U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Marine Fisheries Service

Lesson 4:
The Biogeochemical Cycle

Overview

Lesson 4 introduces the concept of biogeochemical cycles, emphasizing the mechanisms by which elements move through Earth's systems. In the activity, students read an article about the Southern Ocean Divide, a discovery that improved scientists' understanding of the ocean.

Lesson Objectives

Students will:

1. Define the biogeochemical cycle
2. Describe the role of the ocean in the carbon cycle
3. Explain the "Southern ocean divide" and its implications for the ocean's response to climate change

Lesson Contents

1. Teaching Lesson 4
    a. Introduction
    b. Lecture Notes
    c. Additional Resources
2. Teacher's Edition: Circulation in the Ocean
3. Student Activity: Circulation in the Ocean
4. Student Handout
5. Mock Bowl Quiz

Standards Addressed

National Science Education Standards, Grades 9-12
Unifying concepts and processes
Physical science
Life science
Earth and space science
Science in personal and social perspectives

Ocean Literacy Principles
The ocean is a major influence on weather and climate

DCPS, High School
Environmental Science
E.3.7. Explain how water, carbon, phosphorus and nitrogen cycle between abiotic resources and organic matter in an ecosystem and how oxygen cycles via photosynthesis and respiration. Diagram the cycling of carbon, nitrogen, and phosphorus in an ecosystem

Lesson Outline[1]

I. Introduction

Introduce the lesson on biogeochemical cycling by playing a brief game with your students. First, ask students to recall the concept of the ocean as a carbon sink. They should explain that carbon enters the ocean by dissolution of carbon dioxide from the atmosphere (this was covered in the ocean acidification lesson). Tell your students that carbon cycles through all four of Earth's major systems: lithosphere (land), atmosphere, biosphere (organisms) and the hydrosphere (ocean). Let them know that elements besides carbon cycle in this way (e.g., nitrogen). Then complete the demonstration:

1. Designate four areas on the classroom floor as the lithosphere, atmosphere, biosphere and hydrosphere (you can do this with circles of ribbon or pieces of tape)
2. Place the carbon cycle cards included in the Lesson 4 folder (File: Carbon Cycle Cards.pdf) within their designated spheres
3. Assign a student to play the role of a carbon molecule moving through the various spheres
4. Starting in any sphere, have the student pick a carbon cycle card and read it aloud
    a. Other students should identify the two spheres represented by the action described on the card
5. The student should follow the instruction on the card and pick a new card
6. Continue until the student has cycled through each sphere

II. Lecture Notes

Use the PowerPoint for Lesson 4 (File: Lesson 4 – Biogeochemical Cycle.ppt) to present the following information. Distribute the student handout before you begin for students to take notes on key information.

The biogeochemical cycle (slide 4)

1. The **biogeochemical cycle** refers to the movement of elements and compounds moving continuously between Earth and its organisms.
2. The biogeochemical cycle involves the movement of elements and compounds among four major systems: (1) land and soil (lithosphere), (2) organisms (biosphere), (3) air (atmosphere) and (4) the ocean (hydrosphere).

[1] Unless otherwise indicated, all websites provided or referenced in this guide were last accessed in November 2010.

How do elements move through the biogeochemical cycle? (slide 5)

1. Elements move through these four spheres through physical processes (e.g., carbon dioxide is absorbed from the atmosphere to the ocean), biological processes (e.g., plants use carbon dioxide from the air in photosynthesis) and through human activities (e.g., burning fossil fuels moves carbon from the ground to the atmosphere).

Which cycling elements are important in the oceans? (slide 6)

1. Carbon, nitrogen, phosphorus, silicon, iron and trace metals are all vital for marine life.

2. This lesson focuses on carbon in particular.

3. Students will see uses of all these elements throughout the curriculum and they should be aware that these elements are biogeochemical, cycling materials.

The biogeochemical pump (slide 8)

1. This graphic illustrates how carbon enters the ocean and eventually moves to the deep ocean, a process referred to as the "biogeochemical pump."

2. Phytoplankton, key primary producers in the ocean, use CO_2 for photosynthesis.

3. As primary producers and secondary producers are consumed, carbon moves up the food chain.

4. As organisms die and decompose, carbon settles to the deep ocean.

III. Additional Resources

1. Background information
   http://www.windows.ucar.edu/tour/link=/earth/Water/co2_cycle.html
   http://www.gsfc.nasa.gov/topstory/20010327colors_of_life.html

Circulation in the Ocean

Overview
In this activity, students read a NOAA news article that presents research on ocean circulation. Students describe the discovery in the article and explain its importance for biogeochemical cycling, as well as human impacts on the ocean.

Procedure
Break students into groups of 4-5 students per group. Distribute one copy of the Student Activity including the article on the Southern Ocean divide to each student. Instruct students to read the article and answer the accompanying questions in their groups.

Answer Key

1. What is the "Southern Ocean divide" that NOAA scientists discovered?
   A biological division separating the Antarctic from the Subantarctic that might allow these regions to respond to human alterations without impacting one another very much.

2. The article states that "the Southern Ocean could change Northern Hemisphere climate by changing atmospheric carbon dioxide." How does the ocean influence the level of atmospheric carbon dioxide?
   The ocean absorbs CO_2 from the atmosphere.

3. According to the article, about how much carbon is removed from the surface ocean by phytoplankton per year?
   60 billion tons.

4. What do scientists mean when they say that most of this carbon is "recycled" once removed by phytoplankton?
   They mean that the carbon then moves through the food chain as primary consumers eat phytoplankton, and are then eaten by secondary consumers and so forth.

5. According to the article, how much carbon sinks into the ocean? How does the carbon reach the deep ocean?
   About 10 billion tons per year. It typically reaches the deep ocean through decomposition.

6. Scientists often use computer models to help them investigate atmospheric-oceanic interactions. In these models, they used to treat the Southern Ocean as a single, uniform ecosystem. How did the new research described in the article change this assumption?
   Scientists discovered that this assumption is too simple. Actually, a small region around the Antarctic margin controls most of the atmospheric-oceanic

exchange. The existence of a biological divide between this area and the large area to the north of the polar front means that the Southern Ocean has distinct regions, so it shouldn't be treated as a single, uniform ecosystem.

7. What does the discovery of the Southern Ocean divide mean for scientists who study how the ocean is impacted by climate change?
   This study shows that different areas of the southern ocean may respond differently to climate change.

Circulation in the Ocean: A NOAA Discovery

Why is it important for scientists to understand and study biogeochemical cycles? In part, knowing how these cycles work helps scientists understand and predict how climate change and human activities will affect the ocean. In the last lesson, you learned that increasing CO_2 concentrations in the atmosphere have contributed to lowering pH levels in the ocean (ocean acidification).

In the NOAA article below, you will read about an important discovery NOAA scientists made in 2006 regarding circulation and biogeochemical cycling in the ocean. Read the article and answer the questions below.

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NOAA SCIENTISTS DEMONSTRATE SOUTHERN OCEAN DIVIDE[2]

June 28, 2006 - The complex relationships between atmospheric carbon dioxide, biological productivity and the role of the Southern Ocean in carbon sequestration have been demonstrated by scientists at the NOAA Geophysical Fluid Dynamics Laboratory and Princeton University in Princeton, N.J.

Ocean waters that move toward the Antarctic continent sink as their temperatures drop. Once this occurs, these waters then move northwards. New research demonstrates that water at greater depths have a significantly different impact than the high-nutrient waters that flow northwards at intermediate depths. The circulation in the regions around Antarctica where water sinks to depths greater than 1.5km was shown to be largely responsible for controlling the air-sea balance of carbon dioxide (CO_2). The circulation in the Subantarctic regions that feed water to depths between 0.5km and 1.5km controls biological productivity. This research builds on recent studies showing that different parts of the Southern Ocean have responded differently to climate change.

Scientists looked at atmospheric CO_2 and tiny marine plants known as phytoplankton, which remove almost 60 billion tons of carbon from the surface ocean each year. Much of the carbon is recycled by other organisms within the surface layer of the ocean, but about 10 billion tons of this carbon sinks into the deep ocean. This "biological pump" in the Southern Ocean is known to play a central role in the how much CO_2 is contained in the atmosphere, as well as the global nutrient cycle.

"Even though it's a long way from occurring, we've long known that the Southern Ocean could change Northern Hemisphere climate by changing atmospheric carbon dioxide" said Anand Gnanadesikan, research oceanographer at GFDL and a co-author of the paper, which was published in the journal Nature. "What we didn't understand was the importance of the details of circulation."

Gnanadesikan worked with lead author Irina Marinov (currently a fellow in the NOAA Postdoctoral Program in Climate and Global Change), and with GFDL oceanographer J.R. Toggweiler and Jorge Sarmiento of Princeton University. The team used a series of ocean model simulations to investigate which areas of the Southern Ocean control atmospheric carbon dioxide levels, which areas control biological production and whether there is a link between the two.

Using GFDL's Modular Ocean Model coupled with a biogeochemistry model, researchers increased biological productivity in different parts of the Southern Ocean, depleting surface nutrients and forcing more CO_2 into the ocean. They were able to discern which location determined the impact on air-sea carbon exchange. Depleting nutrients in the Antarctic

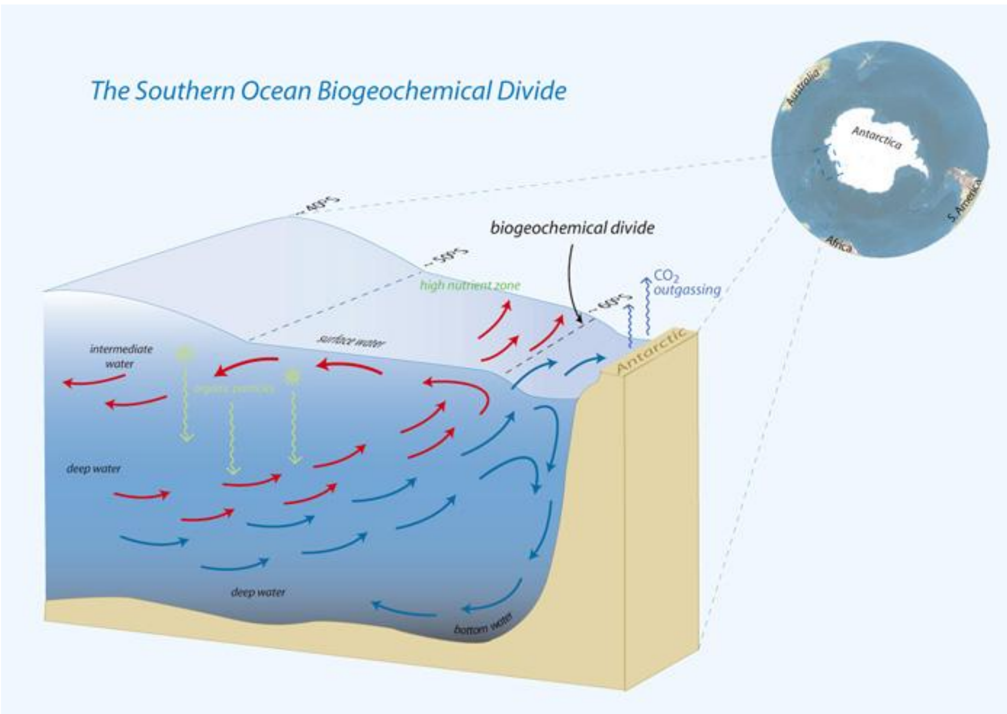
[2] Source: NOAA News, http://www.noaanews.noaa.gov/stories2006/s2653.htm

zone was up to 12 times more effective at reducing atmospheric carbon dioxide as depleting nutrients in the Subantarctic zone.

"The work we had done previously considered the Southern Ocean as a single, relatively uniform ecosystem," Gnanadesikan said, "but J.R. Toggweiler had the idea that this was too simplistic—that more attention needed to be paid to the Antarctic. We decided to put his idea to the test."

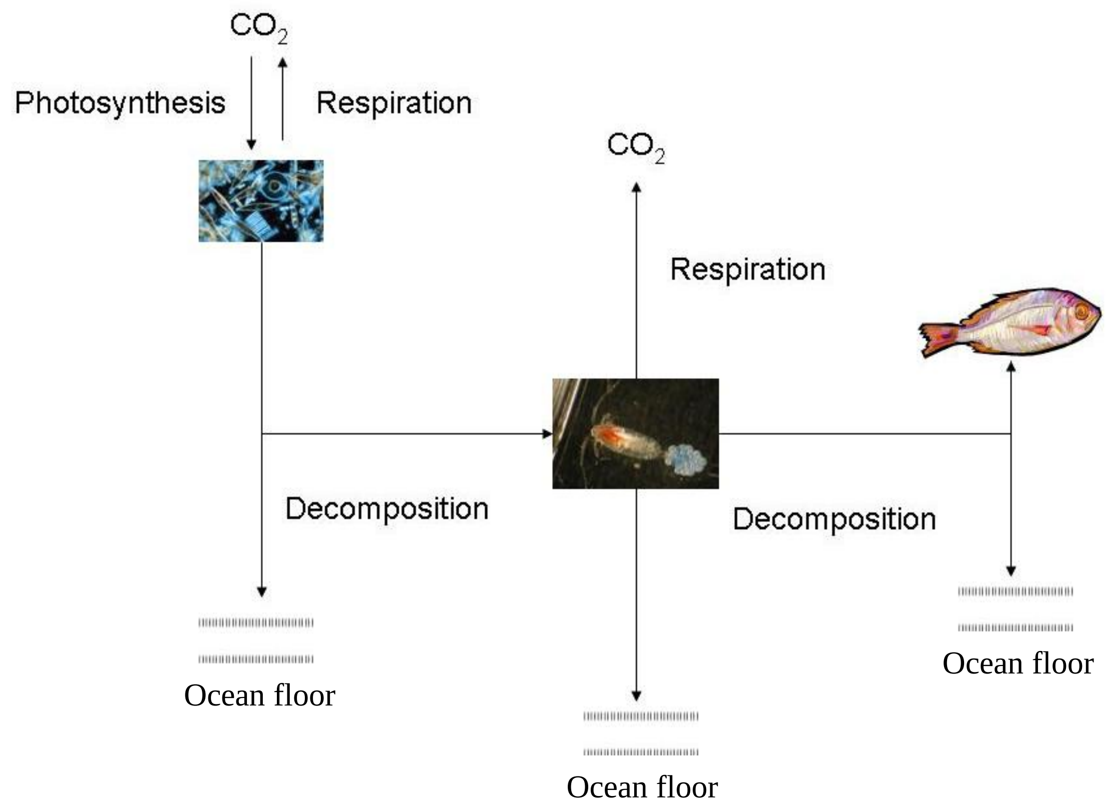
The research confirmed that the key region for understanding atmospheric carbon dioxide is not the relatively large area to the north of the polar front, but the much smaller, poorly sampled region around the Antarctic margin (see picture below). This biological divide separating the Antarctic from the Subantarctic suggests that one area could be modified—by climate change or human intervention—without greatly altering the other. These results have important implications for understanding both past and future variations in atmospheric carbon dioxide and biological production.

The NOAA Geophysical Fluid Dynamics Laboratory advances NOAA's expert assessments of changes in national and global climate through research, improved models and products. The goal of GFDL's research is to understand and predict the Earth's climate and weather, including the impact of human activities.



Tips for the Bowl - The Carbon Cycle

Write down the definitions of relevant terms and processes from today's presentation on the diagram below. These will be important to know for the Bowl. Other important facts and terms are listed below.



Carbon Cycle Facts

- The ocean absorbs more carbon dioxide from the atmosphere than the land
- The deep ocean holds more than 65% of the Earth's carbon[3]
- Carbon can remain in the deep ocean for hundreds of years
- During photosynthesis, plants use CO_2 to make sugar and oxygen:

$6CO_2 + 6H_2O$ + sunlight $\rightarrow$ $C_6H_{12}O_6$ (glucose) + $6O_2$ (oxygen gas)

- Half of the primary productivity (synthesis of organic material from solar or chemical energy, as occurs during photosynthesis) on Earth takes place in the ocean
- A carbon **source** is any process or activity through which a greenhouse gas is released into the atmosphere. Both natural processes and human activities release greenhouse gases
- A **carbon sink** is a reservoir that takes up a chemical element or compound from another part of its natural cycle

[3] National Marine Educators Association. 2010. *Life on an Ocean Planet*. Current Publishing Corps, Santa Margarita, CA. 598pp.

Biogeochemical Cycle

1. Short answer: The pronounced upward movement of deep waters and associated nutrients is called:
   Answer: Upwelling

2. The primary process by which carbon is returned to the surface waters from the deep ocean is:
   w. **Upwelling of deep ocean currents**
   x. Photosynthesis by phytoplankton
   y. Erosion at the coastline
   z. Heating of subsurface waters

3. Short answer: This term describes the decay of dead marine life that releases carbon into the ocean.
   Answer: Decomposition

4. Which of the following terms refers to the continuous flow of elements and compounds between organisms and the Earth?
   w. The nutrient cycle
   x. **The biogeochemical cycle**
   y. The upwelling cycle
   z. The element cycle

5. Reminder question: Shells and exoskeletons are composed of which of the following:
   w. Bicarbonate
   x. Carbon dioxide
   y. The carbon sink
   z. **Calcium carbonate**

6. The following is an energetic process by which phytoplankton intake carbon dioxide from the atmosphere.
   w. Respiration
   x. Decomposition
   y. Sedimentation
   z. **Photosynthesis**

7. About what percentage of Earth's primary productivity (synthesis of organic matter from solar or chemical energy) occurs in the ocean?
   w. 10%
   x. 25%
   y. **50%**
   z. 75%

8. Reminder question: When carbon dioxide is dissolved into seawater, which product forms?
    w. **Bicarbonate**
    x. Calcium carbonate
    y. Carbonic acid
    z. Phosphate

9. During photosynthesis, water, carbon dioxide and light energy react to form glucose and what other product?
    w. **Oxygen**
    x. Nitrogen
    y. Calcium carbonate
    z. Iron

10. Team Challenge Question

Phytoplankton synthesize sugars (CH_2O) in surface waters of the ocean. A generic chemical reaction for this photosynthetic process is:

$CO_2 + H_20 \rightarrow CH_2O + O_2$

1. What is the source of CO_2 that phytoplankton use for photosynthesis? (2pt)

2. How does photosynthesis in surface waters affect the exchange of carbon from the surface water to the deep ocean? (2pt)

3. Name another potential source of carbon into the deep ocean. (1pt)

4. The ocean (hydrosphere) is one part of the broader carbon cycle.
    a. Name three other important carbon sinks. (3pt)

    b. How can human activities affect the carbon cycle? (2pt)

ANSWER

Phytoplankton synthesize sugars (CH_2O) in surface waters of the ocean. A generic chemical reaction for this photosynthetic process is:

$CO_2 + H_20 \rightarrow CH_2O + O_2$

1. What is the source of CO_2 that phytoplankton use for photosynthesis? (2pt)
CO_2 dissolves from the atmosphere into the surface water (1pt) and phytoplankton then use this CO_2 from the surface water for photosynthesis (1pt).

2. How does photosynthesis in surface waters affect the exchange of carbon from the surface water to the deep ocean? (2pt)
When phytoplankton or organisms that eat phytoplankton die, they decompose and some of the carbon from the decomposing matter can settle to the deep ocean (2pt).

3. Name another potential source of carbon into the deep ocean. (1pt)
Sediments washed into the ocean containing carbon may settle to the deep ocean (1pt).

4. The ocean (hydrosphere) is one part of the broader carbon cycle.
   a. Name three other important carbon sinks. (3pt)
   Lithosphere (land, soil), living organisms (biosphere) and atmosphere (1pt each).

   b. How can human activities affect the carbon cycle? (2pt)
   Answers will vary but should include the extraction of carbon-based fossil fuels from the ground, the burning of these materials for industrial, domestic or transport process and the emission of carbon dioxide into the atmosphere. Increasing emissions increase Earth's temperature and increase pH levels in the oceans.