Look again at the global carbon cycle in Figure 1. Consider the three terrestrial reservoirs for carbon:
 - Atmosphere 800 Gt
 - Biosphere 550 Gt
 - Soil 2300 Gt

Make a hypothesis that predicts how the rate of respiration will change in a global warming scenario, and how that will impact the size of the Atmosphere and Soil reservoirs for carbon.