



Greenhouse Gases and Sea Level Rise



Investigation
Manual

GREENHOUSE GASES AND SEA LEVEL RISE

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Overview

In this lab, students will carry out several activities aimed at demonstrating consequences of anthropogenic carbon emissions, climate change, and sea level rise. To do this, students will first create a landform model based on a contour map. They will create models of sea level rise resulting from melting of sea ice and glacier ice and examine the effects of this potential consequence of climate change. Students will critically examine the model systems they used in the experiments.

Outcomes

- Explain the causes of increased carbon emissions and their likely effect on global climate.
- Discuss positive and negative climate feedback.
- Distinguish between glacial ice melt and oceanic ice melt.
- Construct a three-dimensional model from a two-dimensional contour map.
- Evaluate and improve a model system.

Time Requirements

Preparation:

Part 1 5 minutes,
then let sit for 24 hours before starting Activity 1

Part 2 2 hours

Activity 1: Sea Ice and Sea Level Rise 1 hour

Activity 2: Glacier Ice and Sea Level Rise 2.5 hours

Key

Personal protective
equipment
(PPE)



goggles



gloves



apron



follow
link to
video



photograph
results and
submit



stopwatch
required



warning



corrosion



flammable



toxic



environment



health hazard

Background

For the last 30 years, controversy has surrounded the ideas of global warming/climate change. However, the scientific concepts behind the theory are not new. In the 1820s, Joseph Fourier was the first to recognize that, given the earth's size and distance from the sun, the planet's surface temperature should be considerably cooler than it was. He proposed several mechanisms to explain why the earth was warmer than his calculations predicted, one of which was that the earth's atmosphere might act as an insulator. Forty years later, John Tyndall demonstrated that different gases have different capacities to absorb infrared radiation, most notably methane (CH_4), carbon dioxide (CO_2), and water vapor (H_2O), all of which are present in the atmosphere. In 1896, Svante Arrhenius developed the first mathematical model of the effect of increased CO_2 levels on temperature. His model predicted that a doubling of the amount of CO_2 in the atmosphere would produce a 5–6 °C increase in temperature globally. Based on the level of CO_2 production in the late 19th century, he predicted that this change would take place over thousands of years, if at all. Arrhenius used Arvid Högbom's calculations of industrial CO_2 emissions in his equations. Högbom thought that the excess CO_2 would be absorbed by the ocean; others believed that the effect of CO_2 was insignificant next to the much larger effect of water vapor.

It was not until the late 1950s, when the CO_2 absorption capacity of the ocean was better understood and significant increases in CO_2 levels (a 10% increase from the 1850s to the 1950s) were being observed by G. S. Callendar,

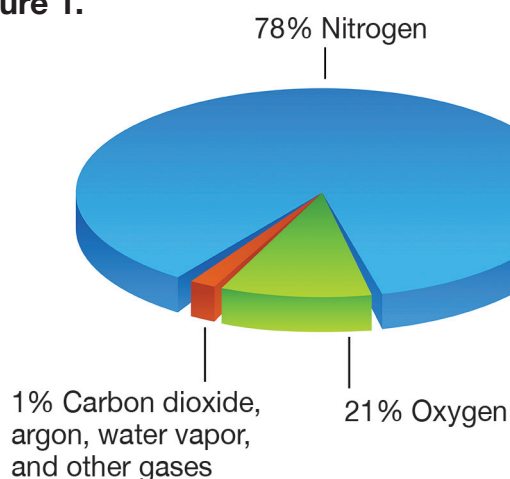
that Arrhenius's calculations received renewed attention.

The Atmosphere

Weather is the condition of the atmosphere in a given location at a specific time. **Climate** is the prevailing weather pattern over a longer period of time (decades or centuries).

The atmosphere is a thin shell (~100 km) of gases that envelops the earth. It is made up principally of nitrogen (78%), oxygen (21%), and argon (0.9%). Trace gases include methane (CH_4), ozone (O_3), carbon dioxide (CO_2), carbon monoxide (CO), and oxides of nitrogen (e.g., NO_2) and sulfur (e.g., SO_2) (see Figure 1).

Figure 1.



Water vapor is sometimes included in the composition of gases in the atmosphere, but a lot of times it is not because its amount varies widely, from 0%–4%, depending on location. The concentration of gases in the atmosphere is not uniform either; the atmosphere consists of several concentric layers. Some gases are concentrated at certain altitudes. Water and

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GREENHOUSE GASES AND SEA LEVEL RISE

Background continued

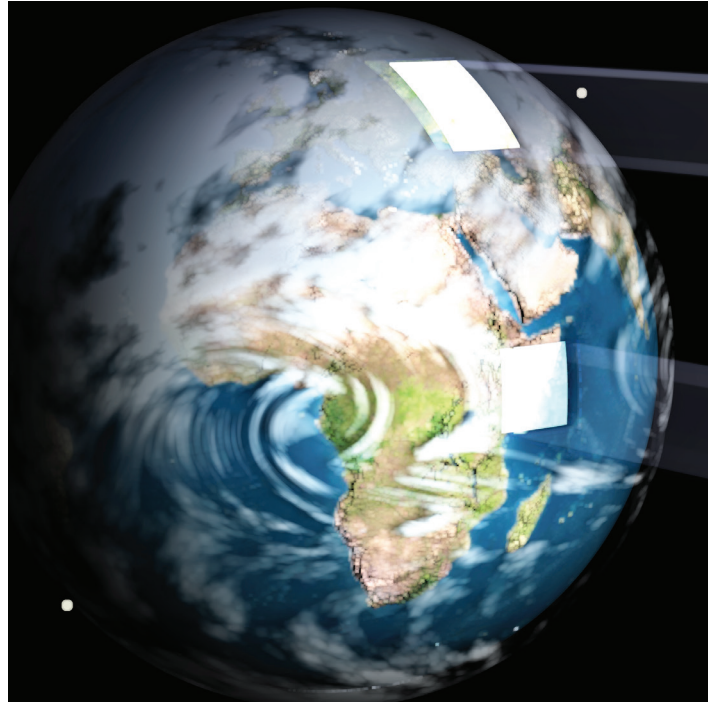
carbon dioxide are concentrated near the earth's surface, for instance, while ozone is concentrated 20 to 30 kilometers above the surface. Energy transfer from the sun at and near the surface of the earth is responsible for weather and climate. Solar radiation heats land, the oceans, and atmospheric gases differently, resulting in the constant transfer of energy across the globe.

Several factors interact to cause areas of the earth's surface and atmosphere to heat at different rates, a process called **differential heating**. The first is the angle at which the sun's light hits the earth. When the sun is directly overhead, as it is at the equator, the light is direct. Each square mile of incoming sunlight hits one square mile of the earth. At higher latitudes, the sun hits at an angle, spreading the one square mile of sunlight over more of the earth's surface. Thus, the intensity of the light is reduced and the surface does not warm as quickly (see Figure 2). This causes the tropics, near the equator, to be warmer and the poles to be cooler.

Different materials heat and cool at different rates. Darker surfaces heat faster than lighter surfaces. Water has a high heat capacity, which is important on a planet whose surface is 72% water. **Heat capacity** is a measure of how much heat it takes to raise the temperature of a substance by one degree. The heat capacity of liquid water is roughly four times that of air. Water is slow to warm and slow to cool, relative to land. This also contributes to differential heating of the earth.

Differential heating causes circulation in the atmosphere and in the oceans. Warmer fluids

Figure 2.



are less dense and rise, leaving behind an area of low pressure. Air and water move laterally to distribute the change in pressure. This is critical in developing prevailing wind patterns and in cycling nutrients through the ocean.

The Role of the Oceans

The oceans play an important role in regulating the atmosphere as well. The large volume of the oceans, combined with the high heat capacity of water, prevent dramatic temperature swings in the atmosphere. The relatively large surface area of the oceans, ~70% of the surface of the earth, means that the oceans can absorb large amounts of atmospheric CO₂.

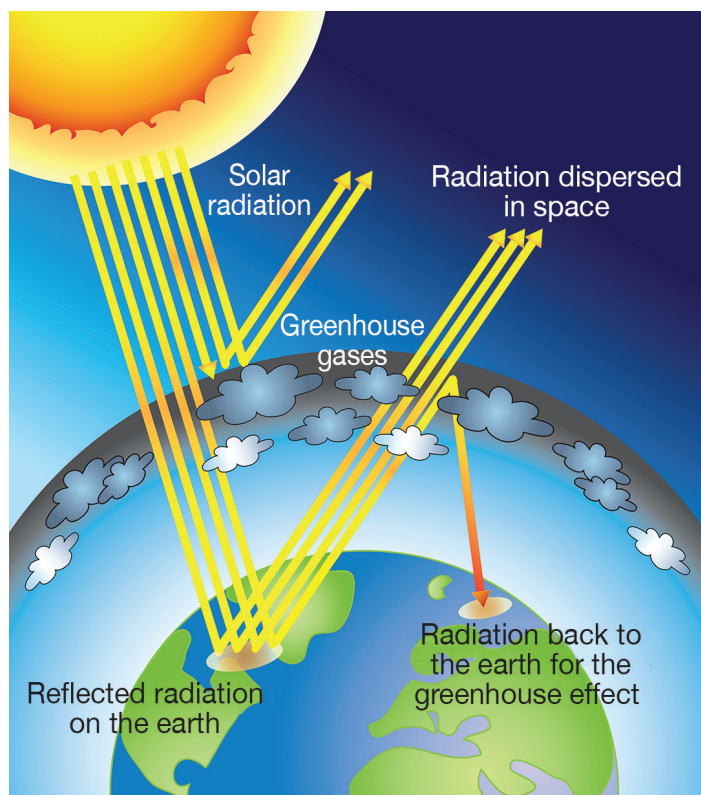
Greenhouse Gases

The greenhouse effect is a natural process;

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without it, the earth would be significantly cooler (see Figure 3). The sun emits energy in a broad range of wavelengths. Most energy from the sun passes through the atmosphere. Some is reflected by the atmosphere and some by the earth's surface back into space, but much of it is absorbed by the atmosphere and the earth's surface. Absorbed energy is converted into infrared energy, or heat. Oxygen and nitrogen allow incoming sunlight and outgoing thermal infrared energy to pass through. Water vapor, CO₂, methane, and some trace gases absorb infrared energy; these are the **greenhouse gases**. After absorbing energy, the greenhouse gases radiate it in all directions, causing the temperature of the atmosphere and the earth to rise.

Figure 3.



Greenhouse gases that contribute to the insulation of the earth can be grouped into two categories: **condensable** and **persistent**. Persistent gases—such as CO₂, methane, nitrous oxide (N₂O), and ozone (O₃)—exist in the environment for much longer periods of time than condensable gases. These times can range from a few years to thousands of years. The longer residence allows them to become well-mixed geographically. The amount of a condensable gas is temperature dependent. Water is the primary greenhouse gas in the atmosphere, but because it is condensable, it is not considered a **forcing factor**. Forcing factors (forcings) are features of the earth's climate system that drive climate change; they may be internal or external to the planet and its atmosphere. **Feedbacks** are events that take place as a result of forcings.

Carbon dioxide, methane, and other gases identified by Tyndall as having high heat capacities make up a relatively minor fraction of the atmosphere, but they have a critical effect on the temperature of the earth. Without the naturally occurring greenhouse effect, it is estimated that the earth's average temperature would be approximately -18 °C (0 °F). The greenhouse effect also acts as a buffer, slowing both the warming during the day and the cooling at night. This is an important feature of the earth's atmosphere. Without the greenhouse effect, the temperature would drop below the freezing point of water and the amount of water in the atmosphere would plummet, creating a feedback loop. A **feedback loop** is a mechanism that either enhances (**positive**

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GREENHOUSE GASES AND SEA LEVEL RISE

Background continued

feedback) or dampens (**negative feedback**) the effect that triggers it.

Since the beginning of the Industrial Revolution, the concentration of CO₂ in the atmosphere has increased from approximately 280 ppm to 411 ppm (see the [Keeling Curve link](#)). This change is attributed to the burning of fossil fuels—such as coal, oil, and natural gas—and changes in land use, i.e., cutting down large tracts of old-growth forests. Old-growth forests, like fossil fuels, sequester carbon from the atmosphere. Burning of either releases that carbon into the atmosphere in the form of CO₂. Clearing old-growth forests has an additional impact on the **carbon cycle** because trees

actively remove CO₂ from the atmosphere to convert it to sugar and carbohydrates (see Figure 4). Removing long-lived trees and replacing them with short-lived crops and grasses reduces the time over which the carbon is removed from the atmosphere.

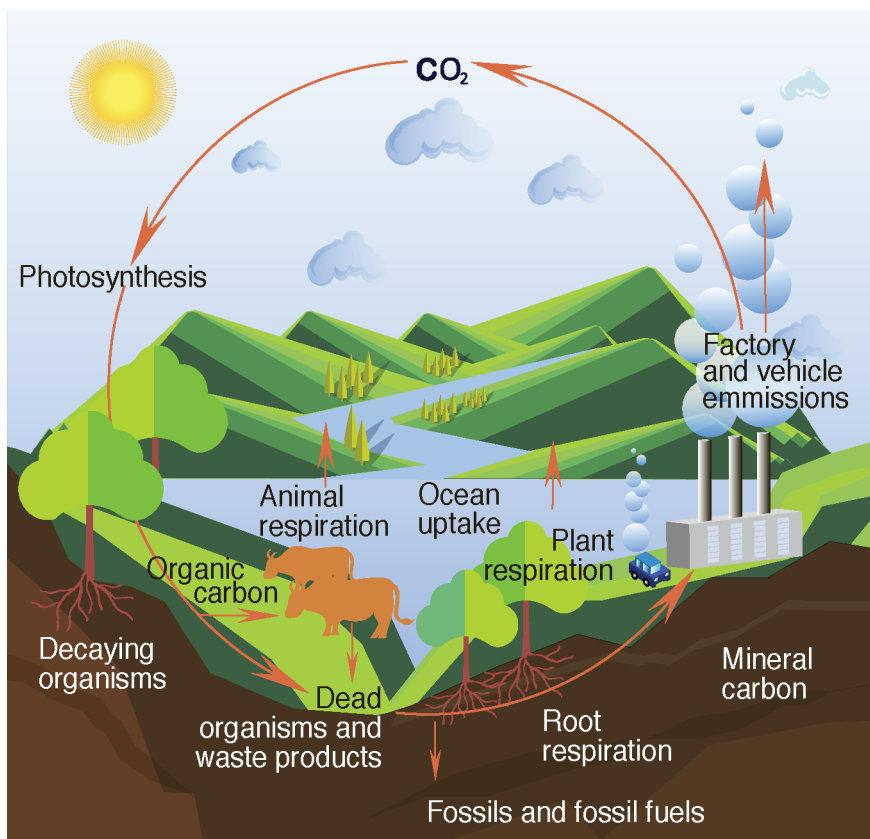
Determining the exact effect that the increase in CO₂ concentrations will have on atmospheric temperature is complicated by a variety of interactions and potential feedback loops. However, the overall impact is an ongoing temperature increase, known as **global climate change** (see Figure 5).

Potential Feedback Loops

Some examples of potential positive feedback loops that may enhance the effects of global climate change are:

1. Higher temperatures allow the atmosphere to absorb more water. More water vapor in the atmosphere traps more heat, further increasing temperature.
2. Melting of sea ice and glaciers, which are relatively light in color, to darker bodies or water decreases the **albedo** (the amount of energy reflected back into space) of the earth's surface, increasing temperatures. Figure 6 shows an ice albedo feedback loop.
3. Warmer temperatures melt more of the arctic **permafrost** (frozen

Figure 4.



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ground), releasing methane into the atmosphere, further raising temperatures.

- Higher temperatures may result in greater rainfall in the North Atlantic, and melting of sea ice creates a warm surface layer of fresh

Figure 5.

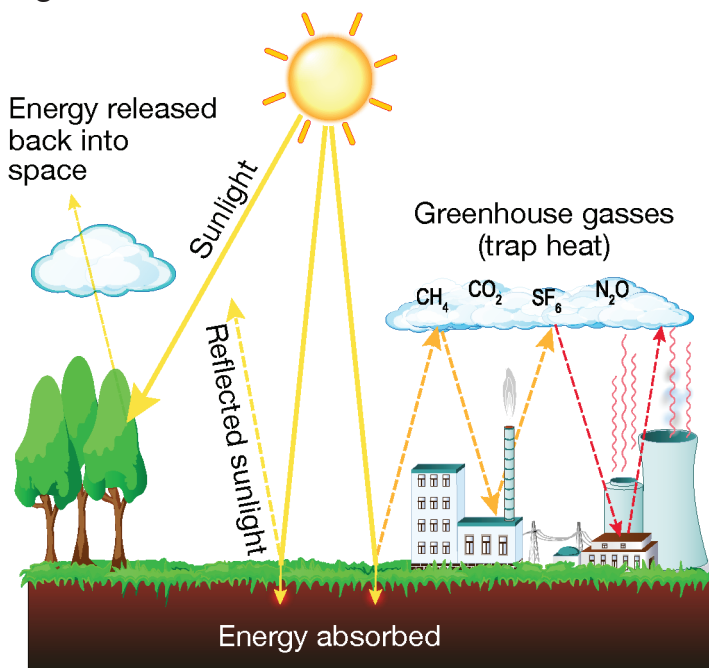
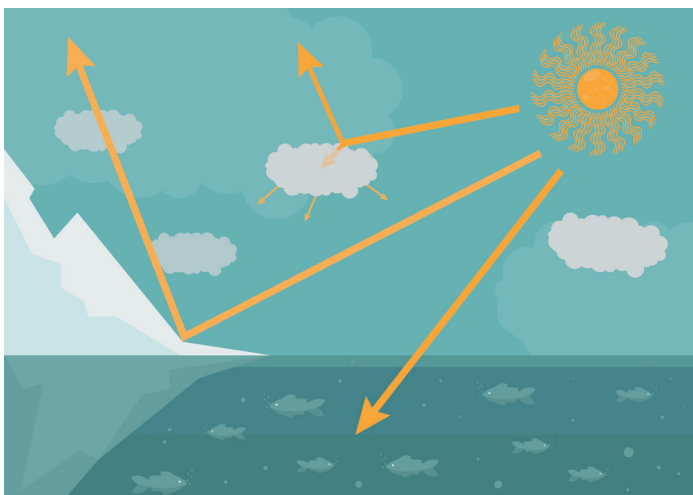


Figure 6.



water there. This would block formation of sea ice and disrupt the sinking of cold, salty water. It may also slow deep oceanic currents that carry carbon, oxygen, nutrients, and heat around the globe.

Other factors may work as negative feedbacks, dampening the effects of global climate change:

1. An increase in CO_2 level in the atmosphere leads to an increase in CO_2 in the oceans, stabilizing CO_2 levels.
2. Increased atmospheric temperatures and CO_2 promote plant and algae growth, increasing absorption of CO_2 from the atmosphere, lowering the CO_2 levels there, and stabilizing temperature.
3. Warmer air, carrying more moisture, produces more snow at high latitudes. This increases the albedo of the earth's surface, stabilizing temperature.
4. Warmer, moister air produces more clouds, which also increases the albedo of the earth's surface, stabilizing temperature.

The relative impact of each of these potential effects is a subject of debate and leads to the uncertainty in models used to predict future climate change resulting from an increase in **anthropogenic** (human-caused) greenhouse gases. However, the consensus among climate scientists is that the positive feedbacks will likely overwhelm the negative ones.

Possible Consequences

Consequences of an increase in average temperature are difficult to predict on a regional

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GREENHOUSE GASES AND SEA LEVEL RISE

Background continued

scale; some, however, can be predicted with a relatively high degree of confidence. One of these is **sea level rise**. Sea level rise is the result of two processes. The first is the melting of glaciers and Antarctic continental ice. Although the melting of sea ice can have complex consequences due to the different densities of salt and fresh water, it will not cause sea level rise. Melting of glaciers and the deep ice over the Antarctic continent, however, can. The second cause of sea level rise, related to warmer temperatures, is that water expands as it warms. As the oceans warm, the water rises farther up the shore. Countries and cities that have large portions of their land area at or just above sea level may be in jeopardy.

The loss of mountain glaciers is already causing changes in freshwater availability. As glaciers shrink, regions that depend on seasonal meltwater for hydroelectric power or for irrigation and drinking water are increasingly affected. Whereas rainfall may increase in these regions (even as the amount of snowmelt decreases), rainwater is considerably more difficult to control because it does not occur at as predictable a rate as meltwater. River systems may be overwhelmed by increased runoff rates, which can cause flooding. One of the richest agricultural regions in the world, California, depends heavily on snowmelt from the Sierra Nevada. One of the world's most populous river valleys, the Indus, is equally dependent on snowmelt from the Himalayas.

Less predictable consequences are the shifting of global weather patterns and the subsequent changes in natural populations. Areas previously ideal for agriculture may become too arid for

crop growth. Climes that are more northerly may experience an increase in productivity. These shifts will put stress on ecosystems as well. How resilient each community is to the change will vary with location and other pressures.

Modeling

The atmosphere and climate are highly complex systems that are challenging to understand and predict. To explore such complex systems, scientists frequently employ **models**. A model is a simplification of a complex process that isolates certain factors likely to be important. Sometimes a model can be a physical representation of something too big or too small to see, such as a model solar system. However, scientists frequently use mathematical equations derived from observed data to predict future conditions. With the addition of computers, mathematical climate equations can be linked together in increasingly sophisticated ways to model multiple factors in three dimensions, producing **global climate models**. Because of computing limitations, some factors must be simplified. How they are represented within the model can lead to a degree of error in the outcome predicted. Ultimately, the quality of all models is determined by their success in predicting events that have not yet taken place.

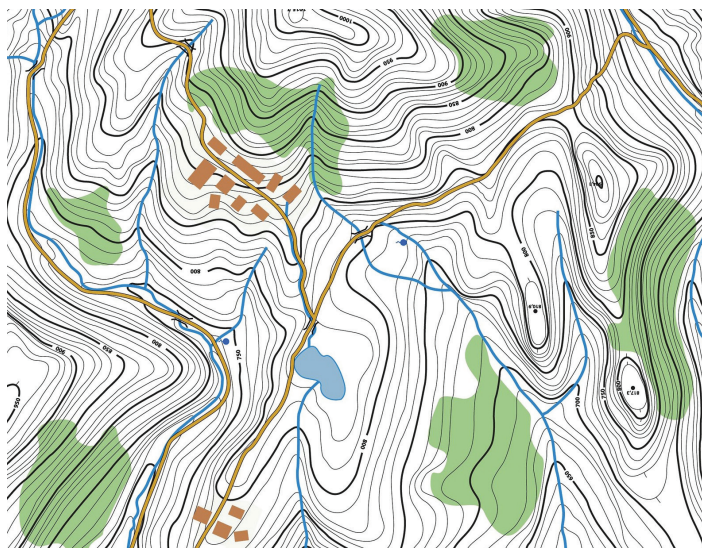
Contour Maps

To determine potential flood risks, scientists, engineers, and insurance companies use a number of tools, including historic river flow, storm tide and rainfall data, hydrological analysis, and topographic surveys.

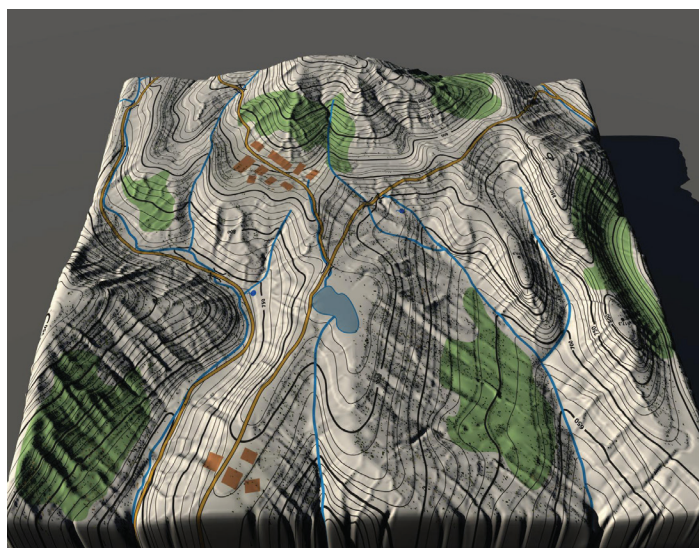
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Figure 7.

A.



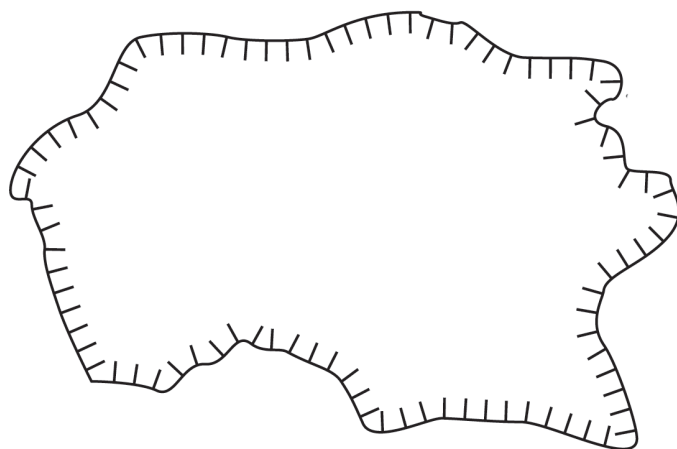
B.



Topographic surveys can be represented graphically as maps with contour lines (see Figure 7). Each contour line represents an elevation. Figure 7B shows the contour map from Figure 7A overlaid on the terrain it was mapped from. Elevations are marked on the map at set intervals, depending on the scale of the map. Small-scale maps might have a contour interval of five feet. Maps of a continent may have an interval of thousands of feet. All points connected by a given contour line are at the same elevation. Depressions in the landscape, such as craters and basins, are marked with hatched lines, as seen in Figure 8.

In the following activities, you will be asked to use a contour map to generate a landform model. You will use this model to examine the consequences of sea level rise.

Figure 8.



GREENHOUSE GASES AND SEA LEVEL RISE

Materials

Included in the materials kit:



Plastic contain-
er with lid



Modeling
clay, 2 pieces



2 Medicine
cups



Food coloring

Needed from the equipment kit:



Ruler



Beaker, 250 mL



Plastic cup



Sharpie® marker

Needed but not supplied:

- Blank white paper
- Water
- Printout of page 12
- Freezer
- Salt, 3 tsp
- Scissors
- Pencil
- 2 Coins (dimes or pennies)
- Timer
- Teaspoon
- Camera (or cell phone capable of taking photographs)

Reorder Information: Replacement supplies for the Greenhouse Gases and Sea Level Rise investigation can be ordered from Carolina Biological Supply Company, item number 580802.

Call: 800.334.5551 to order.

Safety

Wear your safety goggles, gloves, and lab apron for the duration of this investigation.



Read all the instructions for these laboratory activities before beginning. Follow the instructions closely, and observe established laboratory safety practices, including the use of appropriate personal protective equipment (PPE).

Do not eat, drink, or chew gum while performing the activities. Wash your hands with soap and water before and after performing each activity. Clean the work area with soap and water after completing the investigation. Keep pets and children away from lab materials and equipment.

Preparation

1. Read through the activities.
2. Obtain all materials.

Part 1: Making Ice

At least 24 hours before beginning Activity 1, prepare two colored ice cubes:

1. Fill each medicine cup with tap water to the 20-mL mark.
2. Add 5 drops of food coloring to each cup.
3. Remove the lid from the plastic container, and place the cups on the lid to contain spills. Place the lid holding the two cups in the freezer.
4. Allow the mixtures to freeze for at least 24 hours.

Part 2: Building a Model from a Contour Map

1. Print the contour map template (Figure 9, page 12), and cut out the island represented along the lowest contour line. This will eventually serve as the base of the island.
2. Take out one package of clay and knead the clay to soften it.

Note: Although the clay is nontoxic, care should be taken when working with it because the coloring will frequently transfer to hands, clothes, and the work surface. Ensure you are wearing gloves and the lab apron while working.

3. Using your hand, flatten the clay into a thin layer.
4. Place the flattened clay on a piece of scrap paper or a plastic bag to prevent it from sticking to the work surface, and work or roll the clay into a thin 2–3 mm layer that is large

enough to place the cutout on. (Try using the permanent marker as a rolling pin.)

5. Place the island template on the clay and, using a pencil, trace around it, cutting into the clay.
6. Remove the template from the clay.
7. Peel the clay off the work surface and place the inner, template-shaped piece into the plastic container. Gently press down on any ridges formed on the layer by the cutting, making the layer as flat as possible.
8. Work the remaining clay into a ball.
9. Trim the outer contour off the template.
10. Repeat Steps 3–9 for the second and third contours, placing each subsequent contour on top of the previous one, building the island model.
11. Roll out the fourth layer of clay. Place the template on the clay and cut the fourth contour out of the clay. **This time, however, do not place the cutout contour on top of the previous one, but leave it on your work space.**
12. Trim the paper along the hatched line.
13. Place the ring paper template you just cut out back down on the clay.
14. Trace the template with a pencil, cutting into the clay. This will form a ring from the fourth layer of clay.
15. Remove the thin ring of clay from your work paper and place it on the island model in the plastic container, completing your hill. You will use this container and landform in subsequent activities.

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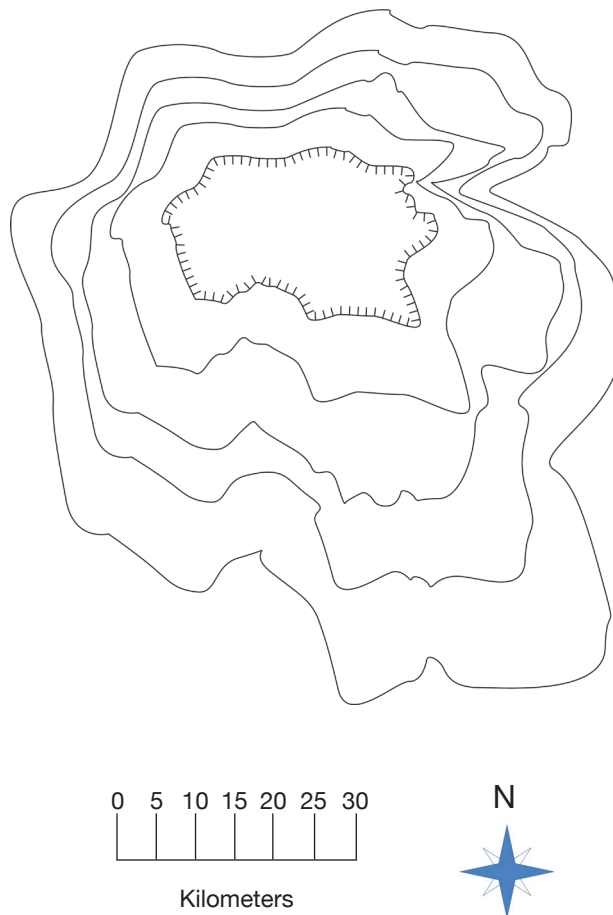
GREENHOUSE GASES AND SEA LEVEL RISE

Preparation continued

Figure 9.

Contour map template

Contour interval = 25 m



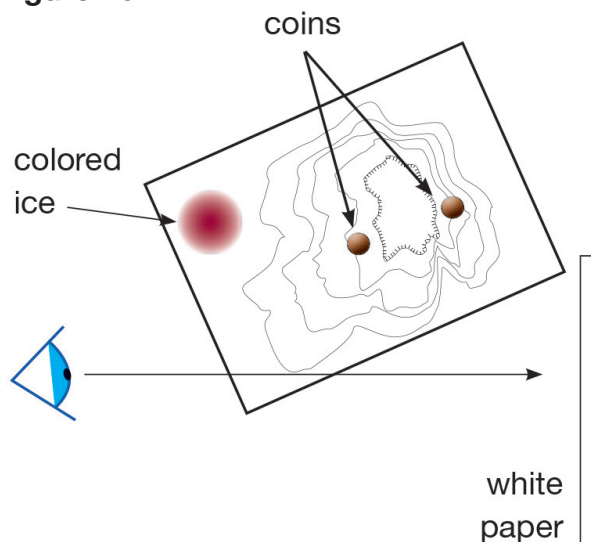
ACTIVITY

ACTIVITY 1

Sea Ice and Sea Level Rise

1. Measure 150 mL of water in a beaker, and then pour the water into the plastic cup.
2. Add 1 tsp of salt to the water in the cup, and stir until the salt is completely dissolved to prepare saltwater.
3. Remove 1 colored ice cube from its medicine cup (from Part 1 of the “Preparation” section), and place it in the container away from the island so that no part of it rests on the clay (see Figure 10). Leave the other colored ice cube in the freezer to use with Activity 2.

Figure 10.



Note: In order to view the water layers as they are forming, it may be helpful to view the water through the side of the container with a piece of white paper behind it.

4. Pour the saltwater into the container, **taking care not to pour water on the ice**, until just the bottom two layers of the island are

completely covered. (You may not need all the saltwater.)

5. Estimate the depth of the water represented in the model based on the contours. Record that depth in Data Table 1 of the “Observations/Data Tables” section of the **Lab Worksheet**. Measure the actual depth with a ruler. Record that depth in Data Table 1 of the “Observations/Data Tables” section of the **Lab Worksheet**.
6. Place a coin, representing a house, on the north side of the island along the steepest slope, so that one edge just barely touches the edge of the water.
7. Place the other coin, representing another house, on the south side of the island, also just touching the water along a more gradual slope. These represent coastal cities with very different topography.
8. How do you think these two houses (coins) will be affected by water? Please hypothesize whether you think both houses will be underwater, neither will be underwater, only the north house will be underwater, or only the south house will be underwater. Describe your reasoning behind why you feel this way. Record this information in the “Hypotheses” section in your **Lab Worksheet**.
9.  At 10-minute intervals, observe the model from above and from the side. You may see a layer of colored water developing. Estimate the depth of the water (in meters) using the contours, and measure the depth of the water (in centimeters) with a ruler. Record your results in Data Table 1 of the “Observations/Data Tables” section of the **Lab Worksheet**.

continued on next page

ACTIVITY

ACTIVITY 1 continued

10. When the ice has completely melted, record the depth of the water in Data Table 1 of the “Observations/Data Tables” section of the **Lab Worksheet**.
11.  Record your observations of how much of each coin is underwater in Data Table 1 of the “Observations/Data Tables” section of the **Lab Worksheet**. Take a photograph looking down on the model, ensuring it shows the locations of the houses relative to the water. Upload this photograph to the “Photographs” section of the **Lab Worksheet**. **NOTE!**
12.  Remove the coins from the model. Without disturbing the island, gently pour the water out of the container into a sink. Flush the dyed water with running water for 30 seconds.

ACTIVITY 2

Glacier Ice and Sea Level Rise

1. Measure 150 mL of water in a beaker, and pour the water into the plastic cup.
 2. Add 1 tsp of salt to the water in the cup, and stir until the salt is completely dissolved to prepare saltwater.
 3. Remove the remaining colored ice cube from its medicine cup, and place it on top of the island.
 4. Pour the saltwater into the container, **taking care not to pour water over the ice or the island**, until just the bottom two layers of the island are completely covered. (You may not need all the saltwater.)
 5. Estimate the depth of the water represented in the model based on the contours.
- Record that depth in Data Table 2 of the “Observations/Data Tables” section of the **Lab Worksheet**. Measure the actual depth with a ruler. Record that depth in Data Table 2 of the “Observations/Data Tables” section of the **Lab Worksheet**.
6. Place a coin, representing a house, on the north side of the island along the steepest slope, so that one edge just barely touches the edge of the water.
 7. Place the other coin, representing another house, on the south side of the island, also just touching the water along a more gradual slope. These represent coastal cities with very different topography.
 8. How do you think these two houses (coins) will be affected by water? Please hypothesize whether you think both houses will be underwater, neither will be underwater, only the north house will be underwater, or only the south house will be underwater. Describe your reasoning behind why you feel this way. Record this information in the “Hypotheses” section in your **Lab Worksheet**.
 9.  At 30-minute intervals, observe the model from above and from the side. You may see a layer of colored water developing. Estimate the depth of the water (in meters) using the contours, and measure the depth of the water (in centimeters) with a ruler. Record your results in Data Table 2 of the “Observations/Data Tables” section of the **Lab Worksheet**.
 10. When the ice has completely melted, record the depth of the water in Data Table 2 of the “Observations/Data Tables” section of the **Lab Worksheet**.

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11.  Record your observations of how much of each coin is underwater in Data Table 2 of the “Observations/Data Tables” section of the **Lab Worksheet**. Take a photograph looking down on the model, ensuring it shows the locations of the houses relative to the water. Upload this photograph to the “Photographs” section of the **Lab Worksheet**. **NOTE!**
12. Use your data from Activities 1 and 2 to develop a line graph (either in Microsoft Excel or by hand) showing the estimated depth (in meters) versus the time (in minutes) to see the correlation between sea ice and glacier ice melting. The time is the independent variable and should be plotted on the horizontal axis. The estimated depth is the dependent variable and should be plotted on the vertical axis. Label your axes and title the graph. See the *Introduction to Graphing* lab manual for more specific detail on creating a graph with Microsoft Excel or by hand. Upload this graph to the “Calculations” section of the **Lab Worksheet**.

Submission

Submit the following two documents to Waypoint for grading:

- Completed **Lab Worksheet**
- Completed report (using the **Lab Report Template**)

Disposal and Cleanup

1. Dispose of liquid mixtures down the drain with the water running. Allow the faucet to run for a few minutes to dilute the solutions.
2. Rinse and dry the lab equipment from the equipment kit, and return the materials to your equipment kit.
3. Dispose of the rinsed clay and any other materials from the materials kit in the household trash.
4. Sanitize the work space, and wash your hands thoroughly.

ACTIVITY

Lab Worksheet

Hypotheses

Activity 1.

Activity 2.

Observations/Data Tables

Data Table 1. Sea Ice

Time (min)	Estimated Depth (m)	Measured Depth (cm)	Observations
0			
10			
20			
30			
40			
50			
melted			

continued on next page

Data Table 2. Glacier Ice

Time (min)	Estimated Depth (m)	Measured Depth (cm)	Observations
0			
30			
60			
90			
120			
150			
melted			

Calculations

Photographs

Activity 1.

Activity 2.

ACTIVITY

Lab Questions

Please answer the following **entirely in your own words and in complete sentences**:

Introduction

1. Background—What is important to know about the topic of this lab? Use at least one outside source (other than course materials) to answer this question. Cite the source using APA format. **Answers should be 5–7 sentences in length.**
2. Outcomes—What is the main purpose of this lab?
3. Hypotheses—What was your hypothesis for Activity 1? What was your hypothesis for Activity 2? Identify each hypothesis clearly, and explain your reasoning.

Materials and Methods

4. **Using your own words**, briefly describe what materials and methods you used in each of the activities. Your answer should be sufficiently detailed so that someone reading it would be able to replicate what you did. Explain any measurements you made.

Discussion

5. Based on the results of each activity, explain whether you accepted or rejected your hypotheses and why.
6. What important information have you learned from this lab? Use at least one outside source (scholarly for full credit) to answer this question. Cite the source using APA format. **Answers should be 5–7 sentences in length.**
7. What challenges did you encounter while doing this lab? Name at least one.
8. How might a scientist create a more realistic physical model to show the effects of global climate change on sea level rise? What factors might be changed?

Literature Cited

9. List the references you used to answer these lab questions. (Use APA format, and alphabetize by the last name.)

Now copy and paste your answers into the **Lab Report Template** provided. Include the data tables and photographs. You may wish to make minor edits to enhance the flow of your resulting lab report.

NOTES

ENVIRONMENTAL SCIENCE
Greenhouse Gases and Sea Level Rise
Investigation Manual

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