

ESR 173 Lab 10: Carbon Cycles & Climate Change

Activity

For this Lab activity, you'll be exploring the simulation [Carbon Cycle Lab](#) by The Habitable Planet provided below; this lab activity is modified from the original instructions and includes additional reflection questions relevant to our course.

Purpose

After completing this Lab, you will be able to:

1. Explore a simulation of carbon circulation through Earth's systems
2. Investigate the impact that fossil fuel usage and deforestation have on carbon cycling and accumulation
3. Form evidence-based predictions about the impact of fossil fuel use on global climate, and on the Earth's plants, animals, and oceans.
4. Draw connections between the carbon cycle and human's impact through industrialization and use of fossil fuels.

Background

This lab uses a robust model of the carbon cycle to give you an intuitive sense for how carbon circulates through the atmosphere, biosphere, oceans, and crust. This model is similar to ones presented by the Intergovernmental Panel on Climate Change. It allows you to experiment with how human input to the cycle might change global outcomes to the year 2100 and beyond. One particularly relevant human impact is the increase in atmospheric CO₂ levels. Between the years 1850 and 2015, atmospheric concentrations have risen from 290 parts per million (ppm) to over 400 ppm - a level higher than any known on Earth in more than 30 million years (see Unit 12 to find out how scientists measure ancient atmospheric carbon levels).

Using the [simulator](#), you will experiment with the human factors that contribute to this rise and explore how different inputs to the carbon cycle might affect the concentrations of the greenhouse gas CO₂.

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Definitions:

Atmosphere: combustion of carbon-based fuel combines carbon, C, and oxygen, O₂, adding CO₂ to the atmosphere. CO₂ is not a by-product of fossil fuel use; it's the direct product of the very reaction that releases the energy.

Biosphere (Terrestrial Plants and Soil): plants (biomass) inhale CO₂ and exhale O₂. When there's more CO₂ available, biomass tends to breathe in more, and therefore grow more. Most scientists now believe that plants have a limited ability to increase their growth rate.

Surface ocean: The amount of gas dissolved in any liquid is proportional to the partial pressure of that gas in the vapor phase above the liquid (Henry's Law). As a result, if we increase the partial pressure of atmospheric CO₂ (i.e. increase the concentration of CO₂), then we force more CO₂ gas to dissolve into the liquid. (In this case, the liquid is the ocean.) In addition to the CO₂ dissolving into the liquid as a gas, CO₂ reacts with H₂O and forms bicarbonate ions (HCO₃⁻) and carbonate ions (CO₃⁻). This combustion of fossil fuels results in an increase in dissolved surface ocean carbon and a decrease in pH.

Deep ocean: Ocean chemistry involves mineral precipitation, and biological activity, and ocean currents transport the carbon from the surface ocean to the deep ocean over long time-scales.

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Instructions

Here are some tips for operating the simulation, including what the controls do. I recommend you explore the tool a bit before diving into the lab questions so you are familiar with what is possible, and what the limitations are.

Simulator Controls

Reset Button

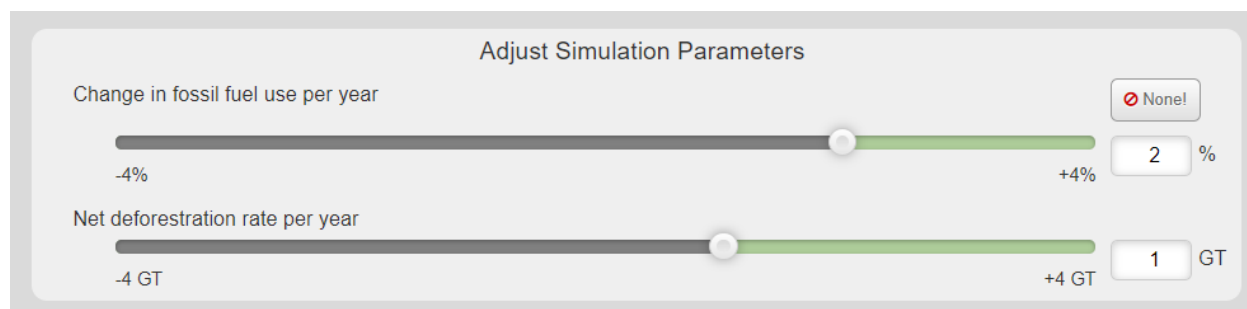
Rewinds to beginning year. Does not re-establish original simulation parameters. For that, first select a different Lesson on the top bar, then re-select the current Lesson. Or reload the browser window.

 Reset Run Decade

Run Decade

Simulates the progress of the carbon cycle at its current settings for ten years.

Simulator Parameters



Change in fossil fuel use per year

Use your mouse to move the white circle knob, to set the percent change in fossil fuel use per year. Moving to the left decreases the rate and moving to the right increases it.

Note: You are increasing or decreasing fossil fuel use, not energy use. Energy use could rise while fossil fuel use falls, if energy generation changed from fossil fuels to some other form (wind, solar, biofuel, etc).

Deforestation rate per year

Use your mouse to move the white circle knob, to set the rate of deforestation per year. Note that deforestation is expressed as GT (metric gigatons) of carbon released, not as a percentage rate of increase. Realistic deforestation rates would remain less than 2 GT per year.

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NONE

Clicking on this button sets fossil fuel use to zero, meaning that all energy, worldwide, suddenly switches to some energy source other than fossil fuels.

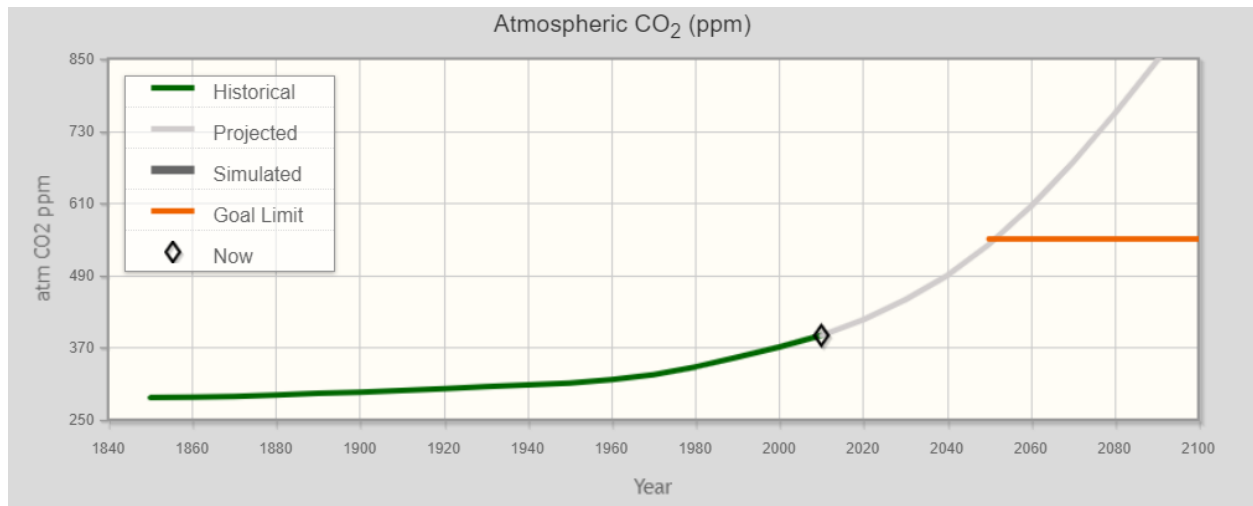
Note: NONE is different from a rate of increase of 0, in which fossil fuel use stops increasing.

Year and numbers

The year tells you where you are in the progression of the simulation. Simulation begins in 2010. The amount of carbon released from fossil fuels in the current year is listed below the year in gigatons, which is abbreviated as GT. Carbon released for a decade is shown on the smokestack.

Year 2010
8.9 GT of carbon released

Graph



The Atmospheric CO₂ graph shows the progression of the carbon cycle and the amount of atmospheric carbon per year in parts per million, abbreviated as ppm. One part per million (ppm) means that for every million molecules in the air, one is carbon dioxide.

There are four lines on the graph: **Historical**, **Projected**, **Simulated**, and **Goal**. There is a diamond marker to highlight "Now". Each of these can be turned off by clicking their name in the legend.

1. Projected

This line comes from the IPCC (International Panel on Climate Change) 2013 Climate Change report ([brief summary](#)). The line shows the "business as usual" projection RCP8.5 for how atmospheric carbon would likely develop in the future. The simulation doesn't affect this line. It is included as a reference.

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Simulated

This line shows atmospheric carbon dioxide calculated by running the simulator. As you change parameters, the slope and general shape of this line will change as well. This line is directly correlated to the carbon cycle illustration, and tracks the number in the middle of the sky on the right hand side, which says XXX ppm CO₂.

Now

The diamond at the end of the Simulated CO₂ line highlights the current simulator status.

Goal

This line refers to the goal of 550 ppm CO₂, which would be twice the amount of atmospheric carbon in comparison to pre-industrial levels. The IPCC established this number as a goal in the 1990's, hoping that carbon emissions can be stabilized at this number instead of continually rising as they have done since the advent of the Industrial Revolution. That goal seeks to limit world warming to 2°C.

Simulator Illustration

All numbers refer to the amount of carbon present in that area. The plus or minus numbers show the change from the original value (in 2010). The scale is at the bottom: one grey rectangle equals 25 gigatons (GT) of carbon.

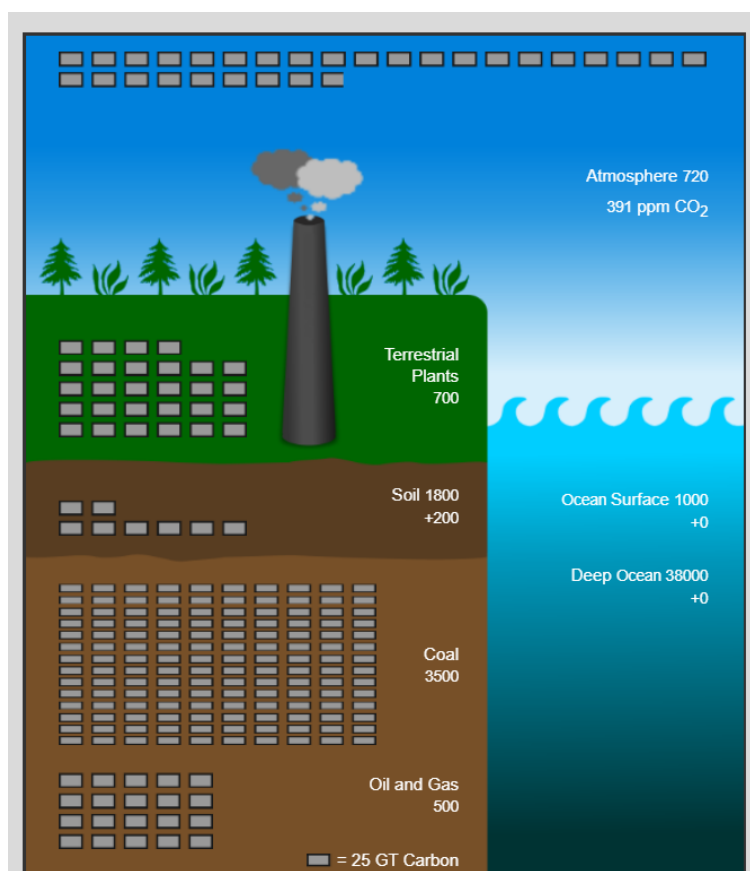
Carbon cycles in this illustration through a rough arc. Fossil fuels rise through the smokestack, into the atmosphere, and down to terrestrial plants and soil and ocean surface. From the ocean surface carbon gradually flows to the deep ocean.

The smokestack number

This number represents the human-generated fossil carbon emissions (in gigatons) released in the last decade's time step.

XXX ppm CO₂

This number represents the current atmospheric carbon dioxide, based on the simulation. This number is also plotted on the Simulated CO₂ line of the graph as the simulator runs.



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Questions & Reflections

The Carbon Cycle - Part A

1. Run the simulation to 2110 with the default settings. **Note:** The default setting for the increase in fossil fuel use per year is **2.5%**. This rate of increase has been our recent experience for the increase in global energy use, as the world's economies ramp up and populations grow.
 - a. Complete the table below by recording the **total carbon levels** in each "sink" (terrestrial plants, soil, oil and gas, coal, surface ocean, and deep ocean) at 2010, 2060 and 2110 (3 points).

	Gaseous Carbon	Ocean Water		Fossil Fuels		Biosphere Gaseous Carbon	
To Year	Atmosphere	Ocean Surface	Deep Ocean	Oil and Gas	Coal	Soil	Terrestrial Plants
2010	720	1000	38000	500	3500	1800 + 200 2000	700
2060	1105	1000 + 123 1123	38000 + 270 38270	0	3114	1800 + 242 2042	766
2110	2502	(1000 + 383) 1383	38000 + 1348 39348	0	0	1800 + 378 2178	950

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- b. Using the data you collect from the model, answer the questions below while thinking about how the model mimics real-life conditions (3 points total; 0.5 points each)

If only one half of the flora in the world existed in 2110 (perhaps due to deforestation), what do you predict the atmospheric carbon level would be? How would you change the simulation to reflect this?

The flora act as Carbon sink through uptake of CO₂ from the atmosphere to facilitate photosynthesis. Reducing the flora by half will increase the level of atmospheric Carbon by a similar value.

The deforestation counter on the simulator should be reset to increase the level of deforestation that occurs every year (4GT/yr = 8GT/decade = 80GT/century)

What is the relationship between increased carbon in the ocean and increased carbon in the soil? How else might carbon be transferred to soil?

The increased carbon in the ocean and increased carbon in the soil are directly proportional. An increase in the carbon level in the ocean increases the carbon level in the soil.

Carbon can alternatively be transferred to the soil by fertilizers and other carbonates carried by surface runoff from higher grounds.

Using the data generated by the simulation, determine the mathematical relationship between the percentage increase in fossil fuel consumption and the increase in atmospheric carbon. Is the relationship linear?

The 2.5 percent increase in fossil fuel use per 100 years will result to 83 percent reduction in fossil fuel consumption and 68 percent increase in atmospheric carbon. In this case, the relationship is not linear.

The Carbon Cycle - Part B

In many scenarios, the atmospheric concentration of CO₂ is projected to increase beyond 700 ppm by the end of the century. However, this increase in atmospheric carbon doesn't account for all of the carbon released by burning fossil fuels.

NOTE: 1 ppm of atmospheric CO₂ is equivalent to 2.1 GT (Gigatons) of carbon.

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2. To find out where all the carbon really goes, run the simulation again, one decade at a time.
 - a. Record the total amount of carbon in the atmosphere (the number in the sky) and other carbon sinks (terrestrial plants, soil, surface ocean, and deep ocean), as carbon moves through the system (6 points)

	Total Carbon Emissions	Gaseous Carbon	Ocean Water		Fossil Fuels		Biosphere Gaseous Carbon	
To Year	Smokestack	Atmosphere	Ocean Surface	Deep Ocean	Oil and Gas	Coal	Soil	Terrestrial Plants
2010	0	720	1000	38000	500	3500	1800 + 200	700
2020	102	755	1000 + 36	38000 + 21	442	3456	1800 + 202	708
2030	130	815	1000 + 52	38000 + 58	368	3400	1800 + 208	719
2040	167	889	1000 + 71	38000 + 110	274	3328	1800 + 217	732
2050	213	983	1000 + 94	38000 + 180	153	3236	1800 + 228	747
2060	273	1105	1000 + 123	38000 + 270	0	3114	1800 + 242	766
2070	436	1332	1000 + 169	38000 + 389	0	2678	1800 + 259	791

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2080	558	1616	1000 + 225	38000 + 552	0	2120	1800 + 281	824
2090	714	1988	1000 + 289	38000 + 763	0	1406	1800 + 309	864
2100	914	2484	1000 + 364	38000 + 1030	0	491	1800 + 342	909
2110	434	2502	1000 + 383	38000 + 1348	0	0	1800 + 378	950

- b. As you record your data, keep in mind that this is a simulation of real life. Think about the questions below (3 points)

What is the relationship between an increase in total carbon concentration (the smokestack) and increased carbon in the ocean surface? How might this change marine life populations? What impact could fifty years at this level of emissions have on marine fauna? On marine flora?

An increase in the total carbon concentration (the smokestack) causes an increase in the ocean surface carbon concentration. The increased carbon concentration in the ocean surface increases ocean acidity, causing massive death of marine organisms and reducing the overall marine life population. The fifty years emission at this level could cause extinction of most marine flora and fauna.

In addition to circulating through the carbon cycle, where else might excess carbon be found? In fifty years, where would you be most likely to see excess carbon?

Excess carbon can be found in the atmosphere, ocean and soil. In fifty years, excess Carbon is likely to found in the soil because of the high rate of deforestation. The trees serve as carbon sink, and extreme deforestation in the next fifty years will increase the level of carbon in the soil.

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Which areas are most highly (and quickly) affected by an increase in carbon emissions (and increase in fossil fuel consumption)? How would these effects manifest themselves? What are the dangers/benefits to these areas?

The areas that are most highly affected by an increase in carbon emission are the atmosphere, soil and oceans. Increased carbon concentration will create the greenhouse effect and increase the rate of global warming. The effect will therefore be manifested through increased global temperature. The effect on soil will be evident by increased soil acidity causing death of terrestrial plants. Ocean acidity will increase as pH reduces, resulting to death of marine life. Increased temperature will cause prolonged drought and famine.