



MODELING HUMAN IMPACT ON EARTH'S CARBON CYCLE

Grade Levels: Grades 9-12

Duration: Varies, 60 minutes to longer depending on background information and discussion

Next Generation Science Standards
HS-ESS3-5 Earth and Human

Activity: Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth's systems.

Content Area: Environmental Science and Geosciences

Learning Objectives/Outcomes

- Students will be able to explain in their own words how anthropogenic carbon leads to an increase in CO₂ in the atmosphere.
- Students will be able to explain in their own words the carbon cycle—specifically the role the atmosphere, oceans, and land masses play.
- Students will be able to hypothesize how different levels of anthropogenic carbon will affect CO₂ in the atmosphere over time.

DESCRIPTION

In this lesson students use a straightforward, manipulative model to understand how anthropogenic carbon is increasing carbon in the atmosphere, which is the driving force of global warming. This model focuses on the global carbon cycle and tracks how carbon moves from anthropogenic sources (human caused) to the atmosphere and then to the oceans and land. Students will test the model and then be able to hypothesize how different amounts of anthropogenic carbon will affect the amount of carbon in the atmosphere over time.

The second part of the lesson has students explore the limitations of the model. Finally students will modify the model to make a more complete representation of the carbon cycle.

For background information we recommend using the Earth Labs lesson "Climate and the Carbon Cycle":

<https://serc.carleton.edu/eslabs/carbon/index.html>

USING THIS LESSON

This lesson can be used for both face to face classes as well as distance learning. The materials are easily sourced and inexpensive. The lesson provides some basic background information about climate change and the Earth Labs "Climate and the Carbon Cycle" lesson provides a more detailed background. There are questions that guide the students through using the model, improving the model, and provide a starting place for class debate on climate change.

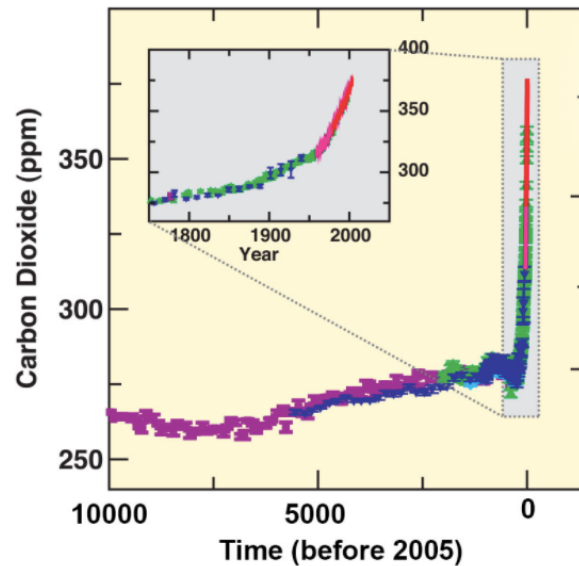
GLOBAL CLIMATE CHANGE

Global warming is a phenomenon that scientists have observed during the 20th century and attributed to the atmosphere trapping and radiating heat back to the earth. This phenomenon is called the greenhouse effect. Gases trapped in the atmosphere are responsible for this effect by blocking the heat from the Earth's surface from escaping to space. The effect is similar to putting on a blanket or another layer of clothes, which prevents heat loss and makes us warmer. The glass of a greenhouse has a similar effect, it reduces heat loss and keeps the surface and the plants in it warmer at night than they would be otherwise. Greenhouse gasses include nitrous oxide, methane, water vapor, and carbon dioxide.

Carbon dioxide (CO₂) is the primary greenhouse gas and thus the primary driver of global warming. While other greenhouse gases are important, this lesson focuses specifically on anthropogenic carbon dioxide. While carbon dioxide is released through many natural processes such as respiration and volcanic activity, it is also released through the burning of fossil fuels. Humans have increased the amount of atmospheric carbon dioxide by more than a third since the industrial revolution (late 18th century).

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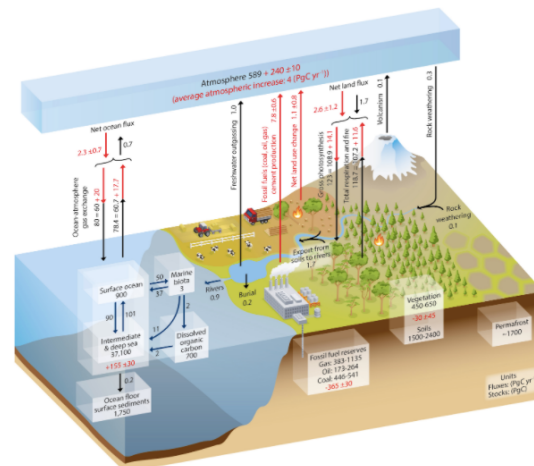
The goal of this lesson is to model how anthropogenic carbon affects the carbon cycle resulting in the large rise in CO₂ levels observed in the atmosphere.



[IPCC 2007](#)

FOUNDATION OF THE MODEL

All models are based on data from the figure below, which examines the amounts of carbon cycling each year. Using this figure will guide students to understand carbon cycling and adapt it to a manipulative model with which they can run various scenarios. This figure is complex and contains data that will not be used during the lesson, but does provide extension for students who wish to provide more information in their model.



The Carbon Cycle. Numbers in boxes represent reservoir mass, also called carbon stocks, inventories, or storage in PgC (1 Pg = 10¹⁵g = 1 Gt). 2.1 PgC = 1 ppm atmospheric CO₂. Numbers next to arrows indicate fluxes in PgC/yr. Black numbers and arrows represent estimates of the natural (pre-industrial) carbon cycle. Red numbers and arrows indicate estimates of anthropogenic effects for 2000-2009. From Ciais et al. (2013). [Image from ipcc.ch](http://image.from.ipcc.ch).

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Materials for

Manipulative Model:

- 2 types of beans (must look different but be of similar size)
- You could also use rice, beads, or other small, uniform items.
- 4 bottles (representing the ocean, land, atmosphere, fossil fuel stores)
- Bottle size does not matter as long as the beans/substitute items fit into them.
- Paper to collect data.

Manipulative Model Set-Up

Label your containers:

- Oceans, Land, Atmosphere

Organize your beans:

- One type of beans will represent natural sources of carbon dioxide
- The other type of beans will represent anthropogenic carbon dioxide
- Each bean will represent 10 PgC (Petagrams of Carbon)

Fill your containers:

- Starting amounts for the containers, representing the amount of carbon dioxide in each reservoir in the year 2009.
- Atmosphere: 60 beans (count)–600 PgC
- Land: 300 beans (measure by weight)–3,000 PgC
- Oceans: 4,000 beans (measure by weight)–40,000 PgC
- Fossil Fuel Carbon: 200 beans (measured by weight)–2,000 PgC

Running the manipulative model:

- Each cycle of the model represents 5 years.

First simulation:

- Maintain current anthropogenic CO₂ emissions based on 2009 levels.
- Each year an increase of 8.9 PgC is released from the fossil fuel carbon into the atmosphere. The ocean takes up 2.5 PgC and the Land takes up another 2.5 PgC for a net increase of 4 PgC into the atmosphere. **We will use some approximation to facilitate removing only whole beans from the containers**
 1. Take 4 of the anthropogenic CO₂ (second type of bean) from the fossil fuel carbon container and put it into the atmosphere container, representing 40 PgC.
 2. Mix the atmosphere container. (Gases in the atmosphere are rapidly mixed by winds.)
 3. Randomly take 2 CO₂ (representing 20 PgC) from the atmosphere and put 1 each into the ocean and land containers representing how much CO₂ they are able to sequester.
 4. This approximates 5 years of CO₂ emission based on 2009 levels.
 5. Repeat cycles of the simulation to represent 80 years and the impact over a human lifetime if 2009 emission levels remained constant.

Second Simulation:

- Increase anthropogenic CO₂ emissions. For the purposes of the model, increase the anthropogenic CO₂ emissions by 2 PgC every 5 years. Remember to take the increase in anthropogenic CO₂ emissions from the fossil fuel carbon container.

Third Simulation:

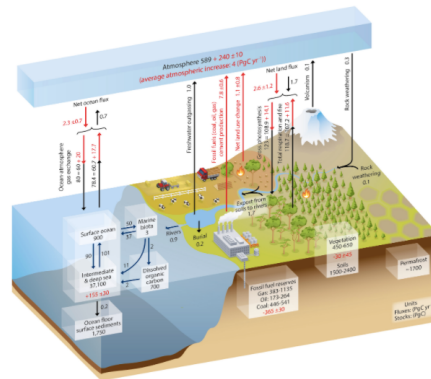
- Zero anthropogenic CO₂ emissions. No anthropogenic CO₂ emissions each cycle of the model.
 - a.) The amount of Carbon from the atmosphere the ocean can uptake (sequester) is directly related to the difference of CO₂ partial pressure (partial pressure is the contribution of one specific gas, in this case CO₂, to the total air pressure) between the atmosphere and the ocean. As the amount of carbon increases in the atmosphere the ocean takes up more carbon. As the amount of carbon in the atmosphere stabilizes or goes down as in this simulation the amount the ocean uptakes goes down as well. For the purposes of our model, once atmospheric carbon drops to 580 PgC (58 beans) the ocean no longer can uptake carbon from the atmosphere. Similarly, the land carbon uptake is in part because re-growth of vegetation that has previously been removed by humans e.g. from deforestation and in part because higher atmospheric CO₂ has a fertilizing effect on plants (they grow faster with the same water supply). Thus, as CO₂ increase stops due to reduced deforestation and reduced burning of fossil fuels this will also reduce the land carbon uptake. You can model this by setting the land carbon uptake to zero once the atmospheric carbon drops to 580 PgC.

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Manipulative model limitations:

A model is a description of a natural process that is used to make predictions. This is especially important for explaining processes that are difficult or impossible to study directly. A good model is one that is both accurate and easy to understand. The manipulative model that you have been using has attempted to do this, but like all models it has limitations. These limitations might come from missing details, approximations, or oversimplification. In this part of the lesson we ask you to identify limitations of the manipulative model and adapt the model to eliminate some of the limitations

Review the simulations that you did with the manipulative model. Identify at least three limitations to your model. Refer to the figure below.



Once you have identified the limitations, list one way you could eliminate or reduce the impact of this limitation.

Creating an improved manipulative model:

Now that you have identified the manipulative model's limitations you are ready to take on the challenge of developing an improved model. The first model only took into account the addition of anthropogenic carbon into the atmosphere of 8.9 PgC (fossil fuels, cement production, and net land use change), net ocean flux of 2.3 PgC, and net land flux of 2.6 PgC. This is a simplified model of the carbon cycle because it does not take into account the ocean atmospheric gas exchange, gross photosynthesis, and total respiration and fire. To take into account this change the process of running the model will have to change, but the overall outcome will stay the same.

Use the same containers and beans for your improved manipulative model.

Use the following values for your improved manipulative model:

Anthropogenic carbon: 9 PgC
Atmosphere to Ocean: 80 PgC
Ocean to Atmosphere: 78 PgC
Gross Photosynthesis (Atmosphere to Land): 123 PgC
Total Respiration and Fire (Land to Atmosphere): 119 PgC
Freshwater outgassing (Land to Atmosphere): 1 PgC
1 Bean equals 10 PgC
Atmosphere container starting amount: 60 beans (600 PgC)
Land container starting amount: 300 beans (3,000 PgC)
Ocean container starting amount: 4,000 beans (40,000 PgC)

Experiment to determine how your model will run to give the accurate amounts of carbon added to the atmosphere, an approximate increase of 4 PgC per year based on 2009 emissions. Once you have figured out the model, write out instructions so a class member could recreate your results.

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Questions

General Questions:

- A carbon sink is any natural reservoir that absorbs more carbon than it releases. Considering the model, name the three anthropogenic carbon sinks on Earth.
- Where are the largest stores of carbon on Earth?
- Where does the majority of anthropogenic carbon emissions come from?

Model Questions:

- In your own words, describe what occurred after running each simulation for 80 years.
- Does maintaining emissions at 2009 levels lower atmospheric CO₂? Why or why not?
- What does eliminating anthropogenic carbon emissions do to atmospheric CO₂? What about carbon in the ocean and land?
- Which carbon sink “fills up” the fastest? Why does this occur?
- If a doubling of atmospheric carbon represents a temperature increase of 3 degrees Celsius, what is the temperature increase after 80 years in simulation one, two, and three?
- What was one thing that surprised you about this model or a simulation that you ran?
- You found limitations with the original manipulative model. Can a model for climate change ever be perfect? Why or why not.
- When you created your improved manipulative model, what improved? Stayed the same? Got worse?
- Most complex scientific models are run on computers. Why is this?

Further Discussion:

- It is not easy to lower atmospheric CO₂. Provide at least two reasons why this is.
- What technologies are humans using that are helping to lower anthropogenic carbon emissions?
- As global temperatures increase the ocean temperature also increases. As the oceans warm they are not able to dissolve as much carbon dioxide. (Like soda becomes stale after you take it out of the fridge and leave the bottle open, its CO₂ outgasses.) What are the consequences of this? How does that affect atmospheric CO₂?
- What could happen with the permafrost carbon if Earth warms?