

# Global Carbon Cycle Modeling with Feedbacks



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## **Purpose**

- To gain a greater understanding of the complexity of models and how they are developed.
- To understand how human actions have an impact on the global carbon cycle.

## **Overview**

The Global Carbon Model with Feedbacks builds on the Simple Carbon Cycle Model by including processes (feedbacks) in the global carbon cycle that modify the movement of carbon into and out of the atmosphere. These added processes allow students to better understand the consequences of human activities in the model. Students will explore the computer model to look at model predictions over hundreds of years, compare model runs to the Simple Carbon Cycle Model, and answer questions by observing model output.

## **Student Outcomes**

Students will be able to:

- Use a model with multiple feedbacks and change model variables to affect model outcomes.
- Describe the individual and combined impacts of the CO<sub>2</sub> and Temperature effects on the global carbon cycle.
- Describe differences in these effects given human actions (eg., fossil fuel burning; land clearing).

## **Questions**

### Essential

- How are models useful in understanding the carbon cycle?

### Content

- How does adding ecosystem feedbacks and other variables improve a scientific model?
- What role do humans play in the global carbon cycle?

## **Science Concepts**

Grades 9-12

*Scientific Inquiry*

- Use technology and mathematics to improve investigations and communications.

### *Life Science*

- The atoms and molecules on the earth cycle among living and non-living components of the biosphere.

### *Science in Personal and Social Perspectives*

- The earth does not have infinite resources.
- Materials from human societies affect both physical and chemical cycles of the earth.
- Human activities can enhance potential for hazards.
- Science and technology can only indicate what can happen, not what should happen.

NGSS (Black- covered directly, gray-addressed, but not directly covered)

### • *Disciplinary Core Ideas*

- Gr.6-8: LS2.B, LS2.C, ESS2.A, ESS3.A, ESS3.C, ETS1.B, ETS.C, ESS3.D
- Gr.9-12: LS2.B, LS2.C, ESS2.A, ESS2.D, ESS3.A, ESS3.C, ETS1.B, ETS.C
- *Science and Engineering Practices*
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations
- Obtaining, Evaluating, and Communicating Information
- *Crosscutting Concepts:*
- Patterns
- Cause and Effect
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter
- Stability and Change

## **Time/Frequency**

60+ minutes

## **Level**

Secondary (High School)

## **Materials and Tools**

- Computers (one per student or student pair)



- Access to online *Global Carbon Cycle Model with Feedbacks* hosted by the ISEE Exchange (<https://exchange.iseesystems.com/public/globeprogam/global-carbon-cycle-model-with-feedbacks>)
- *Global Carbon Cycle Model with Feedbacks Student Worksheet (one per student)*
- *Science Notebooks*
- *Global Carbon Cycle Diagram – class copy, on an overhead or the board.*

### Prerequisites

- Experience with the Simple Global Carbon Cycle Model (e.g., completed *Global Carbon Cycle Student Worksheets 1 and 2*)
- Basics of the global carbon cycle (*Carbon Background, Carbon Cycle Adventure*

*Story, Carbon Travels Game, Getting to Know Global Carbon*).

- Systems thinking concepts including pools, fluxes, box & arrow diagrams, equilibrium (*Paper Clip Factory Analogy, Carbon Cycle Adventure Story*).
- Brief scientific background of climate change (see *Carbon Cycle Introductory eTraining*)

### Preparation

- Make appropriate copies.
- Write essential, unit, and content questions somewhere visible in the classroom.
- Optional: review the Carbon Cycle Modeling eTraining (<https://www.globe.gov/get-trained/protocol-etaining/etraining-modules/16867717/3099387>)

## Background

Scientists use computer models to help them understand the behavior of complex systems and to predict outcomes that cannot be measured directly. Similar to the Simple Global Carbon Cycle Model, in the Global Carbon Cycle Model with Feedbacks all of the Earth's carbon is assumed to be transferred between major carbon pools: the atmosphere, plants, soils, deep oceans, fossil fuels, as well as surface ocean and carbonate rock (the two additional pools in this model). The transfer, or "flux" of carbon is estimated annually. Units are in petagrams (Pg =  $10^{15}$ g) C for stocks and Pg C/yr for fluxes. Although this is still a simplification of how the real Earth works, the added parameters and feedbacks improve the model predictions, and allow students to gain a deeper understanding of how these variables are interconnected in the global carbon cycle.

Two of the new parameters are CO<sub>2</sub> and

Temperature effects, which can be used to examine the consequences of human activity in the model. These factors act as multipliers on photosynthesis, having the effect of enhancing or slowing down photosynthesis, as follows:

- > 1.0, positive effect on photosynthesis
- < 1.0, negative effect on photosynthesis
- = 1.0 neutral effect on photosynthesis

In this model year 0 is right before the onset of the industrial revolution (i.e. fossil fuel emissions were negligible). The model then uses a fossil fuel emissions curve that reflects the patterns recorded since that time and projected to occur up to the year 2100.

For a comprehensive background on the global carbon cycle see the *Carbon Cycle Teacher Background*. For background on positive and negative feedback loops, refer to *Systems and Modeling Introduction: Systems Vocabulary*.

## What To Do and How To Do It

### ENGAGE

**Grouping:** Class

**Time:** 10 Minutes

- Post the *Global Carbon Cycle Diagram*
- Ask students to think back to the Simple Global Carbon Model. What were pools or flows that were missing? How could the model have been improved?

**ELABORATE****Grouping:** Individuals/Pairs**Time:** 45+ Minutes

- Students will now open the *Global Carbon Cycle Model with Feedbacks* online. Students should work through Student Worksheet: *Global Carbon Cycle Model with Feedbacks*.

**EVALUATE****Grouping:** Class**Time:** 15 Minutes

- As a class, discuss students' responses to Student Worksheet.
- Help students make connections between the exercise they completed and other related topics (global carbon cycle, field work, and climate change).
- Inform students of next phases of their carbon investigation (see Extensions for further inquiry opportunities)

**Assessment**

- Students should be graded on the thoughtfulness and thoroughness of their written responses and their ideas/questions shared during class discussions.

**Extensions**

- Students conduct a literature/internet search to further explore the connections and feedbacks in the model. Use the resources listed below as a starting point for research.

**Resources**

- Carbon Cycle Modeling and Introductory eTrainings: <https://www.globe.gov/get-trained/protocol-ettraining/etraining-modules/16867717/3099387>
- The Ocean's Carbon Balance: <http://earthobservatory.nasa.gov/Features/Ocean-Carbon/>
- Larcher W. 1995. *Physiological Plant Ecology*, 3rd ed. Springer-Verlag, Berlin. (*Discussion of temperature effects on photosynthesis starts on page 120. May be able to access these pages through Google Books*).
- Siegenthaler U and Sarmiento JL. 1993. Atmospheric carbon dioxide and the ocean. *Nature* 365: 119-125.
- Intergovernmental Panel on Climate Change: <http://www.ipcc.ch/>
- isee Exchange: <https://exchange.iseesys->

Name:

Date:

## Global Carbon Cycle Modeling with Feedbacks

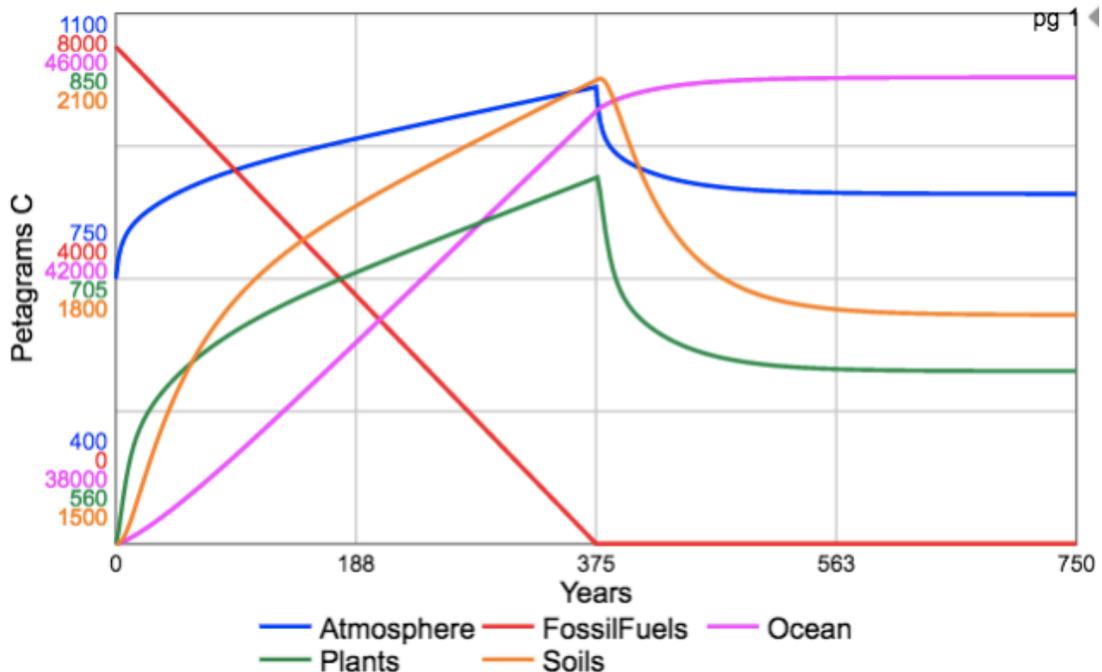
### Task

In this exercise, you will run the GLOBE Global Carbon Cycle Model With Feedbacks to explore how including more parameters in a model can improve/change model results. Record all your work in your science notebook.

### Activity 1. The Simple Model

#### Preliminary Exercise – The Long-Term Carbon Cycle

- Below are a graph and table which contain results from a run using the Simple Global Carbon Cycle Model. As you know, every model has a certain set of assumptions and limitations and therefore can only produce some possible outcomes. Here we are considering how the equations in a model determine its behavior over time. In your science notebook, record your observations of these results. i.e. What are the shapes of the curves for each pool? What happens when fossil fuels reach zero? Where does the carbon from the Fossil Fuel pool end up?

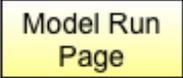


**Figure 1.** Simple Global Carbon Cycle Model run over 750 years. To simulate a high level of CO<sub>2</sub> emissions, Fossil Fuel Combustion was set to 20 Pg C/yr and Deforestation was set to 0 Pg C/yr.

Carbon Pool	Pools Size at Equilibrium (Pg C)
Atmosphere	861.90
Fossil Fuels	0.0
Oceans	45,034.60
Plants	654.46
Soils	1,759.05

Table 1. Equilibrium carbon pool size from the Simple Global Carbon Cycle Model run over 750 years. Fossil Fuel Combustion was set to 20 Pg C/yr and Deforestation was set to 0 Pg C/yr.

## Activity 2. Model Comparisons

1. Open the Global Carbon Cycle Model with Feedbacks.
2. This model builds on the Simple Global Carbon Cycle Model by including ecosystem feedbacks as well as new parameters that were not included in the Simple Model. Feedbacks can be positive (reinforcing) or negative (balancing). How do feedbacks work to stabilize or destabilize a system? Give an example of a positive or a negative feedback in the global carbon cycle.
3. Click on  Model Run Page
4. Click on the Fossil Fuel graphic on the right of the screen. Describe or draw the pattern of fossil fuel combustion. How is this different than fossil fuel combustion in the Simple Model?
5. Check that the Deforestation slider is set to zero, and then click  Run to run the model.
6. Once the model run is complete, look at the top graph. Describe the pattern of the curves for each carbon pool. What happens after fossil fuels run out? How do the lines differ from the Simple Model run shown in Figure 1? What do you think might be causing these differences in model runs? (Use the model, map and equation buttons to assist you.)
7. Look at bottom graph. Which two carbon *pools* were added to the Complex Model that weren't in the Simple Model? Describe what happens to these pools over the course of the model run?
8. The fossil fuel combustion curve is displayed in red on the bottom graph. Describe a scenario that could explain what happened in the year 2100 to cause this pattern.

## Activity 3. The Complex Mode

1. Now click on  Model Map to view the map diagram of the model.
2. Take some time to explore the model map. What are some of the new parameters in this model that weren't in the Simple Carbon Cycle Model?
3. Next you will identify a feedback loop in the model. Draw the feedback loop below and label all the stocks and flows that make up the shortest path to close the loop. At each arrow, predict whether the effect on the next flow or stock is positive or negative.
4. Now return to the model run page. Can you see the effects of the feedback loop you drew in the model graph results? If so how? If not, why not?
5. Two of the important added components in this model, which you may have explored above, are the CO<sub>2</sub> and *Temperature Effects* on Photosynthesis. These factors act as multipliers on photosynthesis, having the effect of enhancing or slowing down photosynthesis, as follows:
  - > 1.0, positive effect on photosynthesis
  - < 1.0, negative effect on photosynthesis
  - = 1.0 neutral effect on photosynthesis

6. To examine how these effects influence the model run, click to Page 2 of the top graph (by clicking on the arrow in the top-right corner of the graph). This graph shows the Temperature Effect (TempEffect), CO<sub>2</sub> Effect, and Photosynthesis as well as the Global Temperature (GlobalTemp) and Atmospheric CO<sub>2</sub> levels. *Remember: you can always click on the Model Map button to help you determine how these variables are connected.*
7. Look at the Photosynthesis, GlobalTemp, and TempEffect curves.
  - a. At what GlobalTemp is the TempEffect the largest? The smallest? (*Hint: By clicking and holding down on a point on the graph, you can see the data values for that point in time appear underneath the variable name.*)
  - b. Is Photosynthesis highest when the TempEffect is largest?
  - c. At what GlobalTemp is Photosynthesis the highest?
8. Now look at the Photosynthesis and CO<sub>2</sub>Effect curves.
  - a. At what CO<sub>2</sub>Effect is Photosynthesis the highest?
  - b. Is Photosynthesis the highest when CO<sub>2</sub>Effect is largest?
9. Describe the overall effect of Temperature and CO<sub>2</sub> on photosynthesis. What implications could this have for plant growth and productivity in the future?

#### Activity 4. Combined Effects of Fossil Fuel Combustion and Deforestation

1. Turn off fossil fuels by clicking on the graph and changing all of the values to “0” and clicking ‘Okay.’
2. Change the Deforestation slider to 1.0 Pg C/yr to reflect 2017 values.
3. Run the model under these conditions and describe how the carbon pool graphs differ from your previous model run.
4. Now explore the combined effects of Fossil Fuels and Deforestation. Turn fossil fuels back on by clicking the ‘U’ button on the Fossil Fuel icon.
5. Run the model and describe how the carbon pool graphs differ from your two previous model runs.
6. Why do you think scientists might model these effects both separately and together?