Climate and Earth Systems

OVERVIEW

This activity focuses on the geological carbon cycle to foster student thinking on Earth systems and develop understanding of how models support and test scientific findings. It can be used in support of Dan Schrag's 2012 Holiday Lecture on Science, *Earth's Climate: Back to the Future*. In this activity students learn that atmospheric composition is one of the major factors in the long-term control of Earth's climate. They then build a model of how carbon cycles through the Earth system.

KEY CONCEPTS AND LEARNING OBJECTIVES

- A system consists of a group of interacting components. Systems can have discrete physical components, like in a home heating system, or the components can be non-physical, like prices and human behavior in an economic system.
- Systems can be described at all scales, from the microscopic to the interplanetary and beyond, but in general a system model works on one scale.
- Systems have processes that transform inputs into outputs that move from component to component.
- The state of a system is a set of attributes or conditions that describe the system at a particular instant – for example, body temperature, level of nutrition, and blood pressure are among the attributes that describe the state of the human body.
- A model is a way of reducing the complexity of systems so they can be studied and tested. Models usually define the components, inputs, and outputs of the system, and together they can describe the state of the system. Models can be on paper, reside in minds or computers, or be physically built.
- Students will construct a model of the geologic carbon cycle on paper and use system thinking to predict behavior of the climate system.

KEY TERMS

System, model, plate tectonics, carbon dioxide

TIME REQUIREMENTS

Approximately 1 50-minute class period, or as a homework assignment.

SUGGESTED AUDIENCE

High school and college level environmental science classes (including AP) and AP high school biology.

CURRICULUM CORRELATIONS

Curriculum Connection	
NGSS (April 2013)	HS-PS1-5, HS-ESS2-2, HS-ESS2-4, HS-ESS2-6, HS-ESS2-7, HS-ESS3-5
AP Environmental Science Course Description (2013)	I.A, I.B, II.D, II.E
AP Biology (2012-13)	1.C.1, 1.D.1, 4.B.4

SUGGESTED BACKGROUND KNOWLEDGE

Students should know about the geologic timescale and the greenhouse effect. They should also know that carbon dioxide is a greenhouse gas. HHMI materials on these topics include EarthViewer and portions of the 2012 Holiday Lectures on Science.

http://www.hhmi.org/biointeractive/earthviewer

http://www.hhmi.org/biointeractive/greenhouse-effect

http://www.hhmi.org/biointeractive/paleoclimate-history-change

MATERIALS

A copy of this worksheet for each student or small group and access to a computer if the above links are included in the assignment.

SUGGESTED PROCEDURE/TEACHING TIPS

Either after the drawing activity or after completing the questions, have students gather in small groups and compare models.

- Did all group members have the same components?
- Did all group members use the same couplings in the same way?
- Pool the ideas within each group to construct an "ideal" model.
- How well do the models explain climate over geologic timescales?

After doing the activity, show the animation from the 2012 Holiday Lectures on Science in which Dan Schrag describes the geologic carbon cycle (6 min 20 sec): http://www.hhmi.org/biointeractive/geologic-carbon-cycle

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Introduction

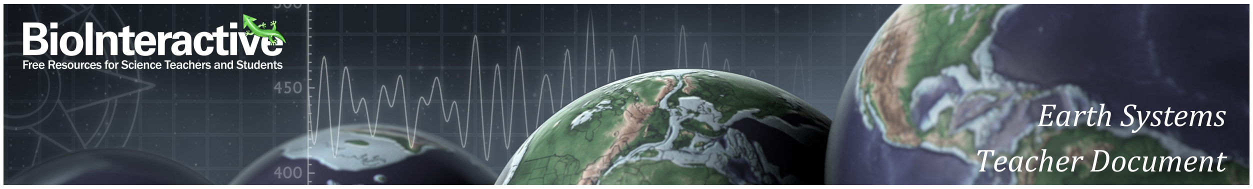
Suppose you want to understand why Earth is habitable to life as we know it, while Venus and Mars are not. The answer is much more complex than simply distance to the sun. To answer this question, you need to consider each planet as a system. A **system** comprises interrelated parts, called **components**, that function as a whole. The links between components are called **couplings**. Scientists construct models as a way to describe and understand complex systems. While system models must leave out many details, they are a useful way to communicate and understand critical concepts.

In this activity, you will construct a model of the inorganic carbon cycle to understand how it regulates Earth's climate over geologic timescales.

Instructions

Read the following text describing the interaction of geology and the carbon cycle. Then use the model components and couplings to design your model. Use your model to explain how Earth's climate system works and how it differs from other nearby planets.

> Carbon dioxide is a gaseous form of inorganic carbon that is an important greenhouse gas. The inorganic carbon cycle is controlled by geologic processes and is critical to the stability of Earth's climate over long timescales. Volcanoes release carbon dioxide from the lithosphere into the atmosphere. Carbon dioxide can dissolve into water droplets in clouds and undergoes a reaction to form a weak acid. Slightly acidic rain falls on continents and contributes to rock weathering –the breaking down of rocks and minerals. This process releases calcium, bicarbonate, and other ions that are transported to the oceans by rivers. Marine organisms use these ions to make calcium carbonate, which is deposited in marine sediments. As the sea floor is recycled by plate tectonics, carbonate sediments are subducted and carbon dioxide is released through volcanoes, completing the cycle.



Components: these parts of system models are often nouns and are commonly represented in boxes. In this example the components are:

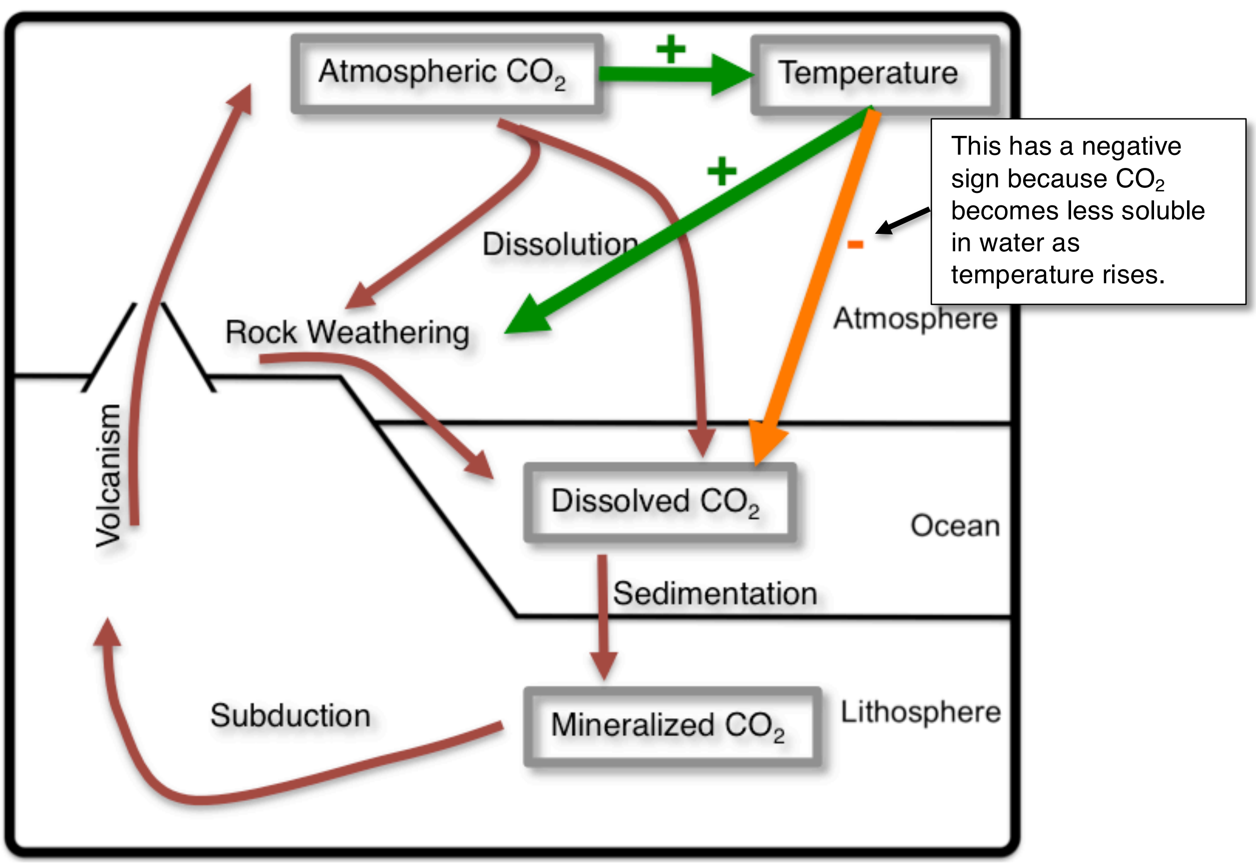
Atmospheric CO_2 | Dissolved CO_2 | Mineralized CO_2 | Temperature

Couplings: these are the processes or mechanisms within the system. Couplings are commonly verbs that explain the relationship between the components and are represented with arrows. In this example the couplings are:

Dissolution → | Rock Weathering → | Volcanism → | Subduction → | Sedimentation →

Use the components and couplings to draw a model in the space below. You can add components or couplings to make your model more complete.

Bonus: In some cases you can indicate if a coupling is positive (+) or negative (-) by thinking about how one component affects another component or coupling. In a positive coupling a change in one component causes a change in a coupling or component in the same direction. In a negative coupling, the change is in the opposite direction.



Use your model to answer the following questions:

1. *Knowing that CO_2 is a critical greenhouse gas that controls temperature over long timescales, how would a long period of excessive volcanism affect the Earth's temperature?*

   High levels of CO_2 would lead to an **increase** in temperature.

   Note that some students may have heard that volcanoes cool the Earth because the ash plumes reflect sunlight. This is true, but it is a short-term effect – months to years instead of millennia. Also, increases in atmospheric CO_2 would also lead to increased dissolution into the ocean, but this happens only at the ocean's surface so the circulation of the ocean limits the overall rate.

2. *The rate of rock weathering increases with increasing temperature. Describe the relationship between temperature and the rate of removal of CO_2 from the atmosphere.*

   As temperature goes up, the rate that CO_2 is removed from the atmosphere increases, thus causing temperatures to fall.

   Bonus information: this is an example of negative feedback.

3. *If all the continents were covered with ice and weathering reactions stopped, what would be the long-term effect on temperature after reactions ceased?*

   Since CO_2 would not be removed from the atmosphere, it would build up, eventually leading to a warmer planet and melting the ice.

4. *Mars has no active plate tectonics and therefore no volcanism. If there were no plate tectonics, how would CO_2 and temperature in your model be affected?*

   With an incomplete cycle, all CO_2 would end up in minerals and would not be returned to the atmosphere via volcanism. If there were no CO_2 in the atmosphere, the greenhouse effect would be weak and the planet would be cold. This is the case on Mars.

5. *The temperature on Venus is above the boiling point of water. What would happen to CO_2 and temperature in your model if you boiled the oceans away?*

   All the CO_2 would stay in the atmosphere, thus leading to a strong greenhouse effect and even higher temperatures. Bonus information: this is an example of positive feedback.

   This is what happened on Venus. Based on its distance to the sun and high reflectivity from cloud cover, the temperature on Venus would actually be lower than on Earth if it had our atmosphere.

6. How does the chemistry of the ocean change in response to high levels of CO_2 in the atmosphere?

   Oceans become more acidic because CO_2 doesn't just dissolve in water —it reacts with water to form a weak acid.

   Bonus information: many marine organisms that remove CO_2 from the ocean to make their shells have a harder time doing so when the water is more acidic.