Climate Change

Investigation Manual

CAROLINA
DISTANCE LEARNING

CLIMATE CHANGE

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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 model how certain gases in Earth's atmosphere trap heat and then how different colors and textures of surfaces reflect differing amounts of sunlight back into space. They will create models of sea level rise resulting from melting of sea ice and glacial 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.

Time Requirements

Preparation .... 15 minutes
Activity 1: Modeling the Greenhouse Effect .... 30 minutes
Activity 2: Modeling Albedo .... 40 minutes
Activity 3: Sea Ice, Glacial Ice, and Sea Level Rise .... 30 minutes

Key

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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.

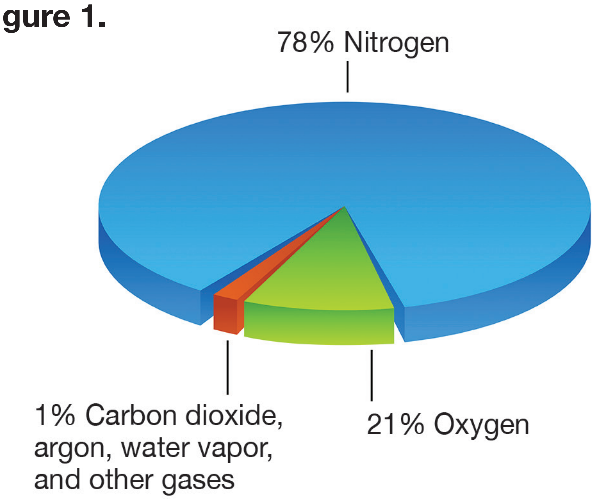
It was not until the late 1950s, when the CO_2 absorption capacity of the ocean was better understood and significant increases in CO_2 levels (a 10% increase from the 1850s to the 1950s) were being observed by G. S. Callendar, that Arrhenius's calculations received renewed attention.

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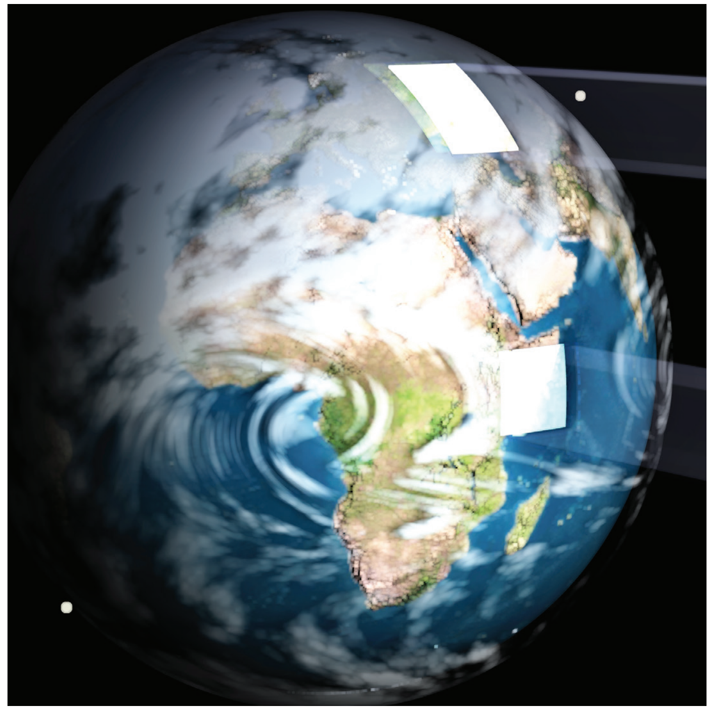
carbon dioxide are concentrated near the earth's surface, for instance, while ozone is concentrated 20 to 30 kilometers above the surface. Energy transfer from the sun at and near the surface of the earth is responsible for weather and climate. Solar radiation heats land, the oceans, and atmospheric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

Figure 2.



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 CO_2.

Greenhouse Gases

The greenhouse effect is a natural process;

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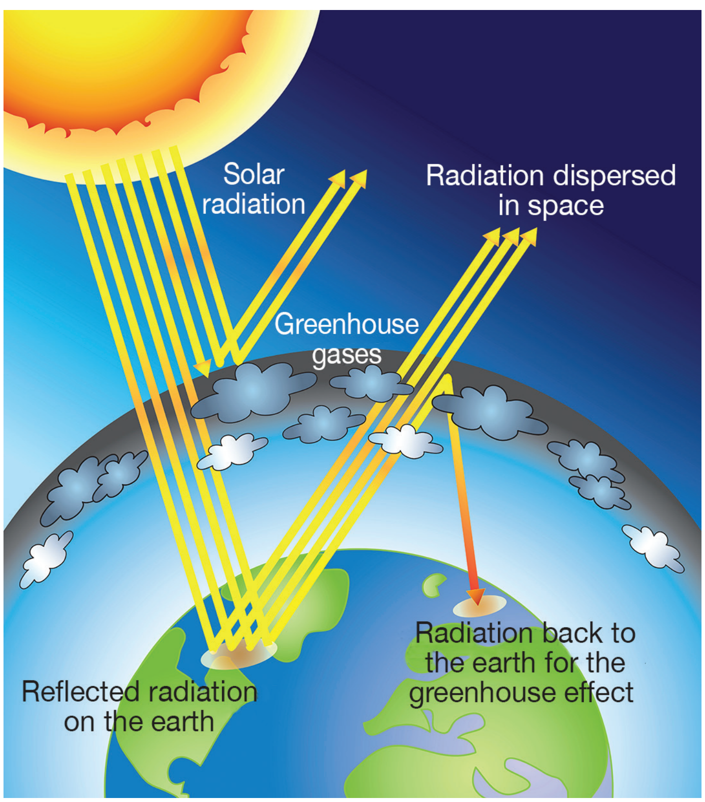
without it, the earth would be significantly cooler (see Figure 3). The sun emits energy in a broad range of wavelengths. Most energy from the sun passes through the atmosphere. Some is reflected by the atmosphere and some by the earth's surface back into space, but much of it is absorbed by the atmosphere 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, CO_2, 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 CO_2, methane, nitrous oxide (N_2O), and ozone (O_3)—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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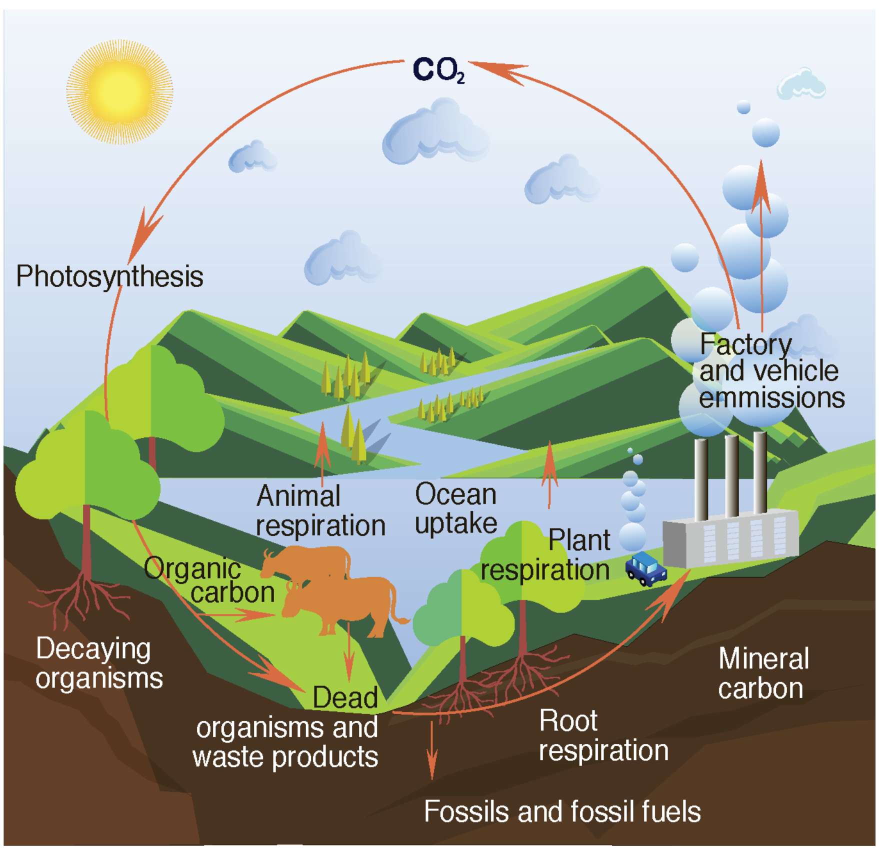
feedback) or dampens (**negative feedback**) the effect that triggers it.

Since the beginning of the Industrial Revolution, the concentration of CO_2 in the atmosphere has increased from approximately 280 ppm to 411 ppm (see the Keeling Curve). 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 CO_2. Clearing old-growth forests has an additional impact on the **carbon cycle** because trees actively remove CO_2 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.

Figure 4.



Determining the exact effect that the increase in CO_2 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

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

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

Figure 5.

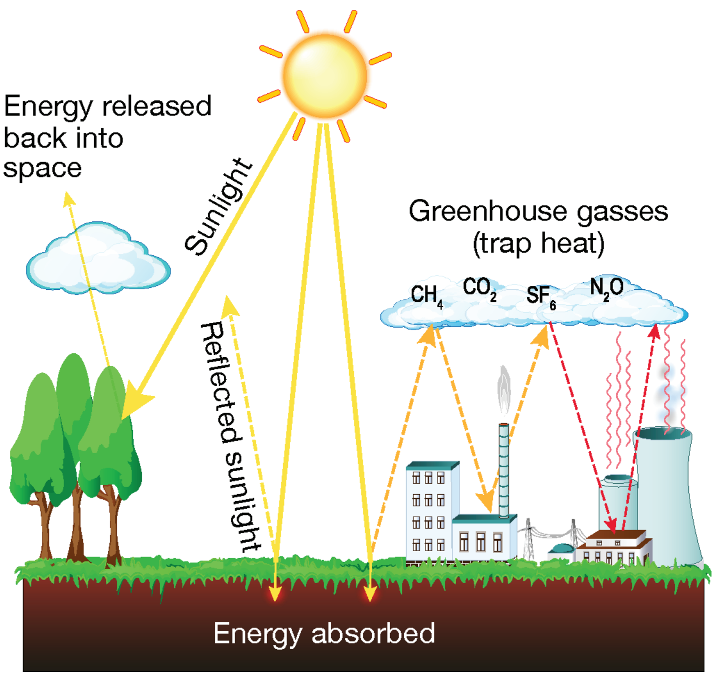
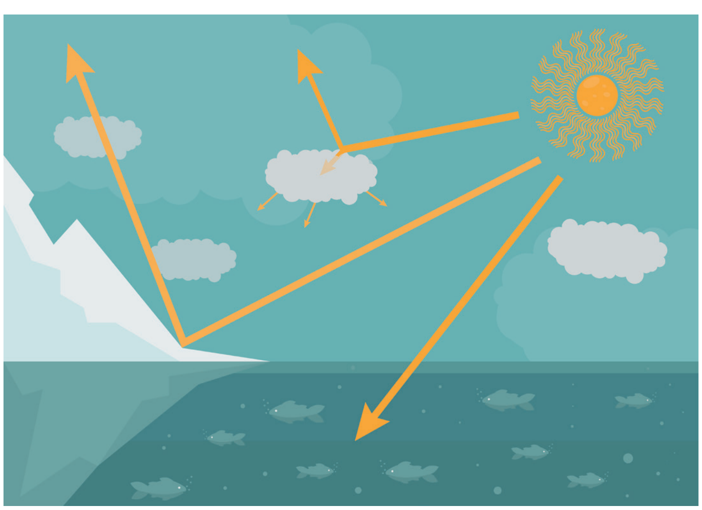


Figure 6.



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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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

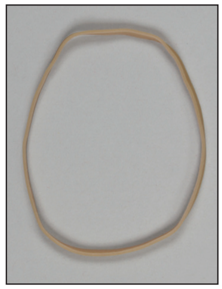
The atmosphere and climate are highly complex systems that are challenging to understand and predict. To explore such complex systems, scientists frequently employ **models**. A model is a simplification of a complex process that isolates certain factors likely to be important. Sometimes a model can 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.

Materials

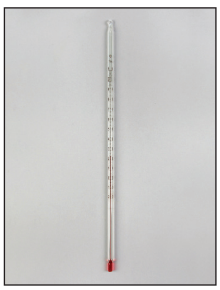
Included in the materials kit:


Construction paper, black


2 Foam cups


Rubber band


Plastic funnel


2 Thermometers

Needed from the equipment kit:


Graduated cylinder, 100 mL

Needed but not supplied:

- Clear plastic wrap
- Aluminum foil
- Tap water
- 4 Small ice cubes, identical in size
- Transparent tape
- Scissors
- Timer or stopwatch
- Pencil
- Digital camera or mobile device capable of taking photos
- Access to bright sunlight (or a heat lamp, halogen lamp, or lamp with an incandescent bulb)

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.
3. Monitor the local weather forecast. Activities 1 and 2 require a bright, sunny day. (Alternatively, you can use a heat lamp, halogen lamp, or lamp with a bright incandescent bulb; compact fluorescent or LED bulbs will not work.)

Reorder Information: Replacement supplies for the Greenhouse Gases and Sea Level Rise investigation (item number 580854) can be ordered from the Carolina Biological Supply Company.

Call: 800.334.5551 to order.

ACTIVITY

ACTIVITY 1

A Modeling the Greenhouse Effect

In Activity 1, you will model how certain gases in Earth's atmosphere (carbon dioxide, methane, and others) trap heat that Earth is radiating back into space. The plastic wrap covering the foam cup mimics the effect of these greenhouse gases (see Figure 7).

Figure 7.

1. Tear off a piece of clear plastic wrap, and place it atop the foam cup.
2. Using the rubber band, gently but firmly secure the plastic wrap on the cup. The plastic wrap represents the heat-trapping greenhouse gases in Earth's atmosphere.
3. Using a pencil point or another thin, sharp object (shish kebab skewers work well), poke a tiny hole into the plastic wrap covering the cup.
4. Slowly press one of the thermometers into the hole until the bulb just touches the bottom of the cup. (If you accidentally make the thermometer hole too big, use transparent tape to seal the gap so that the plastic wrap completely covers the top of the cup.)
5. Propose a hypothesis as to which thermometer (the bare one or the one pressed through the plastic on the foam cup) will indicate the higher temperature when placed in the sunlight or under a hot lamp. Record your hypothesis on the **Lab Worksheet** (see page 14).
6. Find a location currently receiving full sun, either outdoors or by a sunny window. Alternatively, you can use a heat lamp, halogen lamp, or lamp with an incandescent bulb. (Compact fluorescent or LED bulbs will not work.)
7. Place the cup with the thermometer in it in a stable location in the bright sunlight or under the lamp. Hold the other thermometer close to the cup, so that both thermometers are receiving about the same level of light. (Do not touch the bulb of the thermometer you are holding.)
8. Determine the temperatures in degrees Celsius for both thermometers. Record them in Data Table 1 on the **Lab Worksheet**.
9. Once every minute, continue to measure and record the temperatures from both thermometers until the thermometer in the foam cup reads the same temperature twice in a row.
10. Place a strip of paper with your name and the date clearly written on it next to your setup for this activity. Take a photograph of the setup for later uploading to your lab report.
11. When finished, remove the plastic wrap, thermometer, and rubber band from the foam cup. You will need to reuse the thermometers and cup in Activity 2.

ACTIVITY 2

A Modeling Albedo

In Activity 2, you will model how different colors and textures of surfaces reflect differing amounts of sunlight back into space. The more sunlight that is reflected, the higher the albedo of the surface. The less sunlight a surface reflects, the more the surface absorbs and the lower the albedo. Aluminum foil covering one of the foam cups will represent Arctic sea ice. Dark construction paper covering the other cup will represent the open ocean (see Figure 8).

1. Measure 150 mL of tap water in the graduated cylinder, and add it to one of the foam cups.
2. Measure another 150 mL of tap water in the graduated cylinder, and add it to the second foam cup.
3. Using the scissors and black paper, cut a square that is large enough to cover the top of a foam cup and fold over the sides. Fix the paper in place with transparent tape, and use your sharp object to make a tiny hole.
4. Tear a piece of aluminum foil so it's about the same size as the black paper square. Cover the second foam cup with the aluminum foil, and use your sharp object to make a tiny hole.
5. Insert a thermometer into the hole in the black paper and the second thermometer into the hole in the aluminum foil.
6. Propose a hypothesis as to which thermometer (the one in the cup with dark paper or the one in the cup with aluminum foil) will indicate the higher temperature when placed in the sunlight or under a hot lamp. Record your hypothesis on the **Lab Worksheet**.

Figure 8.

7. Place both cups with thermometers in a stable location in bright sunlight. Alternatively, you can place them under a heat lamp, halogen lamp, or lamp with an incandescent bulb. (Compact fluorescent or LED bulbs will not work.)
8. Measure and read the temperatures of both thermometers in degrees Celsius. Record these values in Data Table 2 on the **Lab Worksheet**.
9. Once every minute, continue to measure and record the temperatures until both thermometers have the same temperature reading twice in a row.
10. Calculate the temperature difference between the 2 cups by subtracting the temperature of the thermometer in the cup covered with aluminum foil from the temperature of the cup covered with the black paper. Record your result in Data Table 2 on the **Lab Worksheet**.
11. Place a strip of paper with your name and the date clearly written on it next to your setup for this activity. Take a photograph of the setup for later uploading to your lab report.

ACTIVITY 3

A Sea Ice, Glacial Ice, and Sea Level Rise

In the following activity, you will model the effects of melting sea ice versus melting land ice (**glaciers**) on sea level rise. Ice cubes added directly to the graduated cylinder represent sea ice. Ice cubes placed in a funnel on top of the graduated cylinder represent glacial ice that melts on land and then flows down rivers (through the funnel) to the ocean (see Figure 9).

1. Before starting this activity, propose a hypothesis as to the outcome: Will both glacial ice and sea ice have the same effect on sea level, or will their effects be different? If different, how? Record your hypothesis on the **Lab Worksheet**.
2. Fill the graduated cylinder with tap water to the 50 mL line.
3. Add 2 ice cubes to the graduated cylinder (see Figure 9, left). If the ice cubes will not fit, place them in a small plastic bag and gently strike them with a hammer to break them up; make sure to place all the resulting fragments into the graduated cylinder.
4. Immediately find the volume in milliliters of the water and ice in the graduated cylinder. Record this result in Data Table 3 on the **Lab Worksheet**.
5. Wait until the ice has completely melted. (Depending on the air temperature, this may take about 10 minutes.)
6. Once the ice has melted, find the volume of water in the graduated cylinder. Record this result in Data Table 3 on the **Lab Worksheet**.

Figure 9.

7. Subtract the initial water volume from the final water volume to find the change in water volume from the melting sea ice. Record this volume in milliliters in Data Table 3 on the **Lab Worksheet**.
8. Adjust the level of water in the graduated cylinder so it again reads 50 mL. Record this level as the initial water volume for melting glacial ice in Data Table 3 on the **Lab Worksheet**.
9. Place the funnel in the top of the cylinder.
10. Place 2 ice cubes in the funnel (see Figure 9, right).
11. Wait until the ice has completely melted. (Depending on the air temperature, this may take about 10 minutes.)

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12. Once the ice has melted, find the volume of the water in the graduated cylinder. Record this result in Data Table 3 on the **Lab Worksheet**.
13. Subtract the initial water volume from the final water volume to find the change in water volume from the melting glacial ice. Record this volume in milliliters in Data Table 3 on the **Lab Worksheet**.
14. Place a strip of paper with your name and the date clearly written on it next to your setup for this activity. Take a photograph of the setup for later uploading to your lab report.

Graphing

1. Use your data from Activity 1 to prepare a graph of your results. You may choose to prepare either a **bar graph** of the final temperatures of the 2 thermometers showing the difference between them (worth "Basic" points on the scoring rubric) or a **line graph** of the temperatures every minute for both thermometers, showing the differences in the temperature trends between the 2 thermometers (worth "Distinguished" points on the scoring rubric). For either graph, temperature in degrees Celsius (the dependent variable) is on the vertical axis. For the line graph, time in minutes (the independent variable) will be on the horizontal axis. You may create your graph in Excel or in an online graphing program like this one: https://plot.ly/create/#/. If you prefer to prepare a graph by hand, you are **required** to use graph paper to do so; graphs drawn freehand on blank paper will not be accepted. You can print graph paper for free here: http://www.printfreegraphpaper.com/
2. Repeat Step 1 using your Activity 2 data to prepare a second graph of your results. Again, you can prepare a **bar graph** for "Basic" credit or a **line graph** for "Distinguished" credit.
3. Finally, graph your results from Activity 3. Prepare a **bar graph** that shows the differences in water volume for the melting sea ice versus the melting glacial ice. The difference in water volume before and after the ice melted (in milliliters) will be on the vertical axis.

Submission

Using the **Lab Report Template** provided, submit your completed report to Waypoint for grading. It is not necessary to turn in the Lab Worksheet.

Disposal and Cleanup

1. Rinse and dry the graduated cylinder, and return it to the equipment kit.
2. If you do not have a further use for the thermometers, consider donating them to the science program of a local school.
3. Dispose of all other materials. The plastic funnel may be recyclable.

Lab Worksheet

Hypotheses

Activity 1.

Activity 2.

Activity 3.

Observations/Data Tables

Data Table 1.

Modeling the Greenhouse Effect		
Time (min)	**Bare thermometer (°C)**	**Thermometer in cup (°C)**
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

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Data Table 2.

Modeling Albedo			
Time (min)	Temperature of water in cup with dark paper on the top (°C)	Temperature of water in cup with aluminum foil on the top (°C)	Temperature Difference
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

Data Table 3.

Sea Ice, Glacial Ice, and Sea Level Rise			
	Initial Water Volume (mL)	Final Water Volume after Ice Melt (mL)	Change in Water Volume (Final Volume—Initial Volume) (mL)
Melting Sea Ice (ice cubes in graduated cylinder)			
Melting Glacial Ice (ice cubes in funnel)			

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