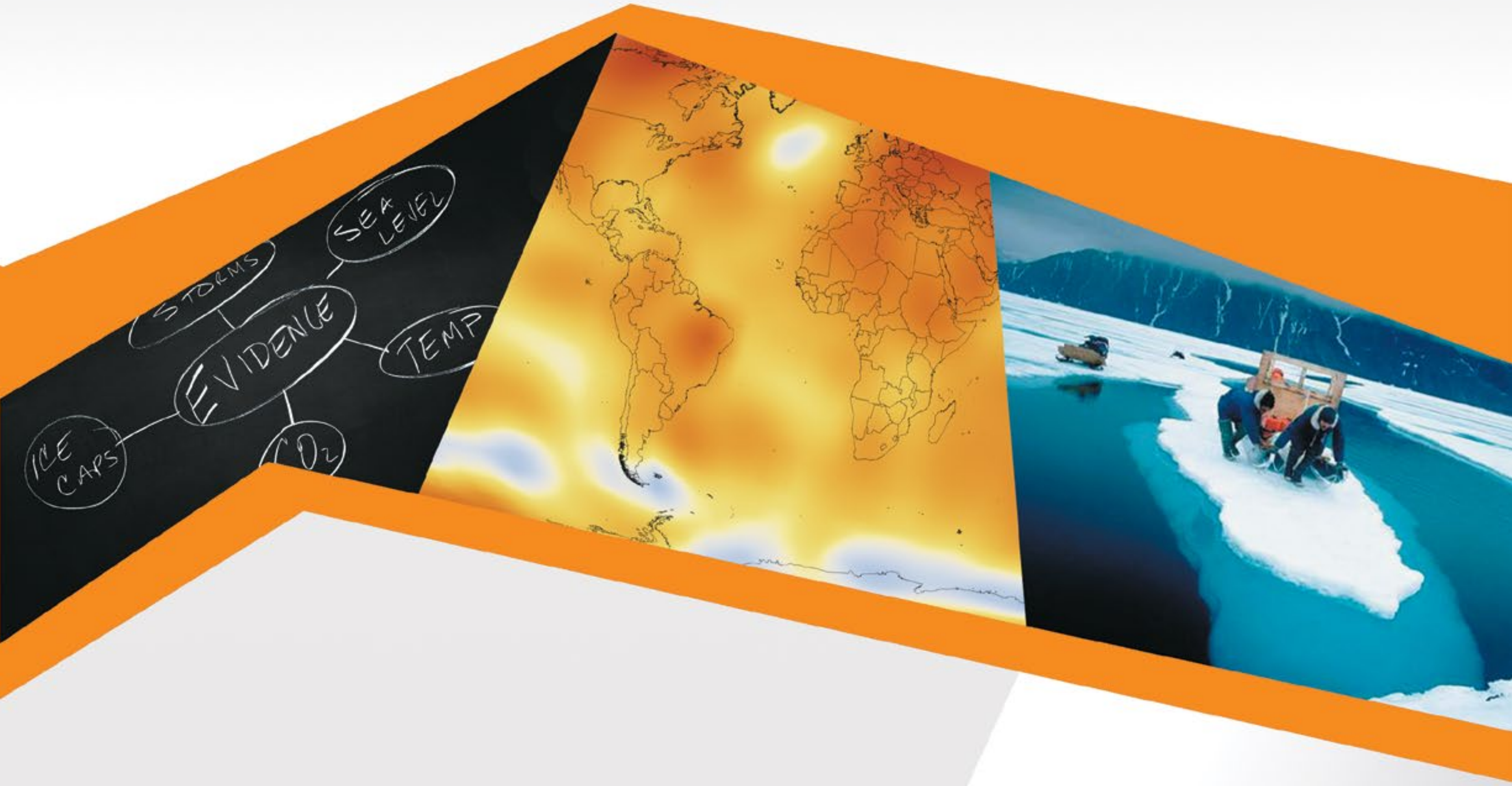


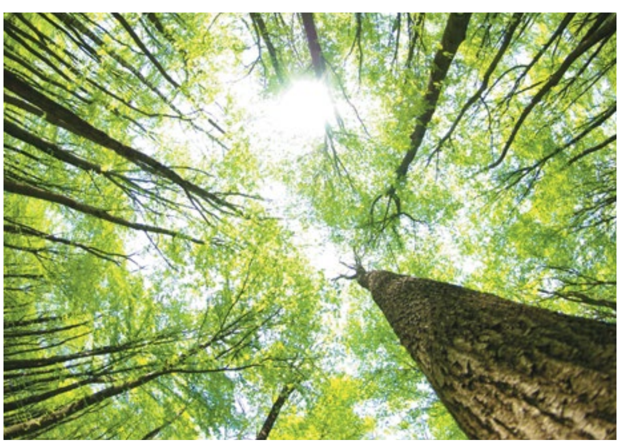
10 Perimeter Inspirations

Grade 10: Evidence for Climate Change

SPARKING INQUIRY THROUGH SCIENCE AND MATH

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

Contents



About Perimeter

Perimeter Institute

Perimeter Institute is the world's largest research hub devoted to theoretical physics. The independent Institute was founded in 1999 to foster breakthroughs in the fundamental understanding of our universe, from the smallest particles to the entire cosmos. Research at Perimeter is motivated by the understanding that fundamental science advances human knowledge and catalyzes innovation and that today's theoretical physics is tomorrow's technology. Located in the Region of Waterloo, the not-for-profit Institute is a unique public–private endeavour, including the Governments of Ontario and Canada, that enables cutting-edge research, trains the next generation of scientific pioneers, and shares the power of physics through award-winning educational outreach and public engagement.

Perimeter Inspirations

This series of in-class educational resources is designed to help teachers inspire students by sharing the mystery and power of science and math through inquiry-based, Ontario curriculum–linked activities. Activities integrate global competencies—critical thinking and problem solving; innovation, creativity, and entrepreneurship; self-directed learning; collaboration; communication; citizenship—all of which equip students to make meaningful contributions to society as they learn, grow, and mature.

Perimeter Inspirations is the product of extensive collaboration between experienced teachers and Perimeter Institute's Educational Outreach staff. This resource has been designed with both the expert and the novice teacher in mind and has been thoroughly tested in classrooms. The digital resource features student activity sheets and a variety of assessment tools in a modifiable format to suit the particular needs of each student.

Introduction

Human activities are having a negative effect on climate. The scientific evidence is robust, and the consensus among scientists is strong. So why is there still debate in the media and among students?

These hands-on, inquiry-based activities aim to address some of the basic science behind, and the clearest evidence for, climate change. Students will explore how carbon dioxide interacts with infrared light, how water expands when heated, how climate modelling works, and more. Students will also be challenged to consider how they can make a difference.

This resource provides classroom activities that teachers can use to enhance the Earth and Space Science strand in Grade 10 Science (both academic and applied) and supports the teaching of Grade 10 Math (both academic and applied). Scientific investigation skills, career exploration, and financial literacy are integrated into the lessons. Specific suggestions for adapting the activities to a wide range of student learning needs ensure learning is inclusive.

The resource package also includes a short, dynamic video, closely tied to the lessons. It features thermal imaging to demonstrate, in a controlled experiment, how greenhouse gases absorb infrared light and then extends that same result to satellite measurements of our atmosphere.

All activities offer an engaging, minds-on experience for students. The resource includes background information, assessment material, and specific teaching tips designed to help you deliver memorable lessons that empower and encourage students to tackle climate issues.

Developed in a year-long project involving high school teachers and students, physics researchers, Perimeter Educational Outreach staff, climate scientists from the University of Waterloo, and media professionals, the module encourages students to ask questions, work collaboratively, and make connections as they examine this critical and urgent problem.

Using This Resource in Your Classroom

Flow of Activities

This resource consists of a video, six activities, and one design challenge. Activity 1 explores the effects of carbon dioxide on the atmosphere and oceans. Activities 2 and 3 examine how climate models work and the evidence for climate change, respectively. These activities are independent of each other and can be used in any order. In Activity 4, students extend the discussion into their own worlds and consider the implications of their transportation choices on climate change. This activity will have more impact after students have already considered the causes and evidence for climate change. Activities 5 and 6 are designed for math courses and can be used in conjunction with the science-based activities, or independently. In Activity 5, students use trigonometry to explore how much carbon is stored in trees. Activity 6 has students consider the economics of environmental choices by analyzing linear equations. The design challenge is a consolidation and reflection of a whole climate change unit, extending beyond this resource.

Structure of Activities

Each of the module's activities can be completed in approximately one hour and includes two parts for students:

1. **Student Activity:** a sequence of hands-on activities and related discussion questions
2. **Consolidate Your Learning:** a series of questions designed to help students cement the content covered in the activity (assessment *for* learning—formative). Teachers may also choose to assign and evaluate the questions (assessment *of* learning—summative).

The activities are supported by modifiable handouts. You are encouraged to adapt these to meet the needs of individual students or your particular class.

Promoting Effective Group Work

The student activities have been designed with small groups of students in mind. Sharing group work expectations with students will keep groups on task and lead to better participation and deeper learning. Two critical components for effective group work are as follows:

1. *Individual accountability:* Ensure that each student has an important, specific role to play (e.g., experimenter, recorder) so that students are responsible for their own learning. With this approach, students who might resist active participation will feel motivated to fulfill their roles and offer meaningful contributions to the group.
2. *Positive teamwork:* When you foster a positive and supportive classroom environment, students will encourage and challenge each other in constructive ways. Guide students to set a clear and meaningful goal for the group activity, or provide students with a goal. Ensure that each student has a different role, and emphasize the significance of each role in achieving the group's goal.

Teacher Background

The information below is designed to provide you with detailed background knowledge about climate and climate change. It goes beyond the curriculum to give you an in-depth understanding of the concepts behind the lessons.

> *"It's real.*
> *It's us.*
> *It's serious.*
> *And the window of time to prevent dangerous impacts is closing fast."*
>
> —Katharine Hayhoe, Texas Tech

What causes climate change?

Every day Earth is bathed in radiant energy from the Sun. This energy is reflected, absorbed, or radiated back into space. On a short-term regional scale, this energy produces ocean currents, winds, and weather. To study weather on a larger, longer scale, we use statistical methods to define climate. If the amount of energy entering Earth were equal to the amount leaving, we would still have weather, but the climate would fluctuate around an average value. Any changes made to the amount of reflection, absorption, or radiation result in an imbalance in the amount of energy coming in and going out. Over the long term, on a global scale, this imbalance results in observable changes to climate. Variables that alter the amount of energy coming in or out are called **forcing factors**. Changes that amplify or diminish the effects of climate change are called **feedback mechanisms**.

The atmosphere protects us

Earth's atmosphere is a mixture of gases that create the conditions necessary for life. The upper atmosphere protects Earth from harmful **ultraviolet** solar radiation and powerful cosmic rays. Gas molecules, clouds, and **aerosols** (tiny particles suspended in the air) reflect about 23% of the incoming energy directly back into space. Another 23% of the energy is absorbed by the atmosphere. Light that makes it through the atmosphere strikes the surface of Earth, where it is either reflected or absorbed. Reflected light travels back through the atmosphere to space. Absorbed light causes the surface to heat up and radiate energy in the **infrared** range of the electromagnetic spectrum. Infrared radiation interacts with several gases, called **greenhouse gases** (GHGs). The most significant GHGs, shown in **Figure 1**, are water vapour, carbon dioxide, methane, and nitrous oxide. Chlorofluorocarbons (CFCs) are also significant greenhouse gases.

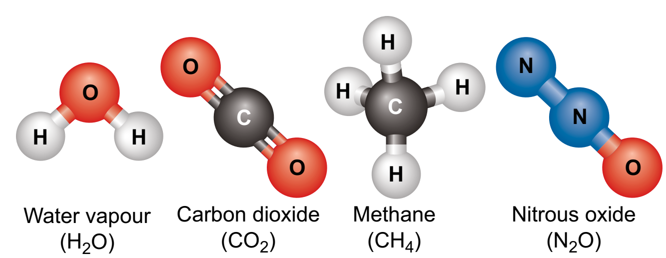


Figure 1 Greenhouse gases

Why does carbon dioxide absorb infrared light?

Molecules absorb and re-emit specific wavelengths of light based on how the molecules vibrate. A carbon dioxide molecule is made up of one carbon atom double bonded to two oxygen atoms on each side. If we model the bonds using springs, we can see that carbon dioxide has at least three vibrational modes (see **Figure 2**). If the vibration changes the symmetry of the molecule, it will absorb energy. Carbon dioxide molecules absorb infrared light because the light matches the vibrational frequencies of the molecule. These frequencies are determined by the mass of the atoms and the strength of the bonds. Oxygen and nitrogen molecules (O_2 and N_2) do not interact with infrared light because their only mode of vibration is symmetric. Other greenhouse gases, such as water vapour (H_2O), methane (CH_4), and nitrous oxide (N_2O), have more than two atoms and asymmetric vibrational modes that allow for more interactions.

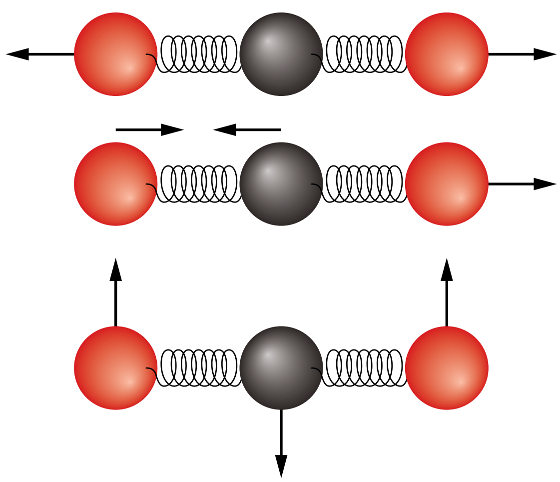


Figure 2 Three vibrational modes of carbon dioxide

Where does the carbon dioxide come from?

The amount of carbon on Earth is fixed. The carbon cycle describes how carbon moves around in different forms, but the total amount of carbon does not change. Carbon spends time in the atmosphere as carbon dioxide, in the biosphere as organic matter, in the ocean as carbonates, and in the lithosphere as fossil fuels. Most of the carbon on Earth is stored in the lithosphere because once a carbon atom reaches the lithosphere, it stays there for a long time. Over millions of years, the carbon cycle achieved a stable balance of carbon in the atmosphere, hydrosphere, biosphere, and lithosphere. Natural events periodically disrupted this balance, resulting in previous climate cycles. Our current challenge is daunting because the disruption is due to humans extracting carbon from the lithosphere and sending it into the atmosphere at unprecedented rates. In fact, **anthropogenic**, or human-caused, emissions of carbon dioxide have quadrupled since 1960. The increased emissions are compounded by deforestation, which reduces the storage of carbon dioxide in the biosphere.

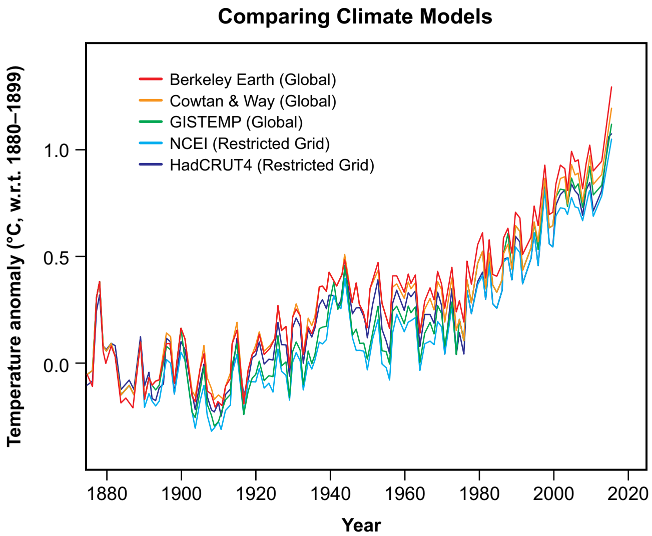
Evidence for and effects of climate change

Thousands of indicators provide evidence that our climate is changing. Over the last 150 years, average atmospheric temperature has increased by more than 1°C, ocean levels have risen by about 20 cm, glaciers are retreating across the globe, and polar ice is in decline. Extreme weather events are becoming more extreme, permafrost is thawing, ecological systems are being disrupted, and the chemistry of the ocean is changing. These changes are being observed, measured, studied, and explained by climate scientists. These changes are also being reported by the Inuit and other Indigenous people, who are experiencing the impact of climate change firsthand.

Climate change also has economic ramifications. For example, the Fort McMurray wildfire cost over $9 billion. The US National Flood Insurance Program was over $25 billion in debt even before the devastation of hurricanes Harvey, Irma, and Maria. Although mitigation efforts are generating new jobs and investment, projections of economic impacts are generally bleak: not addressing climate change will cost trillions of dollars.

How do you measure a global temperature?

Temperature is a localized measurement; on the same day, the temperature might be −20°C in Montreal and +12°C in Vancouver. Determining temperature on a global scale requires averaging thousands of local measurements. Climate scientists use sophisticated computer programs called **climate models** to perform this calculation. Each model uses slightly different data sets and methodologies, but as **Figure 3** shows, they all show that the global temperature has increased by roughly 1°C in the last 150 years. Temperature also fluctuates greatly, so scientists don't usually discuss temperature directly. Instead, they use **temperature anomalies**. Temperature anomalies are based on the average temperature for a particular location and time of year over some historic baseline. In **Figure 3**, a comparison of the most influential models, the average temperature anomaly is expressed relative to a baseline of 1880–1899. The models are validated using historical data and are rigorously analyzed by competing models.



Credit: Gavin Schmidt Twitter feed on 20 Sept 2017: @ClimateofGavin

Figure 3 This graph compares climate models.

Sea level rise

Earth's surface is roughly 70% water. The **heat capacity** of water is higher than that of air, so oceans have absorbed over 90% of the extra heat trapped by greenhouse gases. This extra heat has not resulted in a large temperature change, but even a small change in temperature leads to **thermal expansion**. As water molecules warm up, they vibrate more and more, taking up more space. The volume of the water increases and sea levels rise. Satellite **altimetry** uses radar to measure the exact distance between the satellite and the ocean surface. **Gravimetry** measures changes in water mass and density to determine sea level change. With approximately 40% of the world's population living within 100 km of the coast, sea level rise will have significant impacts.

Declining ice

Two kinds of ice have a large impact on global climate. Sea ice forms seasonally when the surface of the ocean freezes. Land ice forms slowly over thousands of years when snow falls and is compacted under its own weight. Climate warming causes both types of ice melting at an increasing rate, which changes the **surface albedo** of Earth. Surface albedo compares the amount of light reflected from a surface to the amount incident on the surface. Less ice means less reflection of radiant energy and more absorption, a feedback mechanism that accelerates the melting process further. Less sea ice is already affecting species that depend on stable sea ice for hunting, breeding, and migrating. For example, humans who depend on stable sea ice for hunting and travel are affected, as shown in Figure 4. Melting sea ice does not have a direct impact on sea levels since the ice is already in the ocean, just as melting ice cubes don't cause your drink to overflow. By contrast, melting land ice, including ice sheets and glaciers, will affect sea levels as more and more water pours into the ocean. The two largest ice sheets are Greenland and Antarctica. Measurements by NASA satellites show that Greenland and Antarctica have lost almost 6000 Gt (gigatonnes) of ice since 2002. That is more than the total mass of water in Lake Huron and Lake Ontario.

Credit: Government of Nunavut Department of Environment www.gov.nu.ca/environment

Figure 4 Melting sea ice is creating problems for Inuit people.

> *"Inuit are facing the beginning of a possible end of a way of life that has allowed us to thrive for millennia because of the climate changes caused by global warming.... What will be left of our culture if this comes to pass?"*
>
> —Sheila Watt-Cloutier, International Chair for Inuit Circumpolar Council

Impact on marine food chains

A warmer ocean surface reduces the upwelling of deep ocean water that brings nutrients from the deep ocean to the surface. A decrease in nutrients reduces the growth of phytoplankton, which are important sources of food at the base of the ocean food chain. Less phytoplankton also means less carbon dioxide absorbed from the atmosphere, leading to increased warming, and then further decreases of phytoplankton. Scientists are continuing to uncover impacts and feedback loops related to ecosystems like this one. Other ecological impacts are desertification, species extinction, biodiversity shifts, and pathogen development.

Carbon dioxide and the chemistry of ocean water

When water (H_2O) and carbon dioxide (CO_2) mix, they react and form carbonic acid (H_2CO_3), a weak acid. The oceans have absorbed about 25% of the carbon dioxide released by humans since the industrial revolution. As a result, the oceans have become more acidic. In fact, the pH of the oceans has dropped from roughly 8.2 to 8.1 and is predicted to fall at least another 0.2 by the year 2100 (IPCC Fifth Assessment). Although a change of 0.1 in pH might not seem that drastic, the pH scale is a logarithmic scale, which means that a change of 0.1 in pH is roughly a 25% change. The projected fall of 0.2 means oceans would be the most acidic they have been for at least 20 million years. Oceans that are more acidic reduce the amount of available carbonate that marine organisms use to make shells. As the oceans warm due to climate change, they will absorb less carbon dioxide because solubility depends on temperature, so more carbon dioxide will stay in the atmosphere—another feedback mechanism.

Is something other than carbon dioxide causing climate change?

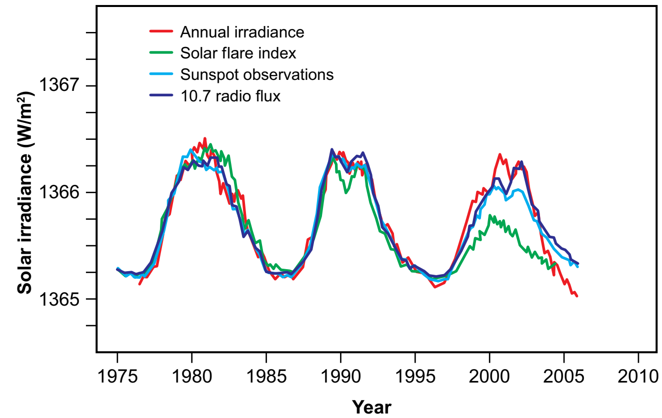
People sometimes wonder why there is such a focus on carbon dioxide emissions in the discussion and study of climate change. What role do other factors play?

What about water vapour?

Water vapour is the largest contributor to the natural greenhouse effect, but it is not considered a forcing factor because changes in water vapour are part of the water cycle, which self-regulates. Warmer temperatures lead to increased water vapour in the air, leading to more clouds, lowering temperatures and causing rain. Water vapour is an important feedback mechanism that is included in all climate models. It amplifies the impact of other factors, but it isn't causing the rise in global temperature.

How about solar radiation?

The amount of radiant energy released by the Sun changes slightly over an 11-year solar activity cycle (see **Figure 5**). Earth also wobbles slowly around its axis, causing the tilt to change over a 41 000-year cycle, which changes the equinoxes. Currently, Earth is closest to the Sun in January, when the northern hemisphere is tilting away from the Sun. In 13 000 years, Earth will be closest to the Sun when the northern hemisphere tilts *toward* the Sun. The combination of tilt and distance will result in hotter summers and colder winters, perhaps cold enough to trigger another ice age, but that is thousands of years in the future.



Source: Robert A. Rohde/Creative Commons

Figure 5 The Sun has an 11-year cycle.

Don't volcanic eruptions influence climate?

Earth is a dynamic planet consisting of a solid crust floating on a layer of hot magma. During a volcanic eruption, magma bursts through weak spots in the crust. These violent eruptions throw ash and sulfates into the upper atmosphere, where they scatter solar radiation. Ash and sulfates that don't reach the upper atmosphere cause more clouds to form. The impact of volcanic eruptions is short-lived, since the ejected materials settle back onto Earth's surface, but since they happen regularly, the cooling effect is continuous, with localized spikes for a year or two following large eruptions.

What is aerosol pollution?

Aerosol pollution consists of small particles of matter suspended in the troposphere. These small particles reflect sunlight back into space and seed clouds, which helps cool the planet. Aerosols don't stay in the atmosphere forever. They fall back to Earth as acid rain or as soot, where they change the surface albedo. The overall impact of aerosols is still being studied, but scientists are confident that aerosols play a cooling role in climate change.

How does land use affect climate?

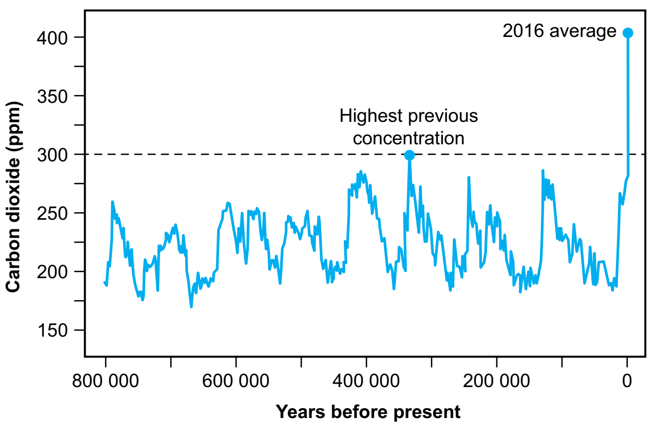
Land use affects climate by altering the surface albedo, changing the water cycle, and changing the transfer of heat. Examples of land use that affect climate are deforestation and urbanization. The type of material covering the ground changes how much radiant energy is absorbed or reflected. Land use affects the water cycle by altering the rate of evaporation and the pattern of run-off. The nature of the surface also affects how much heat is radiated back into the atmosphere. Consider an asphalt parking lot. It absorbs radiant energy and heats up. It does not absorb precipitation, so it alters the water cycle.

How does ozone depletion affect climate?

Ozone plays a significant role in absorbing high-energy ultraviolet light in the upper atmosphere. Anthropogenic chemicals, such as CFCs, react with ozone and cause it to break down into diatomic oxygen, which allows more energetic light to pass through. The production and release of most CFCs has levelled off or decreased since 1989, when the Montreal Protocol came into effect. But CFCs persist for decades in the stratosphere, so this factor will continue to affect the climate.

Isn't the climate always changing?

Paleoclimatology is the study of climate using proxies like ice cores, tree rings, corals, and sediments. A **proxy** is a physical process that can be used to reconstruct past temperatures. Recent analysis of these markers shows that Earth has cycled through warm and cool periods before, but our current situation doesn't fit this cycle. As **Figure 6** shows, levels of carbon dioxide in the atmosphere are higher now than they have been any time in the last 800 000 years.

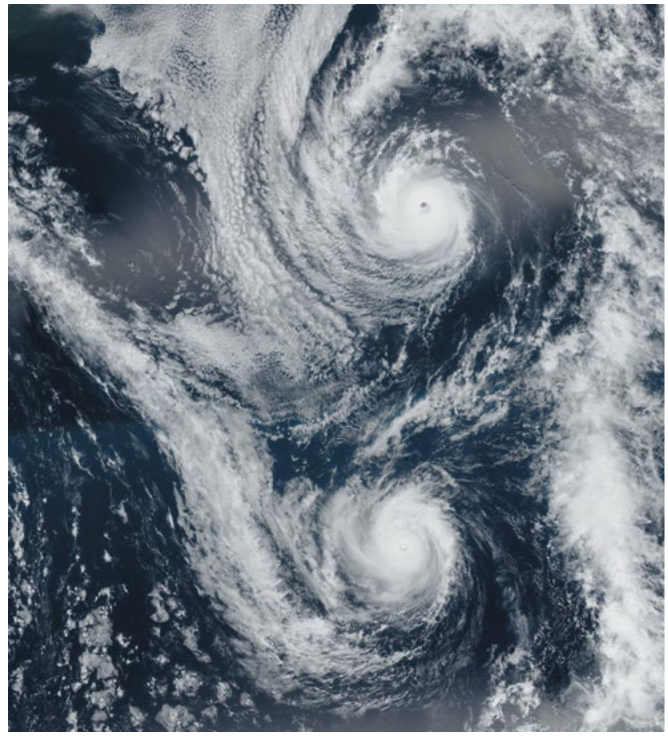


Source: NOAA/NCEI

Figure 6 Carbon dioxide levels for the past 800 000 years

What's next?

Our climate models continue to evolve and improve, but their predictions remain dire; action is required now. Any delay moves us further into unfamiliar, and possibly unpredictable, scenarios in which temperatures and sea levels continue to rise, ice cover continues to decline, weather becomes more extreme (**Figure 7**), and ecosystems are disrupted. Continuing to gather and analyze climate data (**Figure 8**) can help us understand how to mitigate our impact on climate and prepare for what the future will bring.



Credit: Jesse Allen (NASA Earth Observatory)

Figure 7 Satellite composite image of Hurricane Madeline and Hurricane Lester, August 29, 2016

Credit: Maria Strack, Department of Geography and Environmental Management, University of Waterloo

Figure 8 A student researcher measures a tree's biomass near Peace River, Alberta. This data will be used to determine the impact of access roads on boreal peatland carbon storage.

Bookshelf

These high-quality resources are recommended for further reading. Consider collaborating with your school's librarian to set up a display of titles relating to climate and climate change.

For Students

- *Biofuels: Sustainable Energy in the 21st Century*, by Paula Johanson (Rosen Publishing, 2010)
- *Climate Change*, by DK Publishing and John Woodward (Dorling Kindersley, 2008)
- *Environmentalists from Our First Nations*, by Vincent Schilling (Second Story Press, 2011)
- *Hybrid and Electric Vehicles*, by L.E. Carmichael (ABDO Publishing, 2013)
- *Making Good Choices About Nonrenewable Resources: Green Matters*, by Paula Johanson (Rosen Publishing, 2010)

For Adults

- *Are We Screwed? How a New Generation Is Fighting to Survive Climate Change*, by Geoff Dembicki (Bloomsbury Publishing, 2017)
- *Climate Change: What the Science Tells Us*, by Charles Fletcher (Wiley, 2013)
- *The Climate Crisis: An Introductory Guide to Climate Change*, by David Archer and Stefan Rahmstorf (Cambridge University Press, 2009)
- *David Suzuki's Green Guide*, by David Suzuki and David R. Boyd (Greystone Books/David Suzuki Institute, 2008)
- *Just Cool It! The Climate Crisis and What We Can Do*, by David Suzuki and Ian Hanington (Greystone Books/ David Suzuki Institute, 2017)
- *Unstoppable: Harnessing Science to Change the World*, by Bill Nye (St. Martin's Press, 2015)

Web Resources

The following websites provide climate change data and analysis, as well as different perspectives on climate change, including Indigenous voices.

Canada: Climate Change
https://www.canada.ca/en/services/environment/weather/climatechange.html

Carbon Brief
https://www.carbonbrief.org

Climate Change: Find out how you can help ...
https://www.ontario.ca/page/climate-change

David Suzuki Foundation: Climate Change
https://davidsuzuki.org/what-you-can-do/what-is-climate-change/

Global Weirding YouTube Channel
https://www.youtube.com/channel/UCi6RkdaEqgRVKi3AzidF4ow

IDRC: Climate Change
https://www.idrc.ca/en/program/climate-change

Intergovernmental Panel on Climate Change
http://www.ipcc.ch/index.htm

Inuit Knowledge and Climate Change (video)
http://www.isuma.tv/inuit-knowledge-and-climate-change

Met Office: Global Surface Temperature
https://www.metoffice.gov.uk/research/monitoring/climate/surface-temperature

NASA: Global Climate Change—Vital Signs of the Planet
https://climate.nasa.gov/

National Center for Ecological Analysis and Synthesis
https://www.nceas.ucsb.edu/science/climate

National Geographic: Environment
http://www.nationalgeographic.com/environment/

Nunavut Climate Change Centre: Voices from the Land
https://www.climatechangenunavut.ca

Skeptical Science (also available as a smartphone app)
https://www.skepticalscience.com/

Activity 1

Activity 1: Carbon Dioxide

Lesson Plan

Introduction

In this activity, students make connections between the increasing concentration of carbon dioxide and the resulting effects on the atmosphere and oceans. They explore how carbon dioxide interacting with infrared radiation has resulted in the recent global temperature increase. They analyze and discuss the current level of carbon dioxide and compare it to historical levels. They consider causes for the global temperature increase. Further discussion centres on the effect of carbon dioxide on the pH of water.

Suggested Time: 100 minutes

Purpose

- To present evidence of carbon dioxide interacting with infrared radiation
- To understand how real data shows an increase in global temperature
- To show how carbon dioxide concentration affects the acidity of Earth's oceans

PRIOR KNOWLEDGE & SKILLS

- Students need to understand the role of empirical evidence in scientific inquiry.
- Students must know how to read basic trends from graphs, as well as interpret axis labels.
- Students should understand the carbon cycle.

Materials

- 2 versions of the Perimeter Institute video about infrared absorption: *Why Is the Atmosphere Warming?*
- Keeling Curve Graphs (1 copy per group; see Appendix A)
- bromothymol blue
- straws
- 250 mL–500 mL beakers or flasks
- seawater mixture (30 mL of sea salt : 1 L water)

Teacher Instructions

1. Preview the accompanying videos. *Why Is the Atmosphere Warming?* is an introductory overview for the whole module. The other is a cut of the same video that allows students to develop the ideas in Part 1 from observation.
2. Photocopy the Keeling Curve Graphs (see Appendix A) as one sheet with graphs 5–8 on the back. Make one sheet for each group of students. Cut off the header and footer of the sheets. Fold along the dotted line, following the instruction on the sheet. Graphs 1 and 2 should be the only graphs visible at first.
3. Begin by having students predict the effect of carbon dioxide on the environment. Take note of these predictions, using them to guide students' learning.
4. Distribute the Keeling Curve Graphs before students begin working on question 5. Aid students in their interpretation of the graphs in questions 5–13 to ensure that the correct ideas are emerging.
5. When discussing the recent sharp increase in carbon dioxide in question 13, make sure connections are made to anthropogenic sources, such as transportation, electricity, industry, and farming.
6. For Part 2, measure 1 L of water and 30 mL of sea salt. Mix thoroughly to form a seawater solution. Then have students half-fill two beakers with the seawater solution.
7. Students will test the pH of both samples with bromothymol blue. Hand out protective equipment before any handling of bromothymol blue.
8. Have students softly blow through a straw into one of the samples for 30–60 s. Tell them to take in a small breath before placing the straw to their mouths to prevent drawing any solution into the straw.
9. After students have collected their data, they can share their pH values with the class. Then, have them share their predicted consequences of this change in pH with the class.

SAFETY ALERT

Students must wear disposable gloves, goggles, and protective clothing such as a lab apron while using bromothymol blue, which may irritate eyes and skin. Make a shield by cutting a hole in a small paper plate to reduce splashing. Have students place the shield on the beaker and the straw through the hole before they begin to blow through the straw. Remind students that they must not draw any liquid into the straw.

INQUIRY TIP

Open Inquiry: Allow students time to examine the recent raw data from the Scripps website. Instead of looking at the preconstructed graphs in the latter half of Part 1, let students make conclusions about trends from the graphs they create with the raw data. A similar inquiry can be done with the pH graph in Part 2 (see data).

DIFFERENTIATED SUPPORT

To Assist: Remove questions 6 and 8 in Part 1 to simplify this lesson. Similarly, Part 2 can be omitted.

Teacher Tips

- To encourage students' predictions at the beginning of the lesson, use a four corners approach, with the predictions "No Effect, Temperature Goes Down, Temperature Goes up, Something Else" in the corners. Afterward, students can record their predictions on the student activity sheet.
- The Keeling Curve Graphs are used extensively throughout Part 1 of this activity. It might be more powerful for students to analyze the most up-to-date data available. The Scripps Institution of Oceanography updates the Keeling Curve from the Mauna Loa Observatory (see **Figure 1** on the next page) every couple of days. You could also use a projector to show the graphs from the Scripps website. This will lead to a more guided discussion as you review students' answers to these questions.
- If not using the most up-to-date data available, print the graphs on cards and laminate them for reuse. Hand out the cards one at a time to keep the suspense.
- For more details on why the annual cycle of carbon dioxide concentration peaks in May, see "Why Does Atmospheric CO_2 Peak in May?"
- **CAUTION:** Review the safe use of bromothymol blue with students. Because it is sensitive in the range required, this chemical is the best indicator for this experiment. Alternatively, use universal indicator with careful observation and guidance.
- When students are blowing into the beaker/flask, there is potential for a mess if they blow too hard. Provide large containers to lessen the risk of overflow.

Extension

Have students dig deeper into the Mauna Loa data to identify factors that cause the annual cycle. Three major factors lead to atmospheric carbon dioxide concentration peaking in May: (1) most plants can't absorb carbon dioxide in winter and decay during winter months; (2) May is the break-even month when increasing amounts of spring photosynthesis catch up to the accumulated effect of decreased carbon dioxide absorption in the winter; (3) the northern hemisphere has more land than the southern hemisphere.

STSE Connections

Scientists use carbon dioxide's infrared-absorbing property to measure how much of it is in the atmosphere. They pump air between two windowpanes and shine infrared light through them to a detector on the other side. The mechanism, which causes carbon dioxide to contribute to global warming, is the method by which we first detected its concentration increase and will hopefully lead to its reduction in the future. (See "How we measure background carbon dioxide levels on Mauna Loa.")

What's cutting edge about carbon dioxide?

Anthropogenic climate change is likely the greatest challenge humankind has ever faced. If it is left unchecked, drastic changes to terrestrial and marine life and environments will occur. Understanding the evidence behind climate change is a critical part of global citizenship. The increasing concentrations of carbon dioxide in the atmosphere and oceans are major driving forces. The year 2015 was the last in which less than 400 ppm of carbon dioxide was present at any moment in the atmosphere since humans have existed. We have recently passed a symbolic threshold on a course that only collective societal pressure, activism, policy, lifestyle changes, and technologies can reverse.

Find Out More ►

To learn more about the changes in global carbon dioxide concentration before facilitating this activity, you may wish to visit the following websites:

King's Centre for Visualization of Science: CFCs Absorbing Different Spectra of Light
http://www.kcvs.ca/site/projects/JS_files/CFC/CFC.html

Scripps Institution of Oceanography: Keeling Curve Lessons
http://scrippsco2.ucsd.edu/history_legacy/keeling_curve_lessons

Smithsonian National Museum of Natural History: Ocean Acidification
http://ocean.si.edu/ocean-acidification

Credit: Commander John Bortniak, NOAA Corps (ret.), NOAA At the Ends of the Earth Collection

Figure 1 The Mauna Loa Observatory as photographed in 1982. Then, carbon dioxide concentration was about 340 ppm. It has increased over 20% in the last 35 years.

Name: ____________________ Date: ____________________

Student Activity

Carbon Dioxide

Part 1: Carbon Dioxide in the Atmosphere

How does carbon dioxide in the atmosphere affect climate? To investigate, analyze the Keeling Curve Graphs, created from data collected from the Mauna Loa Observatory in Hawaii.

1. What effects do you think carbon dioxide has on Earth's atmosphere? How do we experience these effects?

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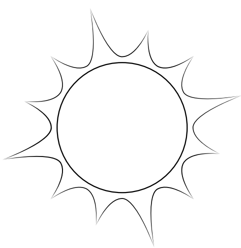
2. Watch the short video clip, and indicate where thermal energy (heat) is being absorbed, reflected, or radiated. Label these energy flows as visible light, infrared light, or both.



3. What effect does carbon dioxide have on the energy being transferred from the Sun to Earth? What about the energy being radiated from Earth to space?

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4. What will happen to the amount of energy radiated from the Sun to Earth if the amount of carbon dioxide in the atmosphere continues to increase? What about from Earth to space?

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5. The Mauna Loa Observatory in Hawaii has been monitoring atmospheric levels of carbon dioxide since 1958. Examine the folded sheet of Keeling Curve Graphs. Graphs 1 and 2 represent the data collected at this observatory over a period of a week and a month. With your group, discuss what you notice, if anything, about the concentration of carbon dioxide.

6. Unfold the sheet to see Graphs 3 and 4. These graphs show data collected over periods of six months and a year. What do you notice about the concentration of carbon dioxide? What does this imply about the energy in the atmosphere during these periods? Compare and contrast with previous graphs.

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7. Turn the sheet over. Graph 5 shows data collected from 2016 to 2018 at Mauna Loa. Discuss how the carbon dioxide concentration of January 2018 compares with that of January 2017. Discuss with your group how May 2016 compares with May 2017.

8. The two-year graph of carbon dioxide concentration shows a regular up-and-down variation that peaks every year in mid-May. Patterns that follow a yearly pattern are called annual cycles. What causes the annual cycle of carbon dioxide concentration in the atmosphere?

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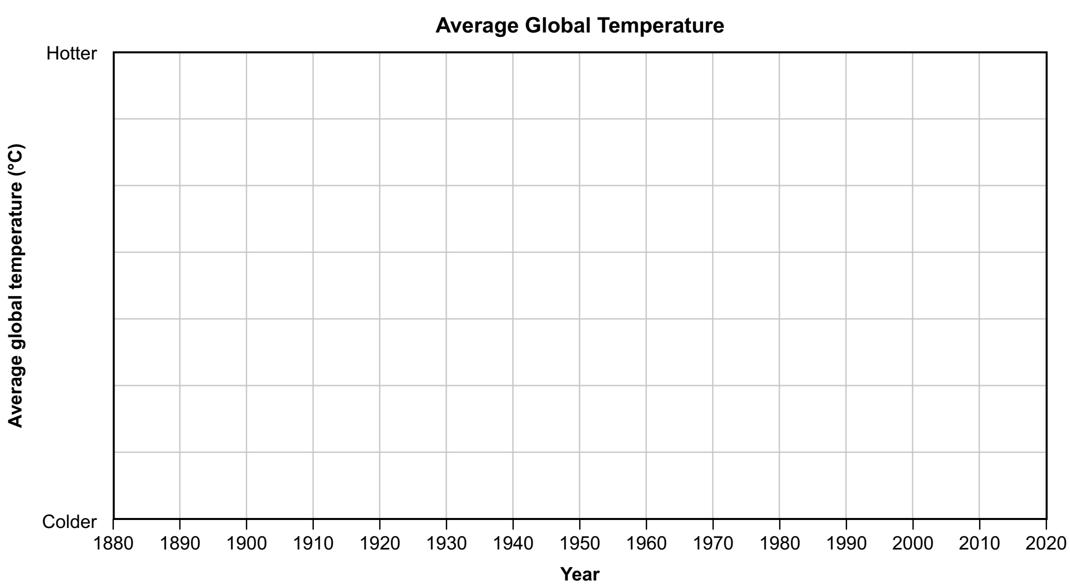
9. Graph 6 shows the full observation history of the Mauna Loa Observatory. Discuss what you notice about the concentration of carbon dioxide over the 60-year observation history. Explain what this implies about the energy absorbed by Earth's atmosphere during this time period.

10. Sketch a trend line on the graph below to predict how the average global temperature has changed over time. When you have finished, your teacher will provide a graph of actual data. Compare your prediction to the graph.



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11. Graphs 7 and 8 show the Mauna Loa data combined with ice core data to provide a longer history of carbon dioxide concentration. As a group, discuss what this trend implies about the temperature of Earth.

12. How has the atmospheric concentration of carbon dioxide changed over the majority of the last 10 000 years of Earth's history? How has the atmospheric concentration of carbon dioxide changed over the last 100 years?

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13. Graphs 7 and 8 both show a sharp increase in carbon dioxide concentration in recent history. What sources of carbon dioxide do you think are causing this increase? Research online to find a graph that supports or challenges your ideas. Share your findings with your group.

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14. The total amount of carbon on Earth today is the same as when Earth was formed 4.5 billion years ago. It has not increased over time. So, why is carbon such a problem now? (**Hint:** Recall the carbon cycle.)

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15. What is driving the overall trend for the concentration of carbon dioxide for the last 10 000 years of Earth's history? What is driving the trend for the concentration of carbon dioxide for the last 100 years of Earth's history?

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Part 2: Carbon Dioxide in the Ocean

While the concentration of carbon dioxide in the atmosphere has increased dramatically in the recent past, the spike is not as sharp as it should be. The ocean actually absorbs and stores a substantial amount of the carbon dioxide produced each year. What is the effect of the ocean storing carbon dioxide?

1. Collect two beakers of seawater solution. Place 5 or 6 drops of bromothymol blue in each solution. Stir using a glass rod to evenly dilute the indicator. Based on the colour of the solution, estimate the pH using an indicator scale.

   The pH of seawater is ______.

2. Predict what will happen if you continuously blow into one of these solutions. What changes will take place, if any?

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3. Take a straw and softly blow into the second solution continuously for 30–60 s. Record your observations. Discuss them with your group.

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Activity 1

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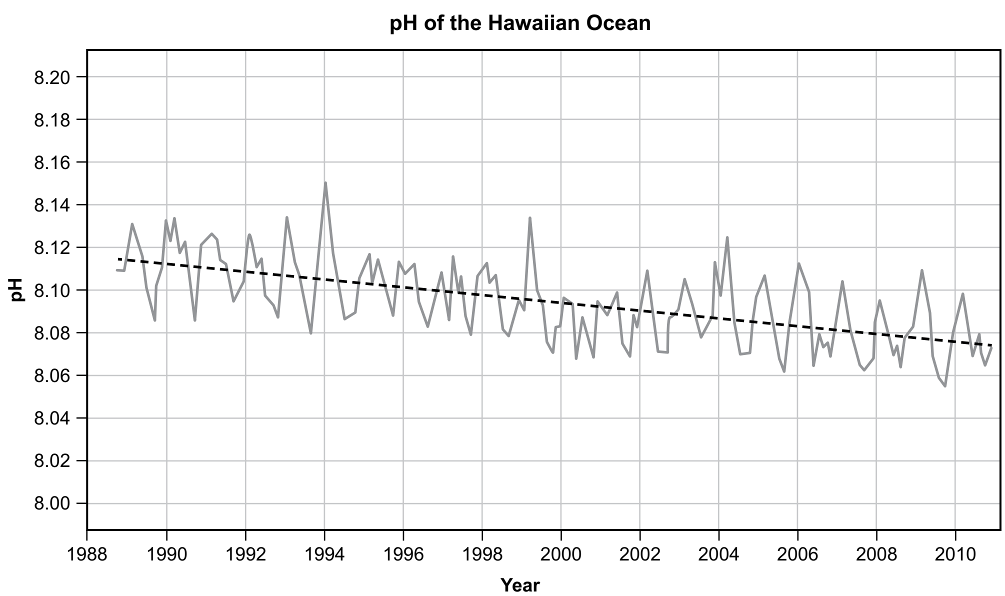
4. Using prior knowledge and what you know about your breath, explain why these changes have occurred.

5. Using the indicator scale, estimate the pH of the seawater you blew into. The pH of the seawater you blew into is ______. Compare this to the pH of the seawater you did not blow into.

6. Using your knowledge about the increasing carbon dioxide concentration from Part 1 of this activity, predict how the pH of seawater has been changing in recent history.

7. Compare and contrast your prediction to the following graph of seawater pH in the Hawaiian Ocean:



Source: Hawaii Ocean Time-series (HOT) Station Aloha, Hawaii, North Pacific

8. What do you think the consequences of the changing pH of seawater are? Compare your answers with those of a partner and be prepared to share your ideas.

9. How is this effect changing over time, and why?

Activity 1

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Consolidate Your Learning

Answer the following questions to check your understanding of concepts relating to carbon dioxide emissions in the atmosphere and in the ocean.

1. Looking at recent trends of atmospheric temperature and ocean pH, do you think these trends will continue indefinitely? Why or why not?

2. If the industrial revolution had not occurred, what would you expect the carbon dioxide levels to be like? What would the relative effects on the atmosphere and the ocean be? Justify your answers.

3. How is the increasing concentration of carbon dioxide affecting Earth's ecosystems? Support your answer using observational evidence.

4. Governments can help reduce carbon dioxide emissions by imposing a carbon tax. A carbon tax attaches a cost to polluting. What are some pros and cons for this approach? What other ideas might work?

Pros	Cons

Activity 2

Activity 2: Climate Modelling

Lesson Plan

Introduction

In this activity, students examine natural and anthropogenic factors driving climate change. They consider the data for individual forcing factors and combine data to get the overall effect on global temperature. Students consider how data can be misunderstood or misrepresented.

Suggested Time: 60–70 minutes

Purpose

- To examine primary factors driving climate change
- To extract information from graphs

PRIOR KNOWLEDGE & SKILLS

- Students should be familiar with interpreting line graphs and identifying trends.

Materials

- Graphs for Climate Forcing Factors, double-sided and cut into individual graphs (1 graph per group; see Appendix B)
- Graphs for Climate Forcing Factors, not cut up (1 per student; see Appendix B)
- Combined Predictions and Observed Data (1 per student; see Appendix D)
- Modified Graphs for Climate Forcing Factors (optional; see Appendix C)

Teacher Instructions

1. Engage students in a discussion about how climate change is perceived in the media. Give them an opportunity to search online for climate slogans or posters from climate marches.
2. Divide the class into six groups. Each group will examine a different climate forcing factor.
3. Have students brainstorm the top five factors that influence global temperature.
4. Give each student a copy of the student activity sheets.
5. Provide each group with one graph only.
6. After groups have completed Part 1, questions 1–3, students form new groups of six. (One representative from each data group should be in each new group.)
7. Give each student their own copy of Graphs for Climate Forcing Factors (see Appendix B). Each representative shares how their forcing factor affects climate. The group then answers Part 2, questions 1 and 2. Students can ignore the factors that do not have a large impact (solar, land use, and ozone) and then combine the data by adding temperature anomalies for the years 1900, 1920, etc.
8. Have each group show you its prediction before giving them Combined Predictions and Observed Data (see Appendix D). Have students discuss and record answers for Part 2, questions 3 and 4.

Teacher Tips

- This lesson uses the jigsaw teaching strategy. For this collaborative strategy, divide your class into groups and have each student learn about a particular topic, thereby becoming an "expert." Next, reorganize students into new "jigsaw" groups that include all the different types of experts. Students then perform a task that requires expert knowledge from every group to be successfully completed.
- The vertical scales on the graphs are not consistent, which can be confusing, but this provides an opportunity to discuss how changing the vertical scales can influence the interpretation of data.
- Allow students the freedom to express doubt and skepticism. The climate data is robust and can handle challenges.
- This activity can be simplified by using fewer graphs with consistent vertical scales (see Modified Graphs for Climate Forcing Factors in Appendix C). Have students focus on the main forcing factors: greenhouse gases, aerosols, and volcanic eruptions. Another alternative is to keep the activity teacher-centred and work through the questions as a class.

INQUIRY TIP

Investigation: For classrooms that have access to technology, students can generate and manipulate the graphs, or they can explore the *Bloomberg Businessweek* interactive graph "What's Really Warming the World?"

DIFFERENTIATED SUPPORT

To Engage: Students with less-developed numeracy skills may be more engaged if you reduce the number of graphs and use consistent scales. (See Appendix C.)

Extension

The Intergovernmental Panel on Climate Change (IPCC) assessment is available online. Students could explore the IPCC website to discover more about the report and the process followed to generate the report. Students can also use the IPCC as the launching point for an Internet search to compile a Top Ten list of sources of anthropogenic greenhouse gases.

STSE Connections

Climate change does not affect everyone equally. Studies show developing countries will suffer more damage even though more affluent regions generate most of the pollution. Consider having students read this *Slate* article, "Climate Change Will Also Exacerbate Wealth Inequality," which discusses data from a study published in *Science*. Students can examine and discuss the economic and political ramifications of climate change and climate mitigation strategies.

Career Connections

Data scientists use computer science, mathematics, and social science to help organizations and governments compile and analyze the huge amount of data involved in understanding complex phenomena such as climate change. Consider having students conduct research to find out more about what data scientists do and the education and training that is required for this career.

What's cutting edge about computer modelling?

The sophistication and accuracy of models have grown as computers have become more powerful. Today's climate models use supercomputers to consider the known factors that might possibly influence climate. These models are cross-checked with other programs that use different methods and are compared to historical data to determine whether the models agree with current measurements.

Find Out More ►

To learn more about climate modelling and the factors that are forcing the change in temperature before facilitating this activity, you may wish to visit the following websites:

Bloomberg Businessweek: What's Really Warming the World?
https://www.bloomberg.com/graphics/2015-whats-warming-the-world/

Carbon Brief YouTube video
https://youtu.be/sKDWW9WlPSc

The Met Office: Climate Science
https://www.metoffice.gov.uk/research/climate

Activity 2

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Student Activity

Climate Modelling

Science Background

How do forcing factors such as ozone depletion or volcanic eruptions change Earth's average temperature? In this activity, you will explore how a climate model can be used to answer this question. A climate model is a computer program that allows scientists to isolate variables called forcing factors to determine the impact of each variable on the global temperature anomaly. The global temperature anomaly describes the change in average temperature relative to a baseline period. Normally, the energy flowing into our planet would be equal to the energy flowing out, and the temperature anomaly would fluctuate around zero. Your group will examine the data generated by the NASA Goddard Institute for Space Studies (GISS) climate model.

Part 1: Analyzing Individual Forcing Factors

1. Examine the graph assigned to your group. Read the information on the back. Discuss the following and record your consensus answers.

   (a) Look at the scale and units for the vertical axis. How much has the temperature changed over the time shown? Does this seem significant to you?

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   (b) Look for patterns in the data. Are there cycles? Are there trends? Are there exceptions? Briefly describe three patterns that you notice.

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   (c) What questions do you have about the data?

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2. The overwhelming majority of scientists agree that climate change is happening and that humans are the primary cause of it. However, there is still debate in the media and general public about this. Write a 140-character tweet that a climate change denier might write, using the data you have been studying to *support* their message. Then, describe what is misinterpreted or misrepresented in the tweet.

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3. Discuss the question below that matches your assigned graph, and develop an answer as a group.

   (a) AEROSOLS: Some experts have proposed increasing the level of aerosols to offset global warming. How would this work? What are some possible consequences of this idea?

   (b) GREENHOUSE GASES: Some politicians have stated that an increase in carbon dioxide is good for agriculture. Describe other ways that increased carbon dioxide might impact agriculture.

   (c) LAND USE: Dark-coloured objects absorb more energy than light-coloured ones. As Earth warms, there is less snow and ice covering the ground. How will melting glaciers affect the rate of climate change?

   (d) OZONE DEPLETION: Ozone depletion is caused by chemicals such as chlorofluorocarbons (CFCs), which were banned in 1989. How is it possible that they are still affecting the temperature?

   (e) SOLAR VARIATION: You know that the seasons on Earth are caused by the tilt of the planet. This tilt is slowly changing. How would a changing tilt affect the seasons?

   (f) VOLCANIC ERUPTIONS: Volcanic eruptions are short-lived events. How long does their impact on climate last? Where do you think the material ejected by the volcanoes ends up?

Part 2: Comparing Forcing Factors

1. Form new groups with one person from each data group acting as the expert on the forcing factor considered above. Examine all of the graphs together.

   (a) Put the factors in order from largest to smallest contributor. (**Hint:** The vertical scales are not the same for all graphs.)

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   (b) Group the factors by their effects: Do they increase temperature, decrease temperature, or have a negligible effect on temperature?

   Effect of Forcing Factors on Temperature

Increase Temperature	Decrease Temperature	Negligible Effect

   (c) Which factors are anthropogenic (made by humans)?

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   ____

   (d) Are you surprised by any of the graphs? Discuss.

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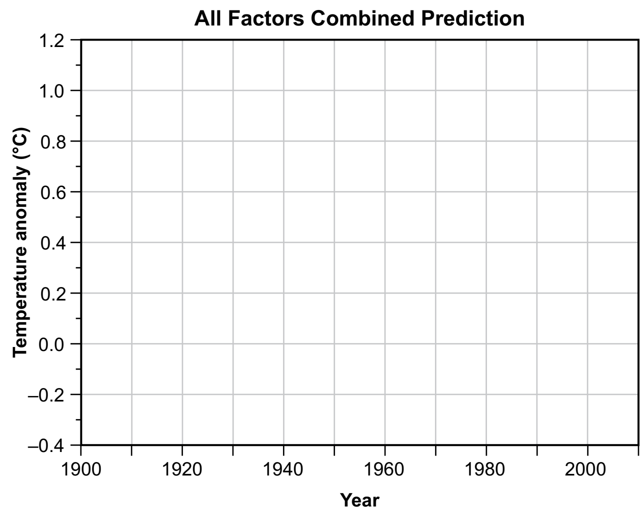
Name: ______________________________ Date: ______________________________

2. Use the axes provided to sketch a prediction of the temperature anomaly that you would get when you consider all of these factors at the same time. (**Hint:** Three of the factors have essentially no impact and can be omitted.) When you are finished, show your prediction to your teacher and get the actual modelling data for all forcings combined.



3. The Temperature Change Due to All Forcings Combined graph shows the average temperature anomaly generated by the model when all forcing factors are included. Examine it closely, and compare it to your prediction and the individual graphs to answer the following questions.

   (a) What is the overall trend when all the forcing factors are combined?

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   ____

   (b) There are several noticeable dips in the graph. What do you think caused these changes?

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4. The Observed Global Temperature Anomaly graph combines data collected by thousands of weather stations around the world since 1900. Examine it closely and discuss the following with your group:

   (a) What is the overall trend? Does it match up with the trend predicted by the models?

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   (b) The Paris Accord set a target of keeping the anomaly below 2°C above pre-industrial levels. Use the data to estimate when we will reach that level if we don't change anything.

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Consolidate Your Learning

Answer the following questions to check your understanding of climate modelling, forcing factors, and climate change data.

1. What are the two most significant forcing factors? How are they similar? How are they different?

2. Some climate change deniers say that the current trend in temperature is due to natural events. Is this statement supported by data? Give examples.

3. Write a 140-character tweet that expresses your opinion on climate change data.

4. Your cousins don't believe that climate change is caused by humans. Refer to the information in this activity, and outline how you would respond to them.

5. What personal actions are you willing to take to reduce your impact on the climate? List at least two, and explain how these actions will help.

Activity 3

Activity 3: A Warming World

Lesson Plan

Introduction

In this activity, students explore the effects of a changing climate with a focus on sea level rise. Students make predictions and observations in response to simple teacher demonstrations, using their findings to make inferences about the planet. Students then examine real data—which tracks how Earth's oceans, ice sheets, and glaciers are changing—and draw connections with the demonstrations.

Suggested Time: 70–100 minutes

Purpose

- To introduce how climate change is affecting our planet, including populations, infrastructure, and ecosystems

PRIOR KNOWLEDGE & SKILLS

- Students should understand density and have had an introduction to Earth's climate system, the greenhouse effect, and anthropogenic causes of climate change.

Materials

- video (optional): *Global versus Local Sea Level*
- video (optional): *NASA Sea Level Rise*
- Climate Data Cards (1 set per group; see Appendix E)
- 2 balloons
- 1 tapered candle or BBQ lighter
- 700 mL–800 mL disposable water bottle with lid
- 1 straw (transparent)
- polyurethane adhesive (e.g., Gorilla Glue)
- drill
- heat lamp (e.g., a 60 W or more incandescent light bulb in a desk lamp) or a heating pad
- 2 large, identical transparent containers, such as plastic storage containers or glass jars
- ice
- rocks
- food colouring (optional)
- bucket (optional)
- tape
- flood risk maps

Teacher Instructions

1. Before class, prepare the demonstration equipment:
   - Fill one balloon with air. Fill the other balloon about one quarter full of water using a faucet. Secure the end of each balloon with a knot. (See **Figure 1**.)

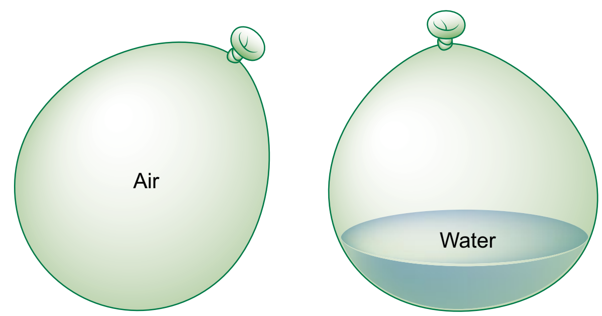

Figure 1 Filling the two balloons

   - Drill a hole in the cap of a water bottle so that a straw will fit through. Place the straw so it is midway through the cap, seal it with adhesive, and allow it to dry.
   - Fill the water bottle with water (minimize air as much as possible). Add food colouring, if you wish. Close the bottle and mark the height of the water in the straw with a marker. (See **Figure 2**.)

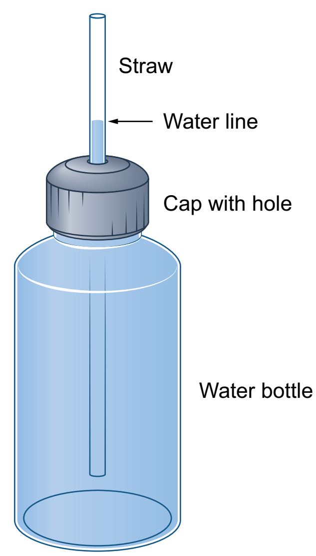

Figure 2 Setting up the water bottle

- Prepare two transparent containers—one empty, and one half-filled with rocks. Pour water into the container with rocks. Make sure the rocks create a surface above the water line. Mark the water line with a permanent marker.
- Just before beginning the demonstrations, place several ice cubes on the rocks and several in the empty container. Fill the "ice-only" container with water, matching the water level in the container with rocks. (See **Figure 3**.)

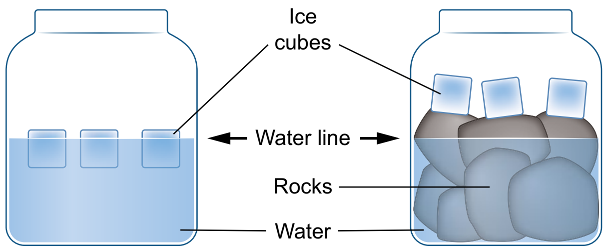

Figure 3 Preparing the containers

2. At the start of the activity, break the class into groups of three or four, and distribute the student activity sheets. Review safety rules for using a heat source.
3. Show students the demonstration setups. Explain that the demonstrations represent simplified models of Earth's climate. The air-filled and water-filled balloons represent the atmosphere and ocean, respectively. The water bottle with a straw models the ocean. The heat sources (flame, heat pad, or lamp) model the heat trapped by increasing amounts of greenhouse gases. Sea ice, which forms when the oceans freeze in winter, is modelled by ice floating in water. Land ice, which forms when snow is compacted under its own weight into glaciers and ice sheets, is modelled by ice on rocks. Have students make their predictions.
4. Conduct each demonstration as described in the student data table. For the balloon demo, the air balloon will pop right away, but the water balloon will remain intact for many minutes. Just in case, hold the balloon over a bucket. For the water bottle and straw demonstration, place the bottle either on a heat pad or close to an incandescent light. The water bottle and ice demonstrations will take 10–15 minutes to complete. After presenting the initial setups for these, have group members take turns checking on them.
5. Have students complete **Table 1**. Discuss their results and inferences. Since students are not yet familiar with heat capacity, explain how the balloon demonstration illustrates this concept.
6. Distribute the Climate Data Cards and have students complete Part 2. Show students the Sea Level Budget graph (see Appendix E) or give them a copy. Discuss how the different measurements add to explain sea level rise.
7. Have students look online at flood risk maps, which show the consequences of sea level rise. Students can either pick a city themselves or pick one of several cities that you suggest. Alternatively, give students a risk map chosen by you from the site. When students have completed the activity, you may wish to show them a video summarizing sea level rise.

SAFETY ALERT

Remind students that light bulbs and heat pads get hot and can cause burns. Tell students to handle light bulbs with care. Be aware that some students may have a phobia of popping balloons and may need to take a break. Pop the air balloon well away from students or have students wear eye protection.

Teacher Tips

- Rather than making the water bottle with straw setup, use a flask with a rubber stopper with a hole and a glass tube. Instead of using a lamp or heat pad as a heat source, place the flask in a pot of warm water.
- In 2010–2011 there was a decrease in sea level. This was due to ocean evaporation that led to heavy rainfall and flooding in Australia. This event offers an opportunity to discuss the water cycle and the variability of sea level.
- Because the ice sheets in Greenland and Antarctica are so large, they are typically separated out. The total land ice (all glaciers and both sheets) shows a decline of −549 ± 50 Gt/year. This amounts to a sea level rise of 1.51 ± 0.16 mm/year and is 61% of the total global sea level rise.
- For an applied class, consider completing the explanation and inferences in Part 1 as a class and completing Part 2 in a separate lesson if time permits. Use a projector or interactive whiteboard to show the data cards and discuss the trends as a class.

- For an academic class, consider asking students to infer the rate of change of the sea level and ice decline from the graphs. Current values of sea level rise are 3 mm/year. Greenland and Antarctica show an ice decline of 286 Gt/year and 127 Gt/year, respectively.
- Consider having students do a research project on how climate change and sea level rise might affect communities other than their own. Suggestions could include island nations, coastal communities, or Indigenous communities in Canada's north.

INQUIRY TIP

Hands On: Have students do some of the demonstrations as experiments in groups, if supplies permit.

DIFFERENTIATED SUPPORT

To Assist: For students who are struggling and/or ELL students, use a whiteboard or chart paper to reproduce the table in Part 1 and fill it in as a class.

What's cutting edge about sea level rise?

While the global average of sea levels is rising, many places on Earth may have falling sea levels. This is due to a variety of factors, including tides, erosion, and currents. Recent studies have shown that areas closest to melting ice sheets, such as Greenland and Antarctica, will likely have falling sea levels. This might seem surprising given the tremendous volume of water that is pouring in from melting ice. However, these ice sheets have masses of millions of billions of tonnes and they exert a gravitational tug on local sea water. As the mass of the sheet diminishes through melting, the gravitational tug lessens, the sea water is less attracted, and the sea level declines.

Find Out More ►

To learn more about sea level rise before facilitating this activity, you may wish to visit the following websites:

Argo: How well is Argo able to observe the global ocean?
http://www.argo.ucsd.edu/global_change_analysis.html

NASA: Earth's Rising Seas
https://svs.gsfc.nasa.gov/11927

NASA: GRACE-FO
https://gracefo.jpl.nasa.gov/science/sea-level/

NASA: GRACE Tellus Scale in the Sky
https://grace.jpl.nasa.gov/resources/26/

Argo: Argo Floats—How do we measure the ocean?
http://www.argo.ucsd.edu/IMOS_video.html

NASA: Vital Signs of the Planet—Sea Level
https://climate.nasa.gov/vital-signs/sea-level/

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Student Activity

A Warming World

Part 1: Where will the heat go?

Humans are emitting greenhouse gases into the atmosphere, causing more and more heat to be trapped. But what effect will this have? Your teacher will demonstrate a set of simplified models of Earth's climate, which you will use to explore the answer to this question.

SAFETY ALERT

Heat sources can cause burns. Follow the safety rules outlined by your teacher.

1. Form a group of three or four. Before watching each demonstration, **predict and explain** what you think will happen in column 2 of **Table 1**.

2. **Observe and explain** the demonstrations and record your observations and explanations in column 3. Use the space in column 4 to make a sketch to support your explanation. Some demonstrations may take 10–15 minutes, so take turns checking their progress.

3. These models allow us to make inferences about our changing climate. Using your observations, answer the questions in column 5.

Part 2: Data from the Sea

Our oceans have absorbed 90% of the excess heat trapped by increasing amounts of greenhouse gases. Measurements of the oceans suggest they are undergoing significant changes. Your teacher will provide you with a set of data cards. Take turns reading the cards, and use the data to answer these questions.

1. What does Argo tell us about how the volume of the ocean is changing over time?

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2. What does GRACE tell us about how the mass of land ice in Antarctica and Greenland has changed over time?

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3. What do satellite altimetry measurements tell us about how sea level has changed over time? How do these measurements compare to historic tide gauge measurements?

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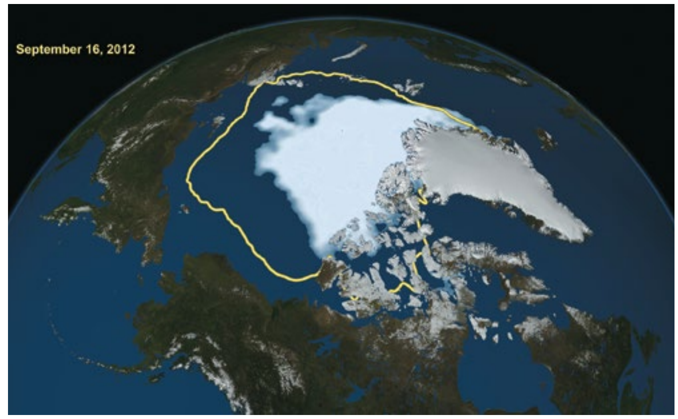
4. Examine the images below, showing the retreat of a glacier and the decline of sea ice in the Canadian Arctic. Brainstorm possible consequences of these changes for humans and animals.

Credit: NASA Earth Observatory

Like the vast majority of glaciers, the Gangotri Glacier in the Himalayas has shown a consistent retreat.



Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

The sea ice in the Canadian Arctic in 2012 has declined significantly compared with 30 years ago (yellow line).

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5. Over 40% of the world's population lives within 100 km of a coast. Scientists project that sea levels will rise by 0.50–1.65 m by the year 2100. Examine the flood risk map suggested by your teacher. Brainstorm consequences of sea level rise on populations and infrastructure.

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6. Your friends in central Canada tell you they aren't worried about sea level rise since they don't live near an ocean. In what ways might populations living far from a coast be affected?

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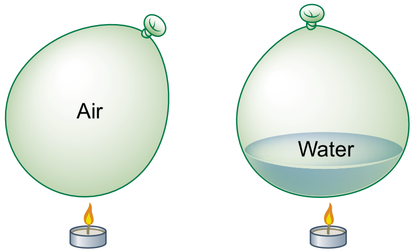
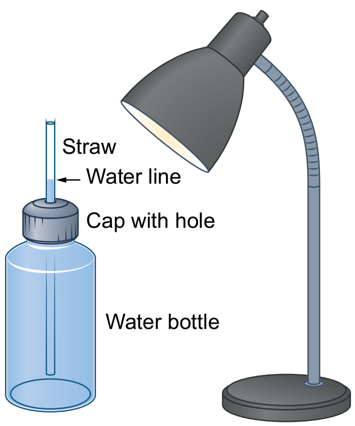
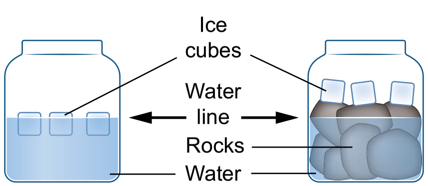
Table 1

1. Demonstration	2. Predict and Explain	3. Observe and Explain	4. Sketch a Model	5. Infer
Balloon with air and balloon with water 	*Which balloon will pop first when held over a flame? Why?*	*Observations:* *Explanation:*		*As the planet continues to warm, where will most of the additional heat be stored? In the atmosphere or in the ocean?*
Water bottle with heat source 	*What will happen to the water level in the straw as the water absorbs heat? Why?*	*Observations:* *Explanation:*		*How will the volume of the ocean change if it absorbs heat?*
Container with water and ice and container with water, rocks, and ice 	*What will happen to the water level in each container over time? Why?*	*Observations:* *Explanation:*		*How will melting land ice and sea ice affect sea levels?*

Activity 3

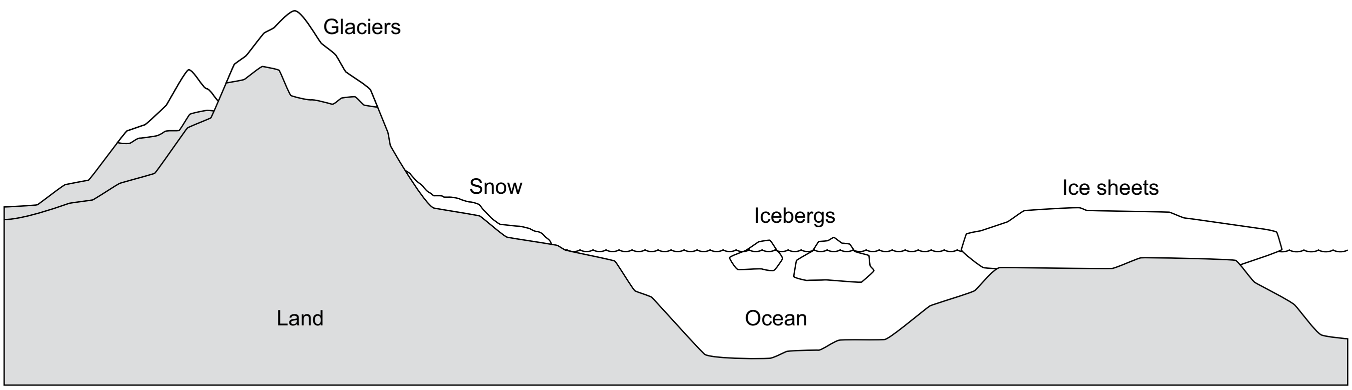
Name: ______________________ Date: ______________________

Consolidate Your Learning

Answer the following questions to check your understanding of concepts relating to the effects of climate change.

1. Some friends are discussing an article stating that the global average temperature has increased by less than a degree since 1880. They wonder whether the climate is really changing. How might you respond?

2. Examine this sketch of different types of ice. Circle the types that will contribute to sea level rise. Explain your answer in the space below.



3. How might sea level change affect you and your community? Specifically consider the financial costs to individuals. What could your community do to lessen the effects?

4. How might decreasing sea ice and rising sea levels affect Inuit communities in the far North?

Activity 4: The Impact of Transportation

Lesson Plan

Introduction

In this activity, students explore how various forms of transportation contribute to climate change through greenhouse gas emissions. They will analyze forms of transportation that they use in their daily lives, as well as commercial transportation that carries goods from one location to another. Students will reflect on their personal transportation habits and consider what changes they could make to help combat climate change.

Suggested Time: 60–70 minutes

Purpose

- To understand that cars and many other forms of transportation are significant contributors to global carbon dioxide levels
- To explore how day-to-day decisions regarding transportation can have a significant impact on carbon dioxide emissions
- To propose ways to reduce carbon dioxide emissions from cars and other forms of transportation

PRIOR KNOWLEDGE & SKILLS

- Students need to be aware of how greenhouse gases such as carbon dioxide contribute to climate change.

Materials

- Transportation Fact Cards (1 set per group; see Appendix F)

Teacher Instructions

1. If necessary, review the energy balance illustration from Activity 1 (Part 1, question 2).
2. Have students work through Part 1 of this activity, in which they will reflect on the environmental impact of their transportation habits. Discuss as a class.
3. For Part 2, divide your class into five groups and give each group a Transportation Fact Card (see Appendix F). Ask students to fill out the table in question 3 to analyze their transportation mode.
4. Reorganize students into new groups of five or six. Each group must include someone from each of the five previous groups (i.e., an "expert").
5. Choose one Transportation Scenario (see below) that is relevant to your community and describe it to the entire class. Alternatively, create your own.
6. Have each group discuss the scenario and agree on the best transportation mode according to the criteria stated in question 5. Have students record their reasoning. As a class, discuss the selections and have each group compare answers.
7. Repeat Steps 5 and 6 with more scenarios. **Note:** Scenario 5 doesn't include all of the transportation modes. If you use it, have students discuss the situation without having each student act as an expert on a particular mode.
8. Finally, have students complete Part 3, which explores the environmental costs of commercial transportation. Discuss as a class.

Transportation Scenarios

1. Ayla is a Grade 10 student who wants to go to the mall. It is 5 km away and the weather is fine. She has a bicycle. A nearby bus goes there and the closest stop is 750 m from her house. A bus comes every 15 minutes. There is also a light-rail system to the mall, and the nearest stop is 1 km away. A train comes every 10 minutes. Or, one of Ayla's parents would probably give her a ride in their gasoline-powered car.
2. Fadil is a Grade 10 student who wants to hang out with his friend Jolon. They live 2 km apart. The temperature has dropped and it's snowing. Fadil could bike or take a bus. The nearest stop is 500 m away and buses come every 20 minutes. It's likely that one of Fadil's parents would give him a ride in their new truck.

Activity 4

3. It's a beautiful day. Jane's office building is 10 km from her home. She has a bicycle that is in good repair. A light-rail system goes close to her work with the nearest stop being 2 km from her house and trains arriving every 10 minutes. It's a 1 km walk to the nearest bus stop. Buses arrive every 20 minutes. Jane owns an electric car, which charges overnight in her driveway.
4. The Choi family needs to buy groceries. The two children are ages three and five. The supermarket is 3 km away and the weather is warm and sunny. A bus goes there every 10 minutes and the closest stop is a 500 m walk from their home. It's also a 500 m walk to the train station, which is part of the community's light-rail system. Trains arrive every 5 minutes. The family recently purchased an electric car, which is charged in their parking spot.
5. Nuttah lives in a remote First Nations community in northwestern Ontario. Today it's –30°C and blustery, and she's agreed to meet her friend Mati at the school to help her get to her home 3 km away. Nuttah has two pairs of snowshoes and a snowmobile that runs well. She also owns a car and the tank is full of gas. There is no public transportation available.

Teacher Tips

- This lesson uses the jigsaw teaching strategy. For this collaborative strategy, divide your class into groups and have each student learn about a particular topic, thereby becoming an "expert." Next, reorganize students into new "jigsaw" groups that include all the different types of experts. Students then perform a task that requires expert knowledge from every group to be successfully completed.
- The lesson's most important element is how students think about the trade-offs between different options, how they justify whatever decision they arrive at, and how they collaborate. You may wish to focus on supporting your students in these areas.
- To make the scenarios richer, direct students to come up with a recommendation for the best *combination* of transportation modes to use.
- You can also modify the transportation scenarios to better resemble your community. For example, you could change the bus and/or light-rail options accordingly. Or you could add different forms of transportation that your students are interested in, such as e-bikes. Research the carbon costs and financial costs associated with these beforehand or assign students this task.
- If your students have trouble estimating the number of kilometres they travel by car each week (Part 1, question 2), direct them to electronic mapping software (e.g., Google Maps) to assist them.
- In Part 3, ask students the day before to bring in a mixture of locally made and imported items so that they can compare their carbon costs.

INQUIRY TIP

Open Inquiry: Prior to doing the activity, you can assign one of the transportation modes to each student. Have them research online to find out more about the modes, including pros and cons.

DIFFERENTIATED SUPPORT

To Engage: For students conducting research who have difficulty staying on task, provide some key websites to get them started.

STSE Connections

Climate change may adversely affect certain modes of transportation in remote communities. For example, people in Attawapiskat in northern Ontario depend on the James Bay Winter Road to bring in supplies more cheaply than via plane. Climate change may lead to this road being open for fewer days, raising the cost of living in Attawapiskat. Discuss with students how climate change may affect remote communities.

Extension

Would switching to autonomous cars reduce greenhouse gas emissions? Challenge students to explore this question through focused research and rich discussion. To facilitate robust discussion, you may wish to offer additional guiding questions such as the following: What challenges will affect the transition to autonomous cars? How would autonomous cars affect the fuel efficiency of vehicles? How would they change people's driving habits? How would they affect traffic congestion? How would they affect careers?

What's cutting edge about transportation?

Autonomous cars are driven by sophisticated computer systems without any human input, as shown in **Figure 1**. Some advantages of these cars are that they drive more efficiently and smoothly than human-driven cars. By not braking inappropriately, they improve fuel efficiency and traffic flow. Autonomous cars reduce urban traffic congestion from people driving slowly, looking for parking spots. Autonomous cars can drop off passengers, drive to a distant parking spot, and return only when needed. This is more fuel efficient than people driving around looking for spots. Some drawbacks are that people might be tempted to commute longer distances. They might take their car more often. The growing popularity of autonomous cars could lead to even more cars on the road.

Find Out More ►

To learn more about transportation and climate change before facilitating this activity, you may wish to visit the following websites:

Global Weirding: I'm Just One Person, What Can I Do?
https://www.youtube.com/watch?v=Q48BvprCFr0

High-Impact Actions for Individuals to Reduce Greenhouse Gas Emissions
http://www.kimnicholas.com/responding-to-climate-change.html

Transport Canada
https://www.tc.gc.ca/eng/programs/environment-programs-index.htm

Figure 1 Autonomous cars allow people to read or work during their daily commute. It is unclear how autonomous cars will affect greenhouse gas emissions.

Activity 4

Name: ______________________ Date: ______________________

Student Activity

The Impact of Transportation

Science Background

According to a recent study, transportation represents 23% of Canada's greenhouse gas emissions. In this activity, you will explore what effects your transportation choices have on the environment.

Part 1: Transportation and the Environment

1. What effects do cars and other forms of transportation have on the environment?

Direct Effects	Indirect Effects

2. An average car emits 250 g of carbon dioxide per kilometre. Estimate the number of kilometres you travel by car each week. An average tree absorbs 50 g of carbon dioxide each week. How many trees are required to absorb the carbon dioxide from your personal transportation footprint weekly?

3. What are three frequent trips that you take using a car or some other type of transportation? (Walking counts as a type of transportation.)

4. What factors do you consider when deciding which mode of transportation to use? Rank them in order of importance.

Name: ______________________________ Date: ______________________________

Part 2: Transportation Scenarios

1. Form a group of five or six.

2. Read the Transportation Card that your teacher gives you.

3. Discuss the information on your card and fill in the table below.

   My mode of transportation: ________________

   Information About My Transportation Mode

Pros	Cons	Level of Convenience	Cost	Environmental Impact

4. Form a new mixed group of five that includes an “expert” for each mode of transportation.

5. Carefully listen to the scenario that your teacher outlines. Which mode of transportation should the person take? Your group must discuss the different options and decide which mode is best based on the following criteria: environmental impact, convenience, cost, and safety concerns.

   Mode of transportation chosen: ______________________

   Justification:

   ____

   ____

   ____

   ____

   ____

6. What is one regular trip you take that could be replaced with a more environmentally friendly form of transportation? Explain.

   ____

   ____

   ____

   ____

Activity 4

Name: ______________________________ Date: ______________________________

Part 3: Commercial Transportation

Commercial transportation contributes to high levels of carbon dioxide in the atmosphere. But trucks deliver goods, such as food and building materials, that people need.

1. Examine three products you are wearing or carrying. Complete the chart.

Country of Manufacture and Mass of Consumer Products

Product	Type of Product	Country of Manufacture	Estimated Mass of Product (kg)
Product 1			
Product 2			
Product 3			

2. Using a paper or digital map, estimate how far each product travelled to reach you. Assume the products took the shortest routes. Write your answers in columns 2, 3, and 4 of the table below.

Carbon Dioxide Cost for Sea, Land, and Air Transportation

1. Product	2. Sea Distance (km)	3. Land Distance (km)	4. Air Distance (km) (Column 2 + Column 3)	5. Amount of Carbon Dioxide, Sea + Land Travel (g)	6. Amount of Carbon Dioxide, Air Travel (g)
Product 1					
Product 2					
Product 3					

3. Using the information below, estimate the amount of carbon dioxide emitted in delivering the products to you by sea and land. Write your answers in column 5.
   - Carbon dioxide emitted per kilometre of sea travel via container ship for every kilogram of mass = 0.0084 g
   - Carbon dioxide emitted per kilometre of land travel via commercial transport truck for every kilogram of mass = 0.062 g

4. Repeat question 3, assuming the products came by air the entire way. Set the carbon dioxide emission per kilometre of air travel at 0.60 g for every kilogram of mass. Write your answers in column 6.

5. What are some ways to decrease your carbon dioxide impact related to commercial transportation?

____

____

____

Name: ______________________ Date: ______________________

Consolidate Your Learning

Answer the following questions to check your understanding of concepts relating to the impact of transportation on climate change.

1. What impact do cars have on the environment compared with other types of transportation? Explain.

2. What could you change to reduce your own contribution to greenhouse gas emissions?

3. How does commercial transportation contribute to climate change?

4. How have your ideas about getting around changed as a result of discussing the scenarios? What key points or arguments made you change your mind?

5. Computer navigation applications only list the travel times to a destination for particular modes of transportation (e.g., walking, biking, and driving). Outline a design for a navigation application that includes the environmental cost of each transportation mode.

Sample screenshot of a mapping application

Activity 5

Activity 5: How Much Carbon Is in That Tree?

Lesson Plan

Introduction

In this activity, students calculate the height of a tree near their school using right-triangle trigonometry. Then, using the calculated height and the radius of the tree, students calculate the amount of carbon and carbon dioxide the tree has stored. A look at their own yearly carbon dioxide footprint then gives this number some perspective.

Suggested Time: 60–75 minutes

Purpose

- To calculate the height of inaccessible objects by first measuring distances and angles and then using right-triangle trigonometry
- To solve problems involving volumes of three-dimensional objects
- To lend perspective to the magnitude of one's carbon footprint by calculating the amount of carbon dioxide stored in a tree

PRIOR KNOWLEDGE & SKILLS

- Students need to know how to use right-triangle trigonometry to calculate the length of a side of a right triangle given one side and the measure of another angle.
- If using a clinometer, students need to know how to measure an angle using a protractor.
- Students need to be able to measure lengths and distances with a measuring tape in metres, to two decimal places.

Materials

- video about trees and mass (optional), for example, *Where Do Trees Get Their Mass From?* (4 minutes)
- Calculations Used for My Yearly Carbon Dioxide Footprint (1 per group; Appendix G) or an online carbon footprint calculator.
- calculator
- 30 m measuring tapes
- clinometers
  - **Option A: spirit level app***
    - available on iPhones as a second page with the compass app, or download an app such as "iHandy Level" (iPhone, iPad, iPod Touch) or "Clinometer + Bubble Level"(Android)*
    - smartphone needed for this option
  - **Option B: student-made clinometers**
    - binder clips, washers, or other weighted objects
    - protractors or photocopy of protractor mounted on cardboard
    - spool of fishing line or string—20 cm per clinometer
    - scissors
- clear tape
- drinking straws

Teacher Instructions

1. The day before, organize students into groups of four. Ensure that at least one student with a smartphone is in each group. Instruct students to check that they have one of the free spirit level apps listed in Materials. Have students tape a straw to one edge of their smartphone to act as a sight.

   Alternatively, have students make a clinometer using the following steps (see **Figure 1**):

   - Attach a binder clip (or other weight) to one end of a 20 cm length of fishing line or string.
   - Attach a protractor to the other end of the string by applying clear tape to one side. The pivot point of the string must be exactly where the 0° and 90° lines meet.
   - Tape a drinking straw along the 90° line on the protractor to use as a sight.

* Perimeter Institute neither created nor endorses these apps.

Users will hold the protractor with the flat side pointed away and sight an object through the straw. The weighted line will hang down and the string will indicate either the angle of elevation or the angle of depression of the object sighted.

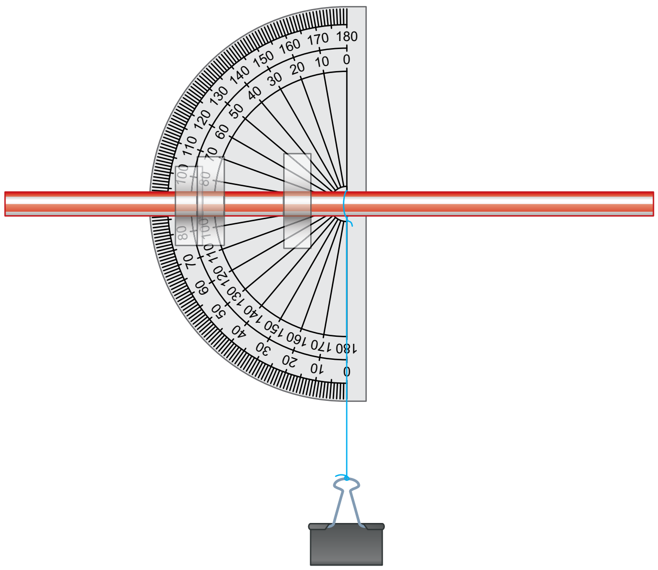


Figure 1 Student-made clinometer

2. To get the class thinking about how carbon dioxide can be stored in trees, you may wish to show the Veritasium video *Where Do Trees Get Their Mass From?*
3. On the day of the activity, distribute the student activity sheets. (See Teacher Tips for details about choosing Sheet 1 or Sheet 2.) Each group of four will need a 30 m measuring tape. Have groups assign one student to take notes, two students to take length measurements, and a fourth student to make the observations through the straw.
4. Outdoors, have students select a large tree to measure. They'll need to choose a location from which they can clearly see the top of the tree. Tell students they should be able to measure the distance from themselves to the tree, along flat ground. Ask students to take the required measurements.
5. Once the height of the tree has been calculated, have students measure the circumference (in centimetres) of the trunk at a height of 1.30 m above the ground.
6. The calculations that follow in the student activity sheets help them use height and radius measurements to estimate the tree's mass, and then to use the mass to estimate the mass of carbon in the tree. Finally, they will estimate the mass of carbon dioxide that the tree has stored.
7. Once students have completed Parts 1–3, return to the classroom. Have students estimate their carbon dioxide footprint using Part 4 or an online carbon footprint calculator. Calculations Used for My Yearly Carbon Dioxide Footprint (see Appendix G) provides the calculations used to determine the factor in Part 4. You may wish to help students estimate some of the data.

Activity 5

SAFETY ALERT

During your trip outside, take note of any bee, pollen, or environmental allergies among students in your class, and take the necessary precautions.

Teacher Tips

- Two sets of the student activity sheets are provided. Sheet 1, suitable for applied-level classes, provides step-by-step instructions and has a simplified height calculation. Sheet 2, suitable for academic-level classes, provides less scaffolding, has a two-triangle SOHCAHTOA height calculation, and has students do some formula rearranging. Part 4 and the Consolidate Your Learning activity can be used with all classes.
- If no trees are nearby, students in an applied class could be given the following data to use with Sheet 1. (The sample answers given for Sheet 1 correspond to this data.)

  From a distance of 27 m, the angle of elevation to the top of an oak tree is 32°. The observer's eye is 1.69 m from the ground and the circumference of the tree at a height of 1.30 m up the trunk is 103 cm.
- If no trees are nearby, students in an academic class could be given the following data to use with Sheet 2. (The sample answers given for Sheet 2 correspond to this data.)

  An observer measures the angle of inclination to the top of an oak tree to be 32°, the angle of depression to be about 4°, and the horizontal distance to the tree to be 27 m. The circumference of the tree at a height of 1.30 m up the trunk is 103 cm.

Career Connections

Collecting data is a big part of the job of a forestry technician. Consider having students conduct research to find out more about what they do and what education and training is required.

INQUIRY TIP

Estimating: The many free online carbon footprint calculators vary greatly in the amount of input required. Part 4, the final part of the activity, has students estimate the carbon dioxide that they generate. Tell students that this algorithm greatly underestimates a full carbon footprint. Ask them to consider why. You may wish to have students compare their results with those of an online tool.

DIFFERENTIATED SUPPORT

To Assist: Before going outside, some students, especially ELL students, may need clarification of what "angle of elevation" means and where it would appear in the right triangle. Model how to measure lengths in metres to two decimal places.

To Engage: Pair students who struggle making calculations with students who have stronger math skills. Have students who are struggling try the task first. Next have the other students perform the task. Observing how calculations are done, and getting clarification from their peers, bolsters student engagement.

Extension

A more challenging activity for students is to find the height of a tree as shown in **Figure 2**. The first step is to measure the angle of inclination of the top of the tree and the distance from the observer's eye to the ground from some point on the ground level with the base of the tree. Then the observer moves a measured distance (e.g., 20 m) directly away from the tree and again measures the tree's angle of inclination.

Using this data, the height of the tree can be calculated.

Find Out More ►

To learn more about trees and their carbon-capturing abilities before facilitating this activity, you may wish to visit the following websites:

Calculate Your Carbon Footprint and Reduce Your Impact
https://www.conservation.org/act/carboncalculator/calculate-your-carbon-footprint.aspx#/

Ecological Footprint
http://www.myfootprint.org/

National Tree Benefit Calculator
http://www.treebenefits.com/calculator/

Natural Resources Canada: Forest Carbon
http://www.nrcan.gc.ca/forests/climate-change/forest-carbon/13085

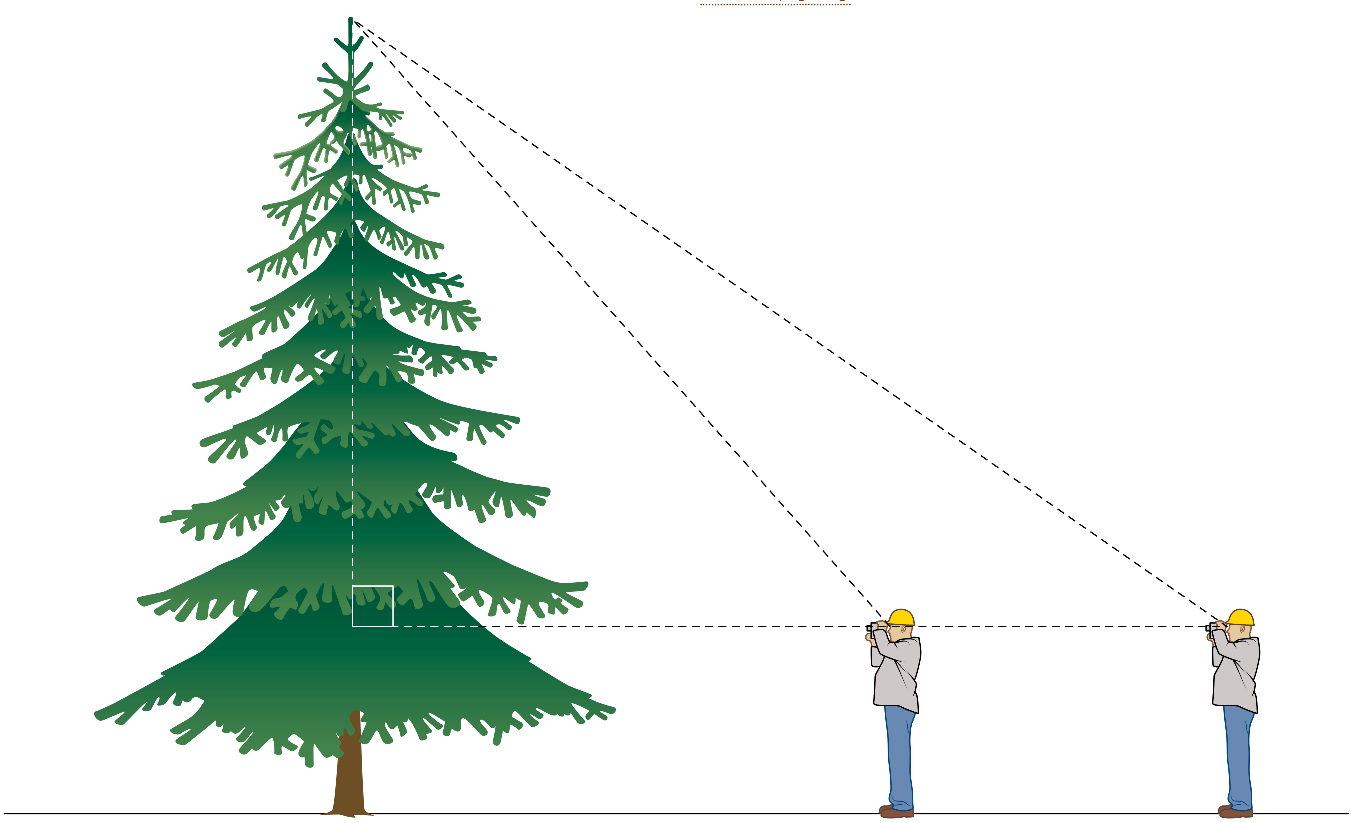


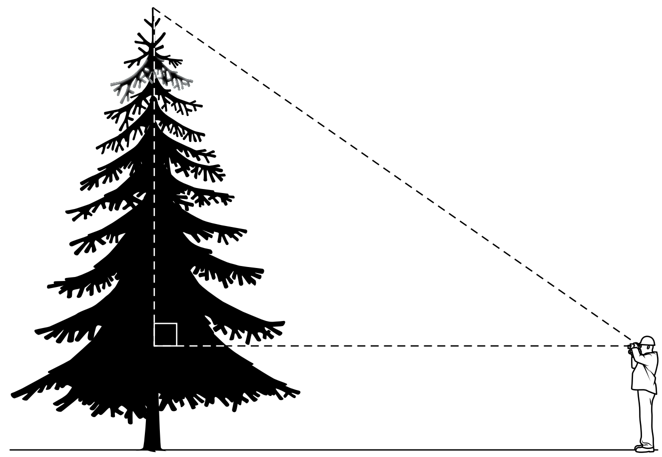
Figure 2 This illustration shows how a forestry technician can use a two-triangle method to find the height of a tree.

Name: ____________________ Date: ____________________

Student Activity–Sheet 1

How Much Carbon Is in That Tree?

Part 1: Calculating the Height of the Tree



1. Measure the following:
   (a) distance from observer to tree (in metres to two decimal places)

   (b) angle of elevation of the top of the tree (to the nearest degree)

   (c) distance from the ground to the observer's eye (to two decimal places)

2. (a) Add your measurements to the illustration on the right.
   (b) Calculate the height of the tree in metres (to one decimal place)

Part 2: Calculating the Size of the Tree

The shape of a tree changes with its height. Most of the mass of the tree is in its trunk, but some is in its branches and roots. To approximate the volume of a tree, we will treat it as a cylinder. The volume of a cylinder is given by the formula $V = \pi r^2 h$.

A tree trunk tapers, so measuring its circumference at the bottom will give a value that is too big. By convention, foresters use the circumference measured 1.30 m above the ground to provide a good approximation of the radius of the trunk (i.e., the cylinder).

1. Measure the circumference of the tree trunk in centimetres at a height of 1.30 m up the trunk. Round to the nearest centimetre.

   $C =$

2. Calculate the radius of the trunk of the tree at this height. Remember that $C = 2\pi r$, where C is the circumference in centimetres, r is the radius in centimetres, and π is about 3.14. We can rearrange this equation to get

   $$r = \frac{C}{2\pi}$$
   $$=$$

3. Convert this to metres. Round your answer to two decimal places.

   $r =$

Activity 5

Name: ______________________________ Date: ______________________________

Part 3: Calculating the Mass of Carbon Dioxide Trapped by the Tree

1. Calculate V, the volume of the tree (in cubic metres, m^3) using the formula $V = \pi r^2 h$, where r is the radius of the tree in metres, h is the height of the tree in metres, and π is about 3.14.

   $V = \pi r^2 h$

   $V =$

2. Calculate the mass of the tree (in kilograms) using the following densities for wood:
   - hardwood (e.g., oak, maple, poplar) is about 700 kg/m^3
   - softwood (e.g., pine, cedar) is about 400 kg/m^3

   mass =

   Since about 20% of a tree's mass is in its roots, multiply this by 1.25 to better approximate the mass.

   mass =

3. About 65% of a tree is solid matter and about 50% of the solid matter is carbon. Calculate the mass of carbon in the tree (in kilograms) using the equation

   $\textit{mass of carbon} = \textit{mass} \times 0.65 \times 0.50$

   $=$

4. Thus,

   $\textit{mass of } CO_2 \textit{ trapped} = \textit{mass of carbon} \times 3.67$ (See below for explanation.)

   $=$

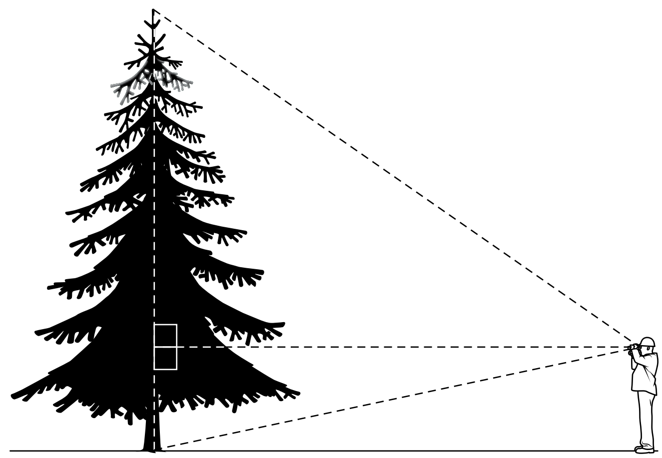
Ratio of Mass of Carbon Dioxide to Mass of Carbon
Carbon has an atomic mass of 12 u (atomic mass units).
When one carbon atom is combined with two oxygen atoms (each with an atomic mass of 16 u), the carbon dioxide molecule has a mass of 12 u + (16 u × 2) = 44 u.
Thus, the mass of carbon dioxide captured is actually $\frac{44\text{ u}}{12\text{ u}}$ or about 3.67 times the mass of carbon in the tree.

Name: ______________________________ Date: ______________________________

Student Activity–Sheet 2

How Much Carbon Is in That Tree?

Part 1: Calculating the Height of the Tree



1. Select a tree. Find a location from which the observer can see the top and the base of the tree. Using a measuring tape, measure the horizontal distance to the tree from this spot.

2. The observer uses a clinometer or level app on a smartphone to measure the angle of elevation of the top of the tree and the angle of depression of the base of the tree.

3. Record the three measurements from questions 1 and 2 on the diagram on the right.

4. Calculate the height of the tree. Round your answer to the nearest tenth of a metre.

Part 2: Calculating the Size of the Tree

The shape of a tree changes with its height. Most of the mass of the tree is in its trunk, but some is in its branches and roots. To approximate the volume of a tree, we will treat it as a cylinder. The volume of a cylinder is given by the formula $V = \pi r^2 h$.

A tree trunk tapers, so measuring its circumference at the bottom will give a value that is too big. By convention, foresters use the circumference measured 1.30 m above the ground to provide a good approximation of the radius of the trunk (the cylinder).

1. Measure the circumference of the tree trunk in centimetres at a height of 1.30 m up the trunk. (**Note:** Round to the nearest centimetre.)

   $C =$

2. Calculate the radius of the trunk of the tree at this height. Remember that $C = 2\pi r$, where C is the circumference in centimetres, r is the radius in centimetres, and π is about 3.14. (You'll need to rearrange this equation.)

   $r =$

3. Express your result in metres. Round your answer to two decimal places.

   $r =$

Activity 5

Name: ______________________ Date: ______________________

Part 3: Calculating the Mass of Carbon Dioxide Trapped by the Tree

1. Calculate V, the volume of the tree (in cubic metres, m^3) using the formula $V = \pi r^2 h$, where r is the radius in metres, h is the height of the tree in metres, and π is about 3.14.

   $V =$

2. Calculate the mass of the tree (in kilograms) using the following densities for wood:
   - hardwood (e.g., oak, maple, poplar) is about 700 kg/m^3
   - softwood (e.g., pine, cedar) is about 400 kg/m^3

   mass =

   Since about 20% of a tree's mass is in its roots, multiply your result by 1.25 to better approximate the mass:

   mass =

3. About 65% of a tree is solid matter, and about 50% of the solid matter is carbon. Calculate the mass of carbon in the tree (in kilograms) using the equation

   $$\begin{aligned} \textit{mass of carbon} &= \textit{mass} \times 0.65 \times 0.50 \\ &= \end{aligned}$$

4. Finally, carbon has an atomic mass of 12 u. When one carbon atom is combined with two oxygen atoms (each with an atomic mass of 16 u), the carbon dioxide molecule has a mass of 12 u + (16 u × 2) or 44 u. Thus, the mass of carbon dioxide captured is actually $\frac{44\ \text{u}}{12\ \text{u}}$ or about 3.67 times the mass of carbon in the tree:

   $$\begin{aligned} \textit{mass of } CO_2 \textit{ trapped} &= \textit{mass of carbon} \times 3.67 \\ &= \end{aligned}$$

Activity 5

Name: ______________________________ Date: ______________________________

Part 4: My Yearly Carbon Dioxide Footprint

Let's estimate how much carbon dioxide you produce in a year.

A: Breathing

Just breathing, you produce about 1 kg of carbon dioxide each day.

365 kg of CO_2/year **(A)**

B: My Trip to School

Transportation is a major source of carbon dioxide.

Round-trip distance from your home to the school and back to your home is _______ km.

Choose one of the modes of transportation and enter the distance from above.

	Annual Carbon Dioxide Contribution Based on Method of Transportation and the Distance Between School and Your Home	Annual Carbon Dioxide Contribution Due to Transportation
Car	______ km × 47.7 kg of CO_2/km =	_____ kg of CO_2 **(B)**
Bus	______ km × 5.24 kg of CO_2/km =	
Bicycle	______ km × 0.00 kg of CO_2/km =	
Walking	______ km × 0.00 kg of CO_2/km =	

C: Electricity

Burning fossil fuels to produce electricity is a major source of carbon dioxide.

Electricity Use from Technologies

	# of Hours Actively on per Day (h)	Annual Carbon Dioxide Contribution Based on Power Consumption and Efficiency of Electricity Generation	Total Annual Carbon Dioxide Contribution Due to Technology
Television		× 1.50 kg of CO_2/hour = ______ kg of CO_2 (C1)	(C1) + (C2) + (C3) = _____ kg of CO_2 **(C)**
Desktop computer		× 12.3 kg of CO_2/hour = ______ kg of CO_2 (C2)	
Laptop computer		× 4.90 kg of CO_2/hour = ______ kg of CO_2 (C3)	

Activity 5

Name: ______________________________ Date: ______________________________

D: Electricity Used to Heat Water

	# of Showers/ Baths per Week	Annual Carbon Dioxide Contribution Based on Amount of Water Used and Water Heater Efficiency	Annual Carbon Dioxide Contribution Due to Heating Water
Showers		× 30.2 kg of CO_2/shower = ______ kg of CO_2 (D1)	(D1) + (D2) = _____ kg of CO_2 **(D)**
Baths		× 58.5 kg of CO_2/bath = ______ kg of CO_2 (D2)	

E: Electricity Used for Lighting

Estimate the number of light bulbs in your own room.

	# of Hours Actively on per Day (h)	# of Hours for Each Type of Light Bulb	Annual Carbon Dioxide Contribution Based on Power Consumption of Type of Light Bulb	Annual Carbon Dioxide Contribution Due to Lighting
Regular light bulbs		× ___ bulbs = ___ hours	× 4.9 kg of CO_2/hour = _____ kg of CO_2 (E1)	(E1) + (E2) = _____ kg of CO_2 **(E)**
Energy-efficient light bulbs		× ___ bulbs = ___ hours	× 0.7 kg of CO_2/hour = _____ kg of CO_2 (E2)	

Estimate of My Annual Carbon Dioxide Footprint

(A) + (B) + (C) + (D) + (E) = ____________ kg of CO_2

Name: ____________________ Date: ____________________

Activity 5

Consolidate Your Learning

Answer the following questions to check your understanding of concepts relating to your carbon footprint.

1. The average Canadian has a carbon dioxide footprint of about 20 000 kg of carbon dioxide each year! How many of your trees would be needed to represent this amount of carbon dioxide?

2. If you wanted to do a more complete analysis of your carbon dioxide footprint, what other sources of greenhouse gases should you include?

3. In Canada, an acre of mature trees can store the equivalent of 2600 kg of carbon dioxide per year. How many acres of trees would be needed to offset your carbon dioxide footprint?

4. How does your electricity use add carbon dioxide to the environment?

5. Storing carbon dioxide is one approach to the problem of greenhouse gases. Another is to reduce the amount produced. Emerging technologies can help. Rooftop solar panels can generate electricity for a household when it needs it and channel any unused electricity back into the grid.

   (a) A typical rooftop installation of solar panels produces about 3360 kWh of electricity per year and the average home uses about 972 kWh per month. What percent of the household's electricity use would this installation supply?

   (b) Electricity generation in Ontario creates about 0.053 kg of carbon dioxide per kilowatt hour (kWh). How many kilograms of carbon dioxide would this solar panel installation keep from being produced each year?

   (c) Why would it be difficult to supply a home's electricity needs with solar panels?

Activity 6

Activity 6: When Does It Make Sense to Switch?

Lesson Plan

Introduction

In this activity, students model costs related to the purchase and use of two household products. They use the skills developed to solve linear systems of equations to make informed economic decisions. They also model the economic and environmental impact of their decisions.

Suggested Time: 60–75 minutes

Purpose

- To practise manipulating and solving algebraic equations in realistic situations
- To model and solve problems involving the intersection of two linear relations using data from realistic situations
- To solve problems described in words arising from realistic situations, and to interpret these solutions to make an informed decision

PRIOR KNOWLEDGE & SKILLS

- Students need to be familiar with solving linear systems by graphing, substitution, or elimination.
- Students need to be familiar with writing equations that describe relations that are partial variations.
- Some students may need to be reminded how to calculate a price including 13% tax.

Materials

- video about electric cars (optional), for example, *Why Norway Is Full of Teslas*
- calculators or graphing software
- whiteboards to facilitate group work (optional)

Teacher Instructions

1. If desired, show a video about electric cars.
2. Engage students in a discussion about what kind of car they would like to buy in the future. Ask, "Would you buy an electric vehicle? Why or why not? What are the factors influencing your decision? In our community, do we see many electric vehicles on the road? Why or why not?"
3. Distribute student activity sheets to each student. As a class, you may wish to brainstorm pros and cons before continuing with the rest of the questions.
4. Have students form groups of two or three. You may wish to let students choose their own method to solve these systems of equations. Alternatively, prescribe a particular method (e.g., by substitution, elimination, or graphically with software such as Desmos).
5. Circulate among the groups as they work, troubleshooting where necessary.
6. Upon completion, have students reflect on what they've learned. Ask whether their opinion about owning an electric vehicle has changed. If not, what would make them change?

Teacher Tips

- In the optional video, the major issues related to electric vehicle (EV) ownership are discussed up to the 4:42 point. The remainder is not essential.
- If time is short in class, assign Part 3, questions 1–3 and Consolidate Your Learning as homework.
- Students may need some prompting to consider range, availability of charging stations, speed of charging, difficulty charging (e.g., if they live in an apartment building), etc.
- Some classes, especially applied, may find it easier to solve the systems generated by these problems by using graphing software, such as Desmos. Graphing will also allow students to see the differences in costs

associated with both types of vehicles. Students may also solve algebraically and check their solutions using graphing software.

- Students may need practice writing equations describing partial variations. Practice examples might include the cost of a pizza with *n* toppings or the cost of a taxi ride of *d* kilometres.

INQUIRY TIP

Collaboration: Pairing students, or grouping them to work at whiteboards, will allow students to share ideas and problem solve together. Having groups present their solution to the rest of the class and field questions will develop students' communication skills.

DIFFERENTIATED SUPPORT

To Assist: Ask groups leading questions and assess student understanding of the problem even if the algebra involved proves difficult. A word wall with definitions may help ELL students with some new vocabulary.

To Enrich: Rather than providing all the numbers, you may wish to omit some information from the table and have students add statistics and costs by conducting research (e.g., the average price of gas in the last year, or how much electricity is used per 100 km).

Extension

When the video *Why Norway Is Full of Teslas* was made, the average price of gas in Norway was $2.45/L, and the price of electricity was about $0.15/kWh. A high-end electric car cost about $92 000 and a compact gas-powered car cost about $45 000, all in Canadian dollars. The electric car is rated at 20.8 kWh/100 km and the standard car is rated at 7.5 L/100 km.

1. Ask students what the break-even point for purchasing the electric vehicle over the gas vehicle is if they ignore all the other incentives (free parking, free charging, waiving of the congestion tax, free use of the HOV lanes, income tax deduction etc.), which are offered in Norway. *(308 000 km)*
2. After they calculate the break-even point above, ask students why the government of Norway would offer so many incentives to switch to an electric car.

STSE Connections

Mathematics is a powerful tool for modelling real-world problems and helping people make decisions. Have students explore and discuss why some cities are choosing to add EV charging stations in recreation centre parking lots at great expense. How do mathematical calculations influence this kind of decision?

Find Out More ►

To learn more about electric vehicles and the environmental effects of economic consumption before facilitating this activity, you may wish to visit the following websites:

CBC Radio: Why electric vehicles are still out of reach for some Canadians
http://www.cbc.ca/radio/checkup/blog/why-electric-vehicles-are-still-out-of-reach-for-some-canadians-1.4229704

Global News: Buying an electric car?
https://globalnews.ca/news/3583146/electric-cars-canada-what-to-know/

Union of Concerned Scientists: In-depth analysis of the topic of electric vehicles versus gasoline-powered vehicles from a number of standpoints in the United States
https://www.ucsusa.org/clean-vehicles/electric-vehicles/ev-fuel-savings#.Wl5V_ahKtaR

University of California: Carbon Neutrality Initiative—Climate Lab
https://www.universityofcalifornia.edu/climate-lab

Name: ______________________________ Date: ______________________________

Activity 6

Student Activity

When Does It Make Sense to Switch?

Part 1: Pros and Cons

1. In your group, discuss and record the pros and cons of owning each type of car:

Gasoline-Powered Car		**Electric Car**	
Pros	**Cons**	**Pros**	**Cons**

2. In Canada, Tarika's family must decide between buying an electric car and a similar gasoline-powered car. A car manufacturer makes a car that is available in both types. Tarika has made a chart to compare information about the costs associated with each type of vehicle:

	Gasoline-Powered Car	**Electric Car**
Market price	$17 928 plus 13% tax	$36 848 plus 13% tax
Additional costs	–	$1700 for purchase and installation of a charger (tax included)
Base Cost:	____________	____________
Expenses per kilometre	This car is rated at 9.3 L of gas per 100 km of driving. Over the past year, the average price of gas in Tarika's province was $1.12 per litre.	This car uses the equivalent of 19.6 kWh of electricity per 100 km of driving. The average cost of electricity is $0.1003/kWh in Tarika's province.
Average Cost per Kilometre of Driving: (round to three decimal places)	____________	____________
Total Cost Equation: (Let *C* represent cost and *d* represent distance driven in kilometres.)	***C*** **= ________ + ________ *d***	***C*** **= ________ + ________ *d***

Part 2: Dollars and Sense

1. After how many kilometres of driving will the cost of the electric and the gas vehicle be the same? (Round to the nearest thousand kilometres.)

2. Tarika does more research and finds that her family is eligible for a $14 000 rebate if they buy the electric vehicle, and a $1000 rebate to cover the cost of the charging station. With the rebates applied after taxes, what is the new Total Cost Equation for the electric vehicle?

Name: ______________________________ Date: ______________________________

3. Consider a 20¢/L increase in the price of gas. Which number in the Total Cost Equation for the gas-powered car would change as a result of this price increase? With this increase in gas price, what is the new Total Cost Equation for the gas-powered car?

4. With the rebates and the increase in gas price in effect, after how many kilometres of driving will the cost of the electric and the gas vehicle be the same? (Round to the nearest thousand kilometres.)

5. What effect did these changes have on the point at which the cost of the electric and the gas-powered vehicle are the same?

6. The average Canadian drives about 20 000 km per year. Based on your answer from question 5, how long would it take the average car owner to reach the point where the cost of the electric and the gas vehicle are the same?

7. At what point would it make sense for you to choose an electric vehicle over a gas vehicle?

Part 3: Carbon Dioxide Production

Consider the effects of the production of carbon dioxide (CO_2) for each type of vehicle:

1. An electric vehicle uses 19.6 kWh/100 km. It's operated in a province where electricity on average generates 0.225 kg of CO_2 per kWh of electricity. After 100 000 km of driving, how many kilograms of carbon dioxide has this vehicle indirectly produced?

2. Burning gasoline produces 2.31 kg of CO_2 per litre of gasoline burned. A gas vehicle burns gasoline at a rate of 9.3 L/100 km. After 100 000 km of driving, how many kilograms of carbon dioxide has this vehicle directly produced?

3. What policies or programs might a government use to encourage Tarika's family to be more concerned about the carbon dioxide that their personal transportation produces?

Activity 6

Name: ______________________ Date: ______________________

Consolidate Your Learning

Answer the following questions to check your understanding of linear systems as they apply to making informed economic and environmental decisions.

1. Tarika's family has an old refrigerator. The EnerGuide sticker says it uses 1540 kWh of electricity each year. A new fridge (same size) uses about 395 kWh of electricity each year and costs $1350 plus 13% tax. In addition, there is a $49.95 delivery charge (on which there is no tax).

	Old Fridge	**New Fridge**
Market price	–	$1350 plus 13% tax
Additional costs	–	$49.95 delivery charge
Base Cost:	______________	______________
Electricity costs	Uses 1540 kWh per year to run, and the average cost of electricity is $0.1003/kWh in Tarika's province	Uses 395 kWh per year to run, and the average cost of electricity is $0.1003/kWh in Tarika's province
Electricity Cost per Year: (to two decimal places)	______________	______________
Total Cost Equation: (Let *C* represent cost, and *n* represent # of years used)	***C*** **= _______ + _______ *n***	***C*** **= _______ + _______ *n***

After how many years will buying the new refrigerator be cheaper than using the old one? (Round to the nearest tenth of a year.) ______________________

2. In considering the purchase of the new fridge, Tarika and her family are also thinking about the greenhouse gas emissions. The carbon dioxide created from the generation of electricity is about 0.225 kg/kWh in Tarika's province, and about 325 kg of CO_2 is emitted in the production and shipping of a new fridge.

	Old Fridge	**New Fridge**
Carbon dioxide generated in manufacturing and shipping fridge	–	325 kg
Initial Carbon Dioxide:	______________	______________
Carbon dioxide from electricity used	Uses 1540 kWh per year, and 0.225 kg of CO_2 per kWh is created from generating electricity in Tarika's province.	Uses 395 kWh per year, and 0.225 kg of CO_2 per kWh is created from generating electricity in Tarika's province.
Carbon Dioxide from Electricity Used Each Year:	______________	______________
Total Carbon Dioxide Equation: (Let *C* represent carbon dioxide and *n* represent # of years used.)	***C*** **= _______ + _______ *n***	***C*** **= _______ + _______ *n***

After how many years will the carbon dioxide emissions generated by the old fridge and the new fridge be equal? (Round to the nearest tenth of a year.) ______________

3. Consider other home products. For which ones does it make sense to calculate the total cost of energy before deciding which model to buy?

____

Design Challenge: Climate in a Container

Lesson Plan

Introduction

In this activity, students design and create a miniature model climate to explore natural and anthropogenic factors that lead to climate change. Students then use their models to determine which factors cause the highest temperature increase in a container. Students also investigate cooling and consider how well their design models phenomena in their local environment as well as Earth's climate.

Suggested Time: 70–90 minutes

Purpose

- To model natural and anthropogenic factors that lead to climate change
- To propose realistic steps and present ideas to help combat climate change

PRIOR KNOWLEDGE & SKILLS

- Students need to be able to measure temperatures accurately with a thermometer.
- Students should understand natural phenomena and human activities known to affect climate.

Materials

- identical containers (1 per group; roughly the size of 2 L pop bottles)
- incandescent lamps or heat lamps (1 per group; higher wattage is better)
- thermometers (1 per group)
- various materials—refer to Step 4 of Teacher Instructions for more details (e.g., light sand and dark soil; rocks, stones, sand, moist soil, water; baking soda and vinegar; banana peels, apple cores, lettuce)

Teacher Instructions

1. Choose a container type, such as 2 L pop bottles or large resealable freezer bags. Recall that most types of glass absorb mid- and far-infrared radiation and will block a lot of thermal energy before it reaches the student-designed climates. Consider your classroom setup and what would work best.
2. Well in advance, start sourcing or collecting containers, lamps, and climate materials.
3. Choose experimental conditions. For example, you might specify that climate models be placed 10 cm away from a 100 watt incandescent light bulb for 10 minutes, with the temperature of the model to be measured at the end. Share these conditions with students ahead of time. Decide whether to make this challenge an individual or group assessment. Consider available materials and time constraints.
4. Provide many options for materials, such as lighter and darker materials for the albedo effect (e.g., white cloth, black cloth), different liquids for moderating effects (e.g., 2% milk, water, salt water), and organic materials (e.g., vegetable peelings) or common chemicals (e.g., baking soda, salt, vinegar) for greenhouse gas creation.
5. When students have finished building their miniature climate models, have them conduct their test according to the experimental conditions you have specified. Be sure that students measure the temperature of the *air* in the container. The thermometer should not be in contact with the container or any of the materials in the container. Consider using a retort stand and clamps to suspend the thermometer. **CAUTION:** Review safety rules for using a heat source.
6. After students compare results, lead a discussion of ways to reduce and mitigate the heating of the extreme climates (i.e., the climate models that had the greatest increases in temperature). Then pivot the discussion to what these changes would look like for Earth's current climate. Some ideas will be pragmatic, others more far-fetched. All discussion is good!

SAFETY ALERT

Remind students that lamps can cause burns. Tell students to handle heat sources with care. When using chemicals to produce carbon dioxide, ensure that pressure doesn't build in containers, causing projectiles or explosions. Gauge student designs for dangers such as sharpness, built-up pressure, and instability. Caution students about tools and materials that could be dangerous.

Teacher Tips

- You may wish to review a design process with students. Use the process outlined in your curriculum or another of your choosing, such as this engineering design process from NASA.
- Consider using this activity as an assessment for learning (diagnostic) by having students design their climate models on notepaper before beginning the module, explaining their reasoning for including various materials. After the module, students can revisit and revise their designs, explaining how their thinking changed as a result of their learning in the module.
- Consider allowing students to bring materials from home for their models. Provide guidelines (e.g., no candles).
- The consolidation of this activity involves students writing a letter or an email to a politician or creating a social media post. You might check with an English teacher to see if this task could be integrated into an English lesson or used as a literacy test activity.

INQUIRY TIP

Open Inquiry: Have students test the effect of a single variable change by setting up a control model and an experiment model in which one variable is changed. (For example, a material could be added or removed.) By comparing the results of several of these tests, students can determine which changes make the most difference to the model's atmospheric temperature.

DIFFERENTIATED SUPPORT

To Support: For group work, ensure that a range of abilities is present and that each group member has specific responsibilities. This will allow students to help each other when confusion arises but also ensure that no one student is carrying the bulk of the work. You may wish to prompt some ideas for students or groups who are struggling.

Extension

Have students dig deeper into global effects of climate change by having them research the climate of Venus, Mars, or Titan. Each of these celestial bodies has a unique climatory evolution with different forcing factors. Students can create a poster or presentation to share what they learn.

STSE Connections

The Intergovernmental Panel on Climate Change is the world's foremost group of climate scientists. In its latest report, it targeted a limit of 2°C to the global temperature increase as a goal to reduce the adverse effects of climate change. Have students track these effects and the current global temperature increase with this link: NASA: Global Climate Change, Vital Signs of the Planet.

What's cutting edge about carbon capture?

Carbon capture takes carbon dioxide directly out of the air so that atmospheric infrared light absorption is reduced. Simple in principle, it's a difficult technical challenge that, in recent years, is starting to become a technological possibility. A Canadian company in Squamish, British Columbia, is taking carbon dioxide out of the air and converting it into fuel. This video, produced by *The Globe and Mail*, explains the process: *Carbon-capture facility aims to transform carbon dioxide into fuel*.

Find Out More ►

To learn more about how societal changes affect climate change before facilitating this activity, you may wish to visit the following websites:

Global Weirding
http://globalweirding.is

Mitigation Contributions: Are we on track for 2°C?
https://www.mitigation-contributions.org

University of Manchester: Build your own Earth
http://www.buildyourownearth.com/index.html

Name: ______________________ Date: ______________________

Student Activity

Design Challenge: Climate in a Container

Introduction

Earth's climate is affected by natural and anthropogenic factors. You've studied these factors in detail over the past few classes. For this activity, you'll be considering the factors and using them to create a climate model that will heat up quickly when placed under a lamp for 10 minutes. Which factors do you think are the most important? Which are the easiest to reverse? It's time to find out!

Design

1. Consider phenomena that could affect the climate in your model. What forcing factors are you most likely to model? How would you model them using the allowed materials?

Forcing Factor	Important Aspect of Forcing Factor	Materials to Include in the Model

2. Sketch your design (use a separate sheet of paper if you wish):

3. Discuss your plan with another student. How does the other student's plan differ from yours? In what ways is the other plan better? How could the other plan be improved?

4. Based on your discussion with the other student, write down one way to improve your design.

____

____

____

____

5. Suggest a way to improve the other student's design.

____

____

– Build Your Model –

Design Challenge

Name: ______________________ Date: ______________________

Test

Initial Temperature	Final Temperature After 10 Minutes	Change in Temperature

Reflect

1. Walk around the room and look at everyone's models. Discuss in your group which forcing factors were the most effective at increasing air temperature. Why do you think they were effective?

2. Examine another student's model that heated up a lot. If you were a climate scientist hoping to lessen the effects of climate change, what steps would you take to reduce the heating in the student's model? Record your answers in the left column.

Step to Take with Model	Change to Local Environment	Change to Global Environment

3. Thinking about Earth and its current temperature, what would these steps look like for the local and global environment? Record your answers in the other columns of the table above.

4. Indicate with an asterisk (*) which step seems easiest to take at the local level. Do the same for the global level. (**Note:** Your choices don't have to be the same.)

5. Which step seems most challenging to accomplish at the local or global level? What social and technological changes are necessary to make this step easier?

____

____

____

6. Compare your answers to questions 4 and 5 with a partner. Be prepared to briefly present this comparison.

____

____

____

Name: ______________________________ Date: ______________________________

Consolidate Your Learning

Answer the following question to check your understanding of concepts relating to climate change and Earth's climate.

Write an email to your local politician or a social media post that outlines your beliefs, experiences, and understanding of climate change, as well as what you hope to see done in the future. Be sure to justify your ideas using evidence and data. After you complete your draft, get peer or teacher feedback to improve it. Be brave and send or post it!

Written Response Rubric

(adapted from National Council of Teachers of English)

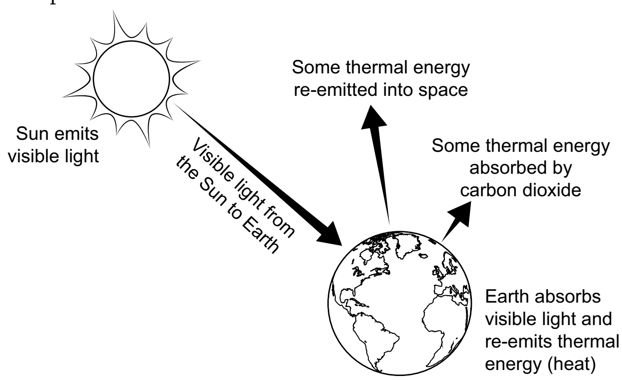
	Level 1	**Level 2**	**Level 3**	**Level 4**
Drafting Process	- receives or considers one piece of feedback	- receives and loosely considers some feedback	- receives and considers feedback for the most part	- respectfully receives and considers critical feedback
Goal/Thesis	- states personal opinion with lack of clarity - identifies a climate change issue	- states personal opinion with some clarity - identifies one climate change issue and implies its connection to climate change	- clearly states a personal opinion - identifies several climate change issues, but details are lacking	- strongly and clearly states a personal opinion - clearly identifies the climate change issues
Supporting Evidence/Underlying Understanding	- provides weak arguments and support; one point is made - implies at least one connection between a key idea from the unit and the climate change issue	- makes two points, showing some supporting evidence or data, but with weak connections - includes several key ideas from the unit, implying the connections between the ideas and climate change issue	- makes three or more points with support, but support is somewhat weak in places - implicitly makes connections between the points, evidence/data, and climate change issue	- makes three or more excellent points with good supporting evidence/data - explicitly makes connections between the points, evidence/data, and climate change issue
Conclusion	- makes concluding statement with no reference to personal opinion	- weakly summarizes personal opinion in a concluding statement	- summarizes personal opinion in a concluding statement	- summarizes personal opinion in a strong concluding statement
Organization	- produces very few sentences and paragraphs with correct structure	- produces some sentences and paragraphs with correct structure	- produces sentences and paragraphs with generally correct structure	- produces sentences and paragraphs that are complete, well written, and varied
Word Choice/Tone	- uses a few clear and descriptive words - uses a persuasive tone at least once	- chooses some words that are clear and descriptive - demonstrates a persuasive tone inconsistently	- chooses words that are clear and descriptive for the most part - demonstrates a persuasive tone in parts of the email/social media post	- chooses words that are clear, descriptive, and accurate - maintains consistent persuasive tone throughout email/social media post
Mechanics and Grammar	- makes many punctuation, spelling, and/or grammatical errors that interfere with meaning	- makes many punctuation, spelling, and/or grammatical errors, but they do not interfere with meaning	- makes several punctuation, spelling, and/or grammatical errors, but they do not interfere with meaning	- makes few, if any punctuation, spelling, or grammatical errors

Answers

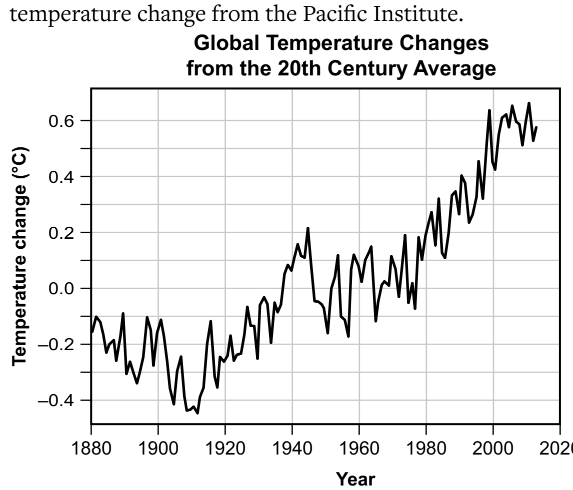
Activity 1: Carbon Dioxide

Part 1

1. Predictions will vary.
2. Sample answer:



3. Visible light passes through the carbon dioxide toward Earth. Carbon dioxide absorbs some thermal energy re-emitted by Earth toward space.
4. The amount of thermal energy absorbed by the carbon dioxide will increase, causing Earth's temperature to increase more. The other transfers and emissions will not change.
5. Discussion should revolve around the idea that carbon dioxide concentration doesn't look like it's changing, on average.
6. Answers will vary, depending on the time of year. Some graphs may show a decreasing concentration of carbon dioxide in the last six months. The year graph will show a slight increase when comparing the start of the year to the end of the year. The energy absorbed in the atmosphere will follow the same trend as the carbon dioxide concentration.
7. Discussion should focus on the idea that the graph shows a clear increase in carbon dioxide when comparing both time periods.
8. Plant respiration is the major driving factor for this graph. Since plants depend on seasons, the six-month variation is due to the seasons changing.
9. Discussion should centre on the observation that carbon dioxide concentration has increased almost 100 ppm (33%) in the past 60 years. The amount of energy absorbed by Earth's atmosphere during this time period has increased along with the increase of carbon dioxide concentration.
10. Predictions will vary but should show a recent increase in average global temperature. Below is a graph of global temperature change from the Pacific Institute.



11. Discussion should focus on the observation that carbon dioxide concentration has recently spiked dramatically. So, the temperature of Earth is increasing and is much warmer than in most of the history shown.
12. The atmospheric concentration of carbon dioxide has remained unchanged for the majority of the last 10 000 years of Earth's history. In the last 100 years, it has changed drastically.
13. Sample answers: transportation, industry, and farming.
14. The carbon part of carbon dioxide comes from oil and coal stores that were long buried. These sources of carbon were not historically part of the carbon cycle.
15. Natural biological and geological factors drove the carbon dioxide concentration for the last 10 000 years. These factors were in balance. Human factors have been driving the increase in carbon dioxide for the last 100 years.

Part 2

1. The pH of the seawater solution will vary. Values between 7.0 and 8.0 are common.
2. Predictions will vary depending on students' background in chemistry. Predictions should reflect an understanding that the colour of the solution will change if the pH changes.
3. Observations should show that the colour of the solution changes, indicating a change in pH. If bromothymol blue was used, the colour will change from blue or green to yellow as it becomes more acidic.
4. Sample answer: My breath contains carbon dioxide, which reacts with water to form carbonic acid. Carbonic acid will lower the pH of the solution, as any acid would.
5. Measurements will vary but should show a relative decrease in pH.
6. Predictions should indicate that the pH of seawater has been decreasing in recent history.
7. The graph should agree with the prediction of the pH decreasing in recent history.

8. Answers will vary, but the most common ones are effects to marine life such as coral bleaching.
9. More carbon dioxide is being put into the atmosphere, which is being absorbed by the oceans. Oceans are becoming more acidic.

Consolidate Your Learning

1. Sample answer: Equilibrium will be reached at some point, although Earth's environment at the new equilibrium state may be inhospitable to life as it currently exists.
2. Carbon dioxide concentration levels would be lower, around 300 ppm. There would still be warming due to carbon dioxide in the atmosphere and a lower pH in the ocean. However, the climate would be in equilibrium, not drastically changing. Reference should be made to the video and/or experiment when making these points.
3. Students should state that an increase in carbon dioxide concentration causes an increase in temperature and a decrease in the pH of the ocean. They should refer to observations they made by watching the video and performing the experiment.
4. Sample answer:

Pros	Cons
• motivates consumers and companies to look for alternatives to polluting practices • makes polluters pay the costs associated with carbon emissions • raises money that can be spent on reducing effects of carbon pollution	• may encourage dishonest practices in companies wishing to avoid the tax • may negatively affect economic growth • may create ill will toward efforts to combat climate change

An alternative to a carbon tax is the cap-and-trade system, in which an upper limit is set for carbon emissions. But companies can pay to increase their allowance or reduce their emissions and sell some of their allowance.

Activity 2: Climate Modelling

Part 1

1. (a) Aerosols (−0.5°C), GHGs (+1.1°C), Land Use (−0.1°C), Ozone (+0.15°C), Solar (+0.05°C), Volcanoes (0°C). Some of the changes are so small that the scale had to be adjusted to show them.
   (b) The trends are GHGs go up, aerosols go down, land use creeps down, ozone and solar creep up, and volcanoes show large spikes. (The spikes coincide with major eruptions.)
   (c) Answers will vary. Students might wonder why the data is so "noisy" or why there aren't plots for other factors.
2. Sample tweet: "NASA's own data shows that temperature is not going up ... it's going down! #climatefraud." The misrepresentation is that this tweet uses the data from only one factor (aerosols) and not the combined effect.
3. (a) Aerosols reflect energy back into space and create more clouds that cool the planet. Drawbacks might include unwanted effects on the atmosphere, such as acid rain or ozone depletion.
   (b) Carbon dioxide might be useful for plants, but the problems created by increased carbon dioxide levels will far outstrip any gains. Climate change contributes to droughts and desertification. As temperatures change, it will become difficult to grow crops that have traditionally grown in a given location.
   (c) Shrinking sea ice and melting glaciers decrease the surface albedo. More energy being absorbed by the surface means more heat, which means increased climate change and more melting of glaciers and sea ice: a feedback mechanism.
   (d) CFCs are persistent in the atmosphere. They are still floating around in the upper atmosphere.
   (e) A changing tilt will change the differences between summer and winter. The change is real but takes a long time (~40 000 years). Researchers point to solar variations as a possible contributor to ice ages.
   (f) The main impact of volcanoes lasts for about 3–5 years after the eruption. After this, most of the ash has settled back to Earth, where it has an impact on the surface albedo.

Part 2

1. (a) GHGs, aerosols, volcanoes, land use, ozone, solar variation
   (b)

Increase Temperature	Decrease Temperature	Negligible Effect
GHGs	Aerosols Volcanic eruptions	Solar Ozone Land use

   (c) GHGs, aerosols, ozone depletion and land use changes are all anthropogenic factors.
   (d) Answers will vary.
2. Sketches will vary but will likely show the temperature anomaly increasing in the positive direction. Have students describe what their graphs show to demonstrate their understanding of the temperature anomaly and the combined effects of forcing factors.
3. (a) The temperature anomaly is increasing.
   (b) The dips line up with the volcanic eruption plot. They show when big volcanoes erupted.
4. (a) The measurements show the same basic trends as the model. Temperature is increasing.
   (b) At the current rate, we will probably hit 2°C by the year 2050.

Consolidate Your Learning

1. Greenhouse gases and aerosols are the two largest forcings. They are both anthropogenic but act in opposite directions. Greenhouse gases push the temperature up, while aerosols push it down.
2. Natural forcing factors are not driving current trends. Solar variance has a tiny effect on the anomaly, and volcanic eruptions have short-term negative impacts. The clearest connection between the observed trend and forcing factors is greenhouse gases.
3. Sample tweet: "Our planet is getting warmer because we are pumping greenhouse gases into the atmosphere! #climatechangeisreal"
4. Sample argument:
   • Start by establishing the science that carbon dioxide and methane trap heat.
   • Show data that carbon dioxide and methane levels are increasing.
   • Show how models predict change in temperature.
   • Compare to actual observations.
5. Sample answer: I'll reduce greenhouse gases by getting fewer rides in cars, turning off lights, and eating less meat.

Answers

Activity 3: A Warming World

Part 1

1. Demonstration	3. Observe and Explain	5. Infer
Balloon with air and balloon with water	Observations: The air-filled balloon pops right away. The water-filled balloon does not. Explanation: The air-filled balloon pops right away because the flame melts the plastic (some students might say that the air expands, but there is not enough time for that to happen). The water-filled balloon does not pop because the water absorbs the heat. This is because the heat capacity of water is four times as high as that of air. It takes four times as much energy to increase the temperature of water by 1°C than air.	*As the planet warms, where will most of the heat be stored? In the atmosphere or in the ocean?* As the planet warms, most of the heat (thermal energy) is absorbed by the ocean.
Water bottle with heat source	Observations: The water level rises. Explanation: The water level rises in the straw due to the increasing volume of water. The additional heat causes the water molecules to "jiggle," and they take up more space.	*How will the volume of the ocean change if it absorbs heat?* The heat (thermal energy) absorbed by the ocean leads to an increase in volume, and sea levels will rise.
Container with water and ice and container with water, rocks, and ice	Observations: The water level stayed roughly the same for the ice floating in water. The water level rose for the ice sitting on rocks. Explanation: In the first case, the ice volume displaced the water by roughly the same amount, so no level change occurred. In the second case, the additional volume of water caused the levels to rise.	*How will melting land ice and sea ice affect sea levels?* Ice melting on land leads to sea levels that *rise*. Ice melting in the water leads to sea levels that *stay the same*.

Part 2

1. The volume of the ocean has been increasing over time.
2. The mass of land ice has decreased over time.
3. Tide gauges and satellite altimetry show that global sea levels are rising.
4. Sample answer: The glacier and sea ice coverage has decreased, which lowers the albedo and may accelerate climate change. Animals will experience habitat change. Changes in shipping routes are possible. The salinity of the ocean will decrease.
5. Sample answer: Large populations on the coast will be displaced. Expensive infrastructure, including roads, bridges, buildings, and dams, will be destroyed.
6. Sample answer: Populations on the coast will be displaced to offshore areas. To cover the cost of lost infrastructure, other communities may be forced to supply relief funds.

Consolidate Your Learning

1. Sample answer: The specific heat of water is higher than that of air. It takes more energy to raise the temperature of water. Therefore, the oceans absorb more heat than air does.
2. The melting of glaciers and ice sheets will contribute to sea-level rise.
3. Sample answer for a coastal community: The values of properties will fall as a result of predicted erosion, flooding, and encroaching water. Dikes could be installed to prevent flooding.

   Sample answer for a non-coastal community: Houses will become more expensive as residents from threatened coastal communities move in. Build subsidized housing and prepare relief funds for other communities.
4. Sample answer: The communities could be flooded. Transportation and hunting practices that rely on sea ice could be disrupted.

Activity 4: The Impact of Transportation

Part 1

1. Students can draw on knowledge acquired from previous climate change lessons. Sample answer:

Direct Effects	Indirect Effects
• Cars and other vehicles powered by gas emit carbon dioxide and contribute to greenhouse gas levels. • Air exhaust leads to smog.	• If the energy needed to manufacture cars comes from fossil fuels, there are greenhouse gas emissions. • Building roads destroys natural environment. • Animals are killed accidentally by cars. • Air temperatures increase. • Sea levels rise. • Ocean acidification occurs. • Ice melt increases.

2. (5 trees) × (number of kilometres travelled by car per week)
3. Sample answer: travel by car to visit relatives; walk to the pool; travel by bus to music lessons
4. Sample answer: 1. fastest; 2. distance to destination; 3. weather; 4. time of day; 5. mass of items that need to be carried

Part 2

5. Students' answers should show that they have carefully considered environmental impact, convenience, cost, and safety concerns for each option.
6. Sample answers: walking instead of being driven to a nearby friend's house, taking the bus instead of being driven to the mall

Part 3

1. Sample answer:

Product	Type of Product	Country of Manufacture	Estimated Mass (kg)
Product 1	Jeans	Thailand	0.10
Product 2	Plastic lunch box	China	0.10
Product 3	T-shirt	Bangladesh	0.10

2–4. Sample answer:

1. Product	2. Sea Distance (km)	3. Land Distance (km)	4. Air Travel (km)	5. Amount of Carbon Dioxide, Sea + Land Travel (g)	6. Amount of Carbon Dioxide, Air Travel (g)
Product 1	6760	6860	13 620	48	820
Product 2	5920	4660	10 580	34	630
Product 3	4260	8190	12 450	54	750

5. Sample answer: Buy local goods, buy fewer goods

Consolidate Your Learning

1. Cars have a large impact. They emit large quantities of carbon dioxide (3.7 billion tonnes annually). They also have many indirect effects, including the environmental cost to make them.
2. Sample answer: Use a transportation mode other than a car, buy fewer goods, buy more local goods.
3. Sample answer: Greenhouse gas emissions from trucks, ships, and other vehicles contribute to climate change in a huge way. We need to transport goods from where they are manufactured to where they are sold.
4. Sample answer: I realized that I should walk more; I was persuaded by the argument that we should consider the long-term impact of our transportation decisions.
5. Sample answer: Some of the ways students could redesign a mapping app so that it displays the environmental costs of various trips are as follows:
   - Display the carbon dioxide cost of each transportation mode near the time it takes.
   - Colour-code different transportation modes based on their environmental cost (e.g., green for environmentally friendly modes.)
   - Have a setting whereby the app displays only transportation modes that have an environmental cost below a certain threshold value.

Activity 5: How Much Carbon Is in That Tree?

Sample answers, based on data given in Teacher Tips on page 39.

Sheet 1

Part 1

1. (a) 27 m; (b) 32°; (c) 1.69 m
2. (b) 18.6 m

Part 2

1. 103 cm
2. 16.4 cm
3. 0.16 m

Part 3

1. 1.5 m^3
2. Oak tree: 1050 kg, 1313 kg
3. 427 kg
4. 1566 kg

Sheet 2

Part 1

1. 27 m
2. 32° to the top and 4° to the bottom
3. 18.8 m

Part 2

1. 103 cm
2. 16.4 cm
3. 0.16 m

Part 3

1. 1.5 m^3
2. Oak tree: 1050 kg, 1313 kg
3. 427 kg
4. 1566 kg

Sheet 1 and Sheet 2

Part 4

Sample answers:

A 365 kg

B 7 km/d by car = 333.9 kg

C 3 h of television = 4.5 kg
1 h desktop = 12.3 kg
1 h laptop = 4.9 kg

D 4 showers 0 baths = 120.8 kg

E 2 regular light bulbs for 2 h each day = 19.6 kg
4 energy efficient bulbs for 3 h each day = 8.4 kg

Total yearly estimate = 869.4 kg CO_2

Consolidate Your Learning

1. Answers will vary.
2. Travel that is not to and from school, heating and cooling of residence, production and transportation of food consumed, air travel, etc.
3. Answers will vary.
4. The production of electricity generates greenhouse gases, with some methods producing more than others. Building electricity plants generates greenhouse gases, too.
5. (a) 29%
   (b) 178 kg
   (c) Sample answer: ability to fit enough panels on the roof, nighttime electricity demand when the Sun isn't out, snow on panels, etc.

Activity 6: When Does It Make Sense to Switch?

Part 1

1. Sample answer:
   Gasoline-powered car:
   Pros:
   - wide variety of models and types of vehicles available
   - gas is available everywhere so cars have great range
   - initial cost of purchasing is lower

   Cons:
   - running costs are higher
   - more damaging to the environment

   Electric car:
   Pros:
   - environmentally friendly
   - lower operating costs
   - excellent choice for city driving

   Cons:
   - initial cost is higher
   - limited distances that vehicles can drive
   - lack of widespread charging infrastructure
   - low power of vehicles to pull trailers, etc.
   - limited models and body types available
   - up to a 40% decrease in battery life during cold weather

Answers

2.

	Gasoline-Powered Car	Electric Car
Base Cost:	$20 258.64	$43 338.24
Average Cost/km:	$0.104/km	$0.020/km
Total Cost Equation:	$C = 20258.64 + 0.104d$	$C = 43\,338.24 + 0.020d$

Part 2

1. 275 000 km
2. $C = 28338.24 + 0.020d$
3. $C = 20258.64 + 0.124d$
4. 78 000 km
5. The effect was to reduce the number of kilometres that the owner would have to drive before it made economic sense to buy the electric vehicle.
6. Almost 4 years based on driving 20 000 km/year
7. The break-even point of 78 000 km means that based solely upon the electricity and gas costs, until the owner has driven the vehicle 78 000 km, it would have been cheaper to have bought the gas-powered vehicle. After 78 000 km of driving, the electric vehicle is cheaper.

Part 3

1. 4410 kg
2. 21 483 kg
3. Sample answer: if the production of carbon dioxide were taxed, if people were able to see the effects of carbon dioxide gas on the environment more clearly, if people were to see an environmental improvement from decreased carbon dioxide levels, etc.

Consolidate Your Learning

1.

	Old Fridge	New Fridge
Base Cost:	$0	$1575.45
Electricity Cost/Year:	$154.46	$39.62
Total Cost Equation:	$C = 0 + 154.46n$	$C = 1575.45 + 39.62n$

13.7 years

2.

	Old Fridge	New Fridge
Initial CO_2:	0 kg	325 kg
CO_2 from Electricity/Year:	346.5 kg	88.875 kg
Total CO_2 Equation:	$C = 0 + 346.5n$	$C = 325 + 88.875n$

1.3 years

3. Sample answer: freezer, water heater, dehumidifier, furnace, air conditioner, hot tub, and lighting

Design Challenge: Climate in a Container

Design

1. Answers will vary, depending on topics of the unit. Students might include forcing factors such as albedo effect, lack of moderators (moisture), presence of greenhouse gases. Check that they have correctly associated the important property and materials with the forcing factors they include. For example, if albedo effect is listed, the important aspect is having black or dark surfaces present. In the associated materials there should be black or dark materials, such as black construction paper or dark rocks. Check for consistency between columns.
4. Students could suggest adding in other forcing factors, such as greenhouse gases. They might also suggest removing items that could act as moderators, or possible sources of heat loss (sealed containers versus unsealed containers).
5. See previous answer.

Test

Temperature changes vary, depending on the experimental setup. Increases of 1–3°C are common.

Reflect

2. Answers will vary, depending on topics of the unit. Students might include steps such as increasing white or light surfaces, adding moderators (water), decreasing the presence of greenhouse gases, or venting the container to allow for convection.
3. Check for consistency between columns. For example, if a student suggests increasing the amount of white or light surfaces, a change to the local environment could be to change the roofs of houses in their community to be light instead of dark. A change to the global environment could be to reduce the amount of asphalt on the planet, or create an asphalt substitute that is light in colour.
4. Answers will vary. Students should consider logistics, costs, and other factors in deciding which steps would be easiest to take.
5. Answers will vary; the point of this question is to get students thinking about change that is possible in the future. For example, if venting the container seems like the most difficult step, students can suggest creating a thermal conductor that spans between the exosphere and troposphere. Improvements in cutting-edge technology, such as carbon nanotubes, would be necessary for such a solution. Remember that there are lots of problems to fix. No step is too small.

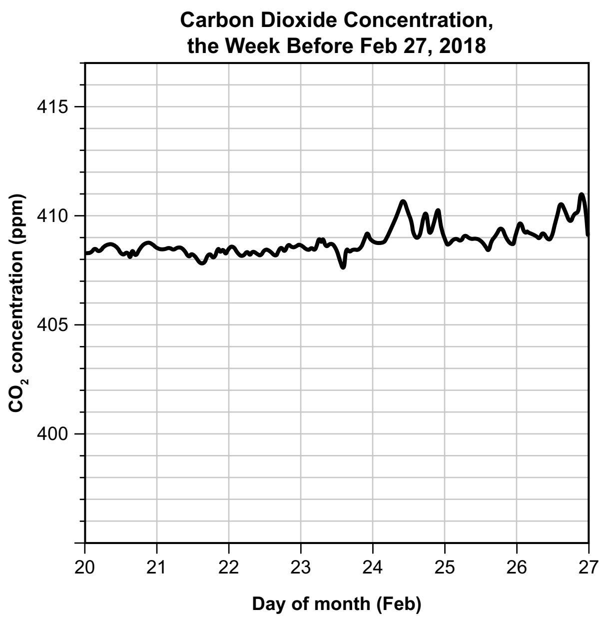
Consolidate Your Learning

Answer length should be roughly a page. Students should be concise and keep their audience in mind. Exemplary emails and posts will include the following: empirical evidence for climate change, scientific arguments for climate change, how climate change is affecting the writer personally, as well as their local and global community, and what steps can be taken to mitigate the effects.

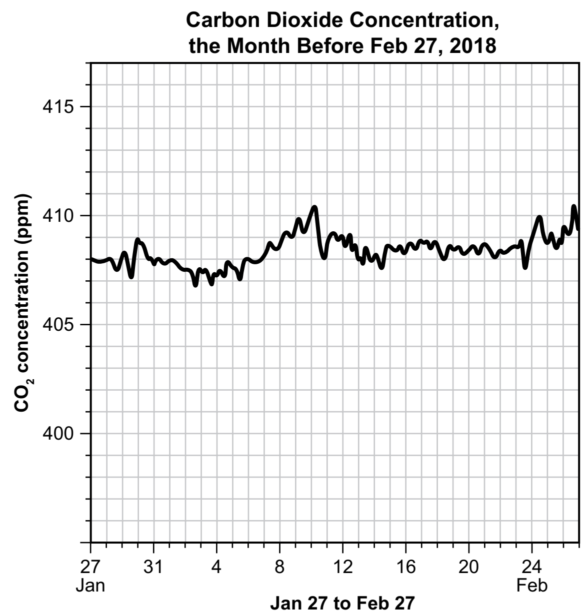
Appendix A: Keeling Curve Graphs

Activity 1

Graph 1



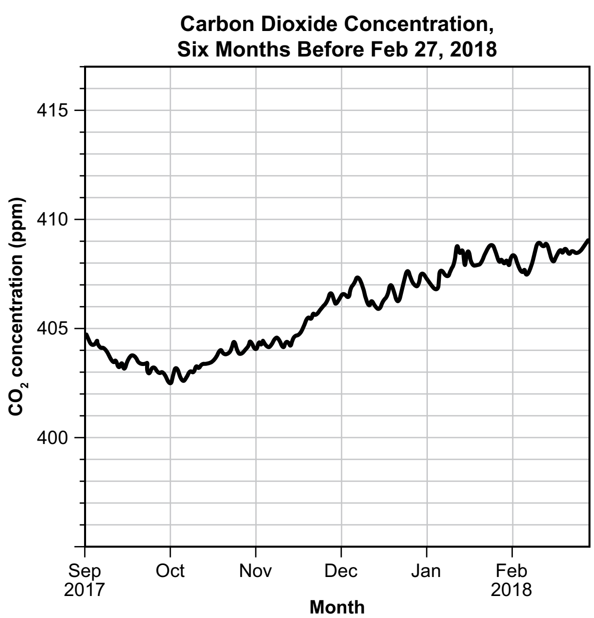
Graph 2



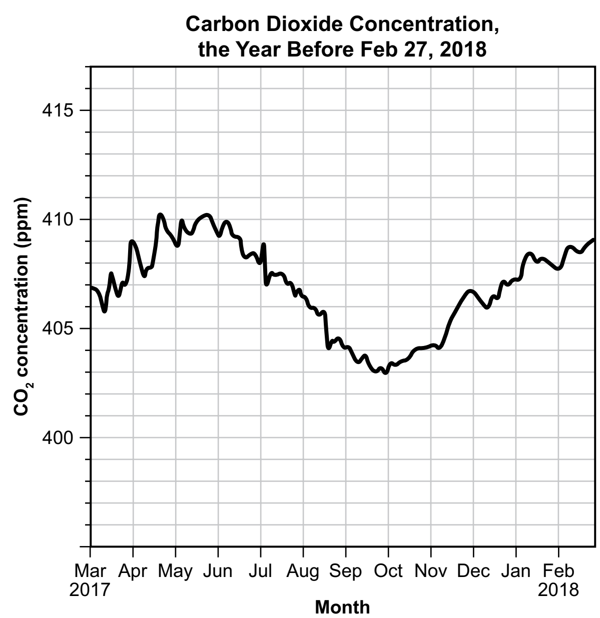
fold along this line

fold along this line

Graph 3

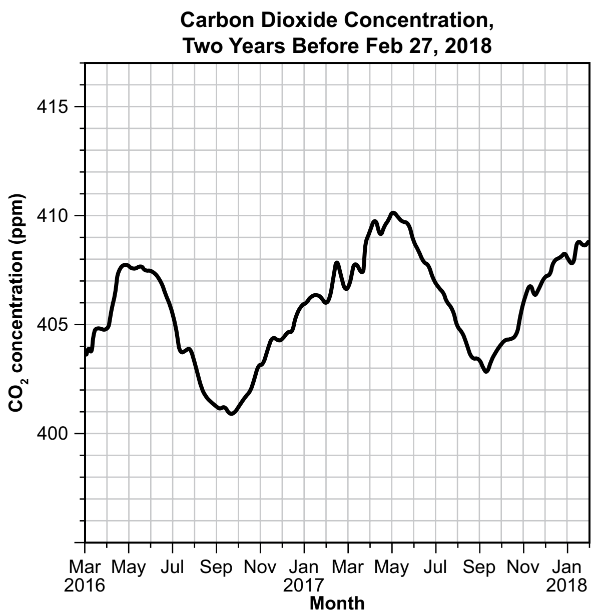


Graph 4

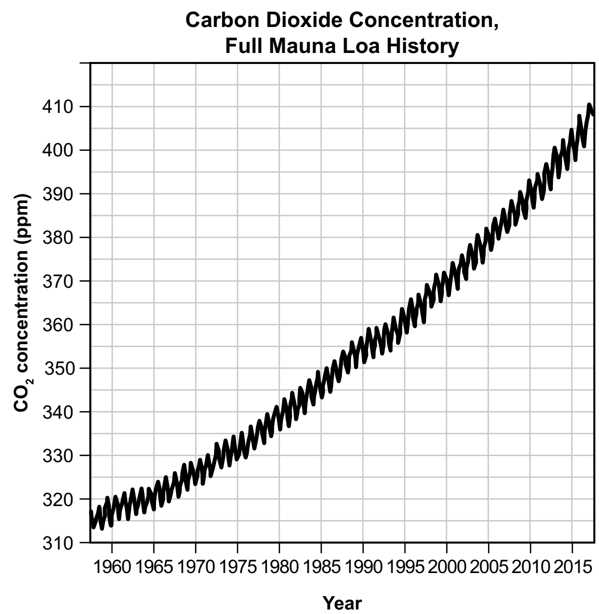


Source: Scripps Institution of Oceanography

Graph 5



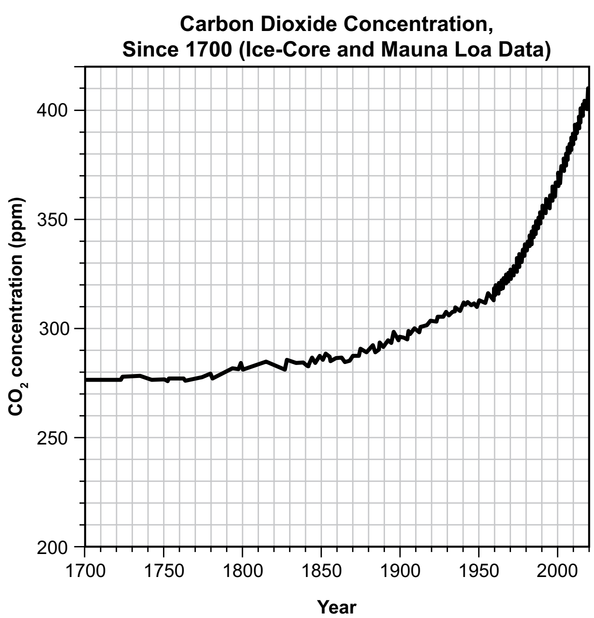
Graph 6



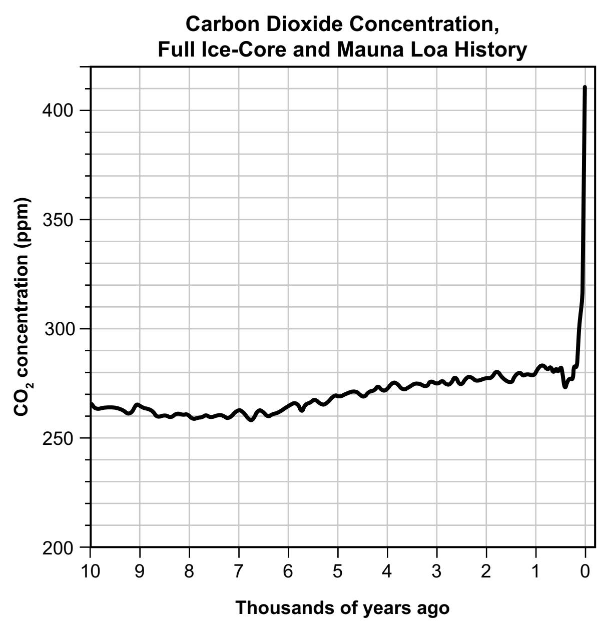
fold along this line

fold along this line

Graph 7



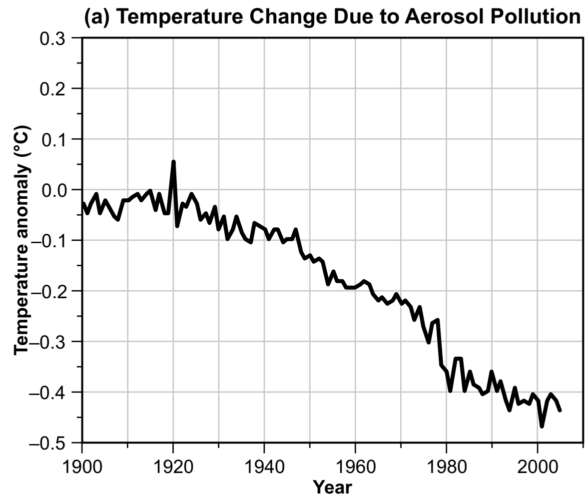
Graph 8

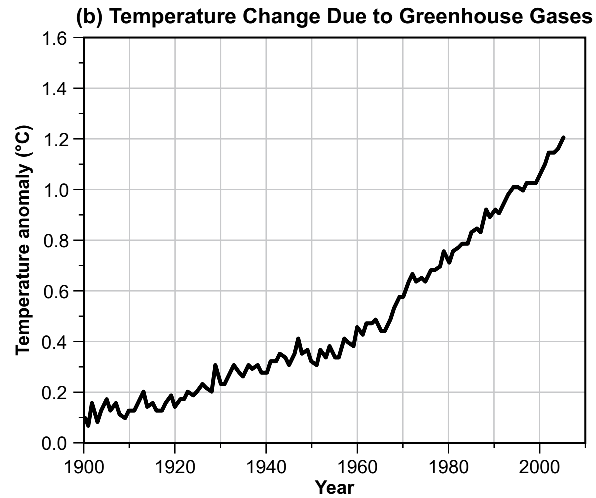


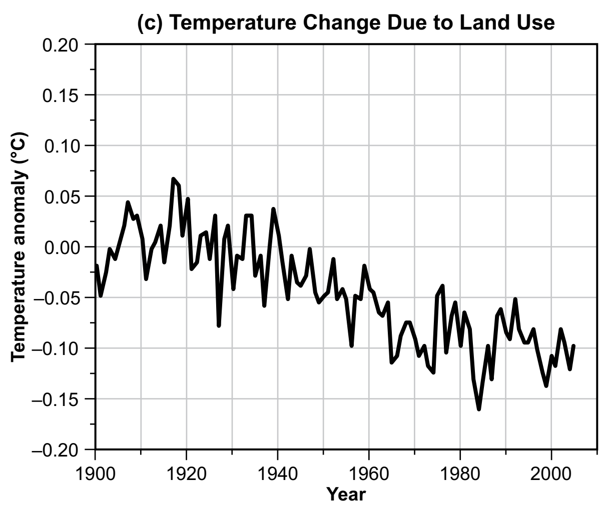
Source: Scripps Institution of Oceanography

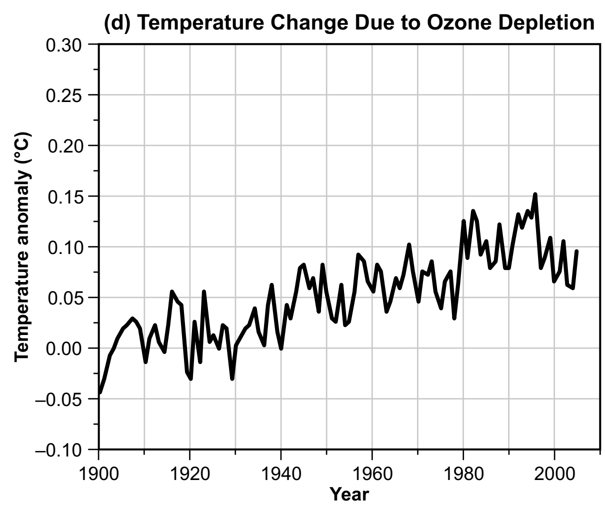
Appendix B: Graphs for Climate Forcing Factors

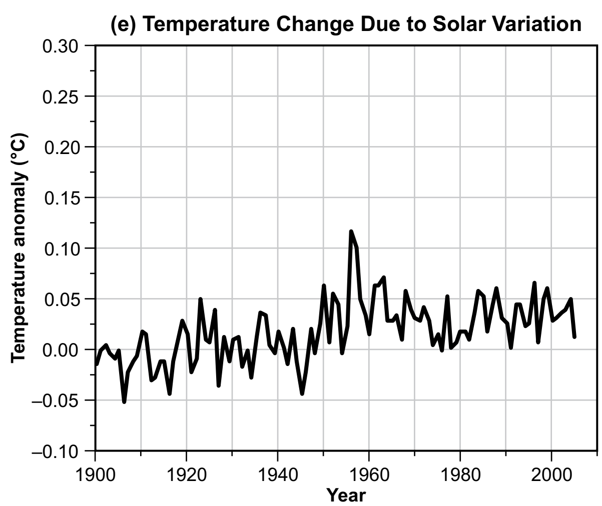
Activity 2

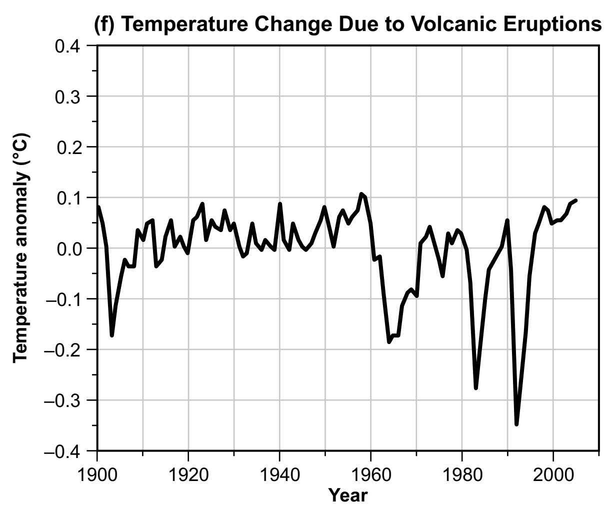












Source: NASA GISS; using a baseline relative to 1850–1859

(b) Greenhouse Gases

Greenhouse gases include carbon dioxide, methane, nitrogen oxide, and halocarbons (like chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)). The amount of these gases is increasing due to human activity. These molecules interact with infrared radiation, which means they trap heat in the atmosphere.

(a) Aerosol Pollution

Aerosol pollution involves small particles of matter or droplets suspended in the atmosphere. These small particles reflect sunlight back out into space, help clouds to form, and settle back down onto the surface as soot.

(d) Ozone Depletion

Ozone is a form of oxygen that absorbs high-energy ultraviolet light in the upper atmosphere. Anthropogenic chemicals, such as CFCs, react with ozone and break it down into normal oxygen, which lets the ultraviolet light through.

(c) Land Use

Deforestation and urbanization are two examples of land use that affect climate. Land use changes how much light is absorbed or reflected from the surface, how water moves through the water cycle, and how much heat leaves the surface.

(f) Volcanic Eruptions

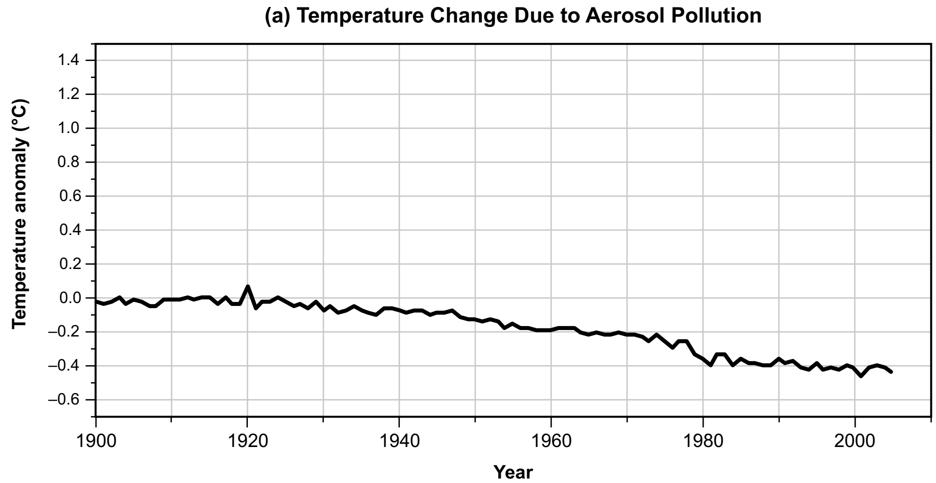
Volcanic eruptions throw ash and sulfates into the upper atmosphere, where they play an important role in reflecting solar radiation back into space and in creating more cloud cover.

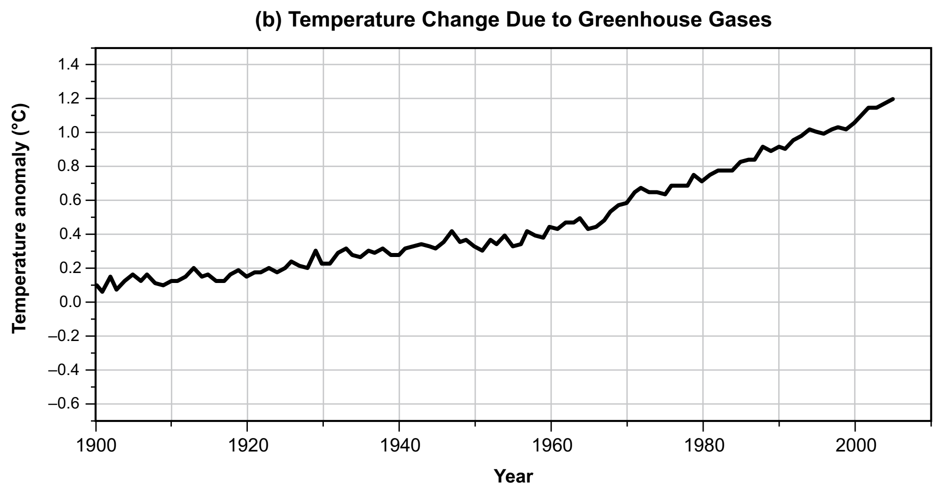
(e) Solar Variation

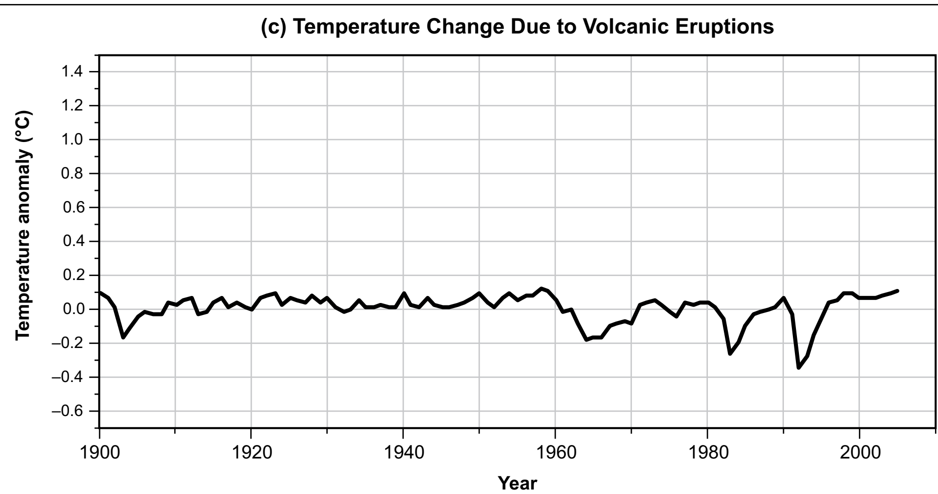
The amount of solar energy incident on Earth varies. The Sun changes over an 11-year solar activity cycle. Earth wobbles around its axis, causing the tilt to change over a 41 000-year cycle. These changes are connected to previous climate changes, like ice ages.

Appendix C: Modified Graphs for Climate Forcing Factors

Activity 2







Source: NASA GISS; using a baseline relative to 1850–1859

(a) Aerosol Pollution

Aerosol pollution involves small particles of matter suspended in the atmosphere. These small particles reflect sunlight back out into space, help clouds to form, and settle back down onto the surface as soot.

(b) Greenhouse Gases

Greenhouse gases include carbon dioxide, methane, nitrogen oxide, and halocarbons. The amount of these gases is increasing due to human activity. These molecules interact with infrared light, which means they trap heat in the atmosphere.

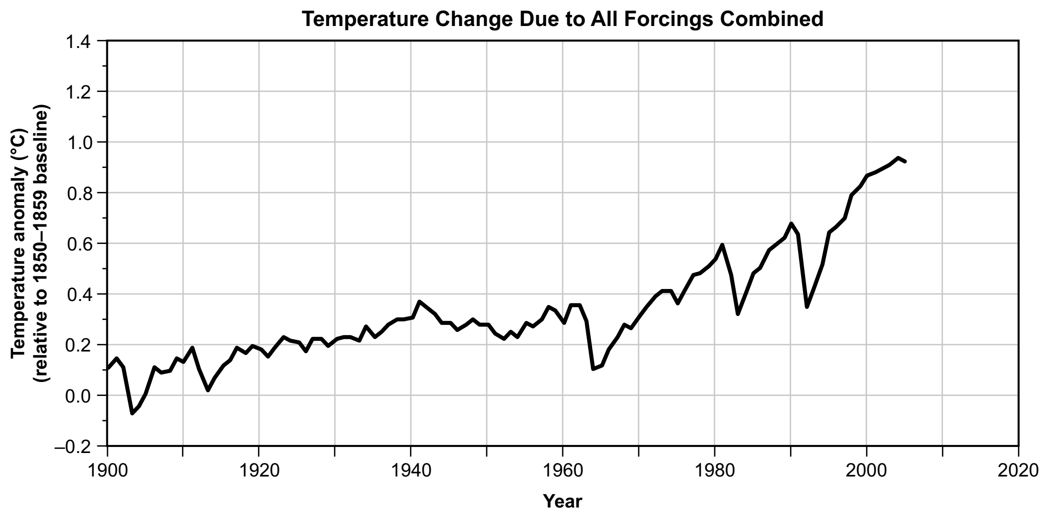
(c) Volcanic Eruptions

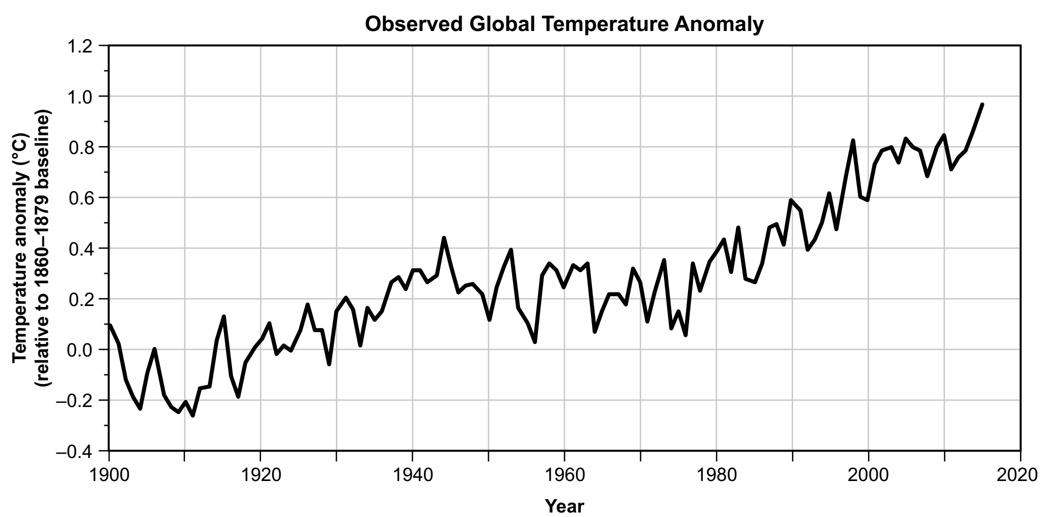
Volcanic eruptions throw ash and sulfates into the upper atmosphere, where they reflect solar radiation back into space and create more cloud cover.

Appendix D

Appendix D: Combined Predictions and Observed Data

Activity 2





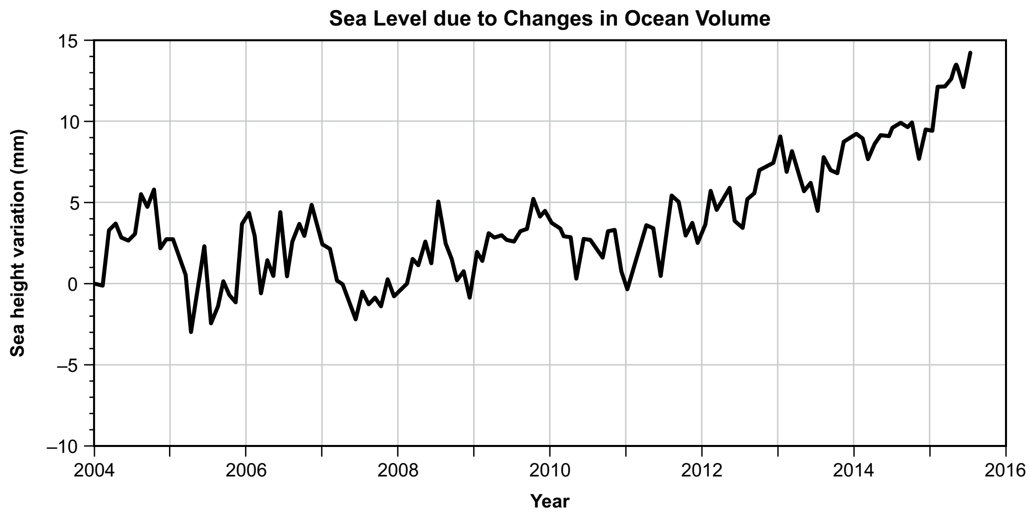
Source: NASA GISS

Appendix E: Climate Data Cards

Activity 3

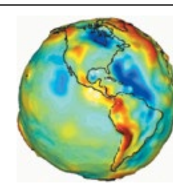
Argo: Measuring the Ocean's Volume

To measure the volume of the sea, scientists use Argo, an array of over 3500 floats. The floats measure the heat content of the sea at different depths and transmit the data back to land via satellite. These measurements allow researchers to calculate how the volume of the ocean is changing.

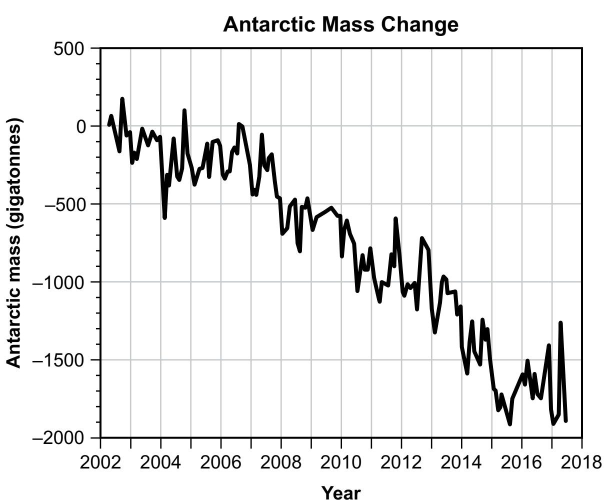


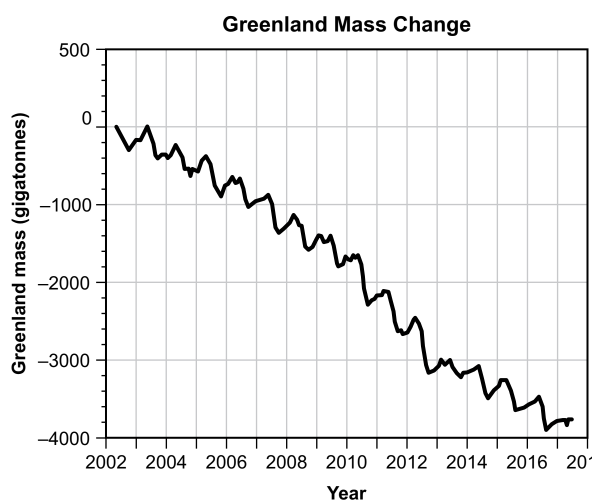
Source: Scripps/JPL

GRACE: Measuring Land Ice Mass



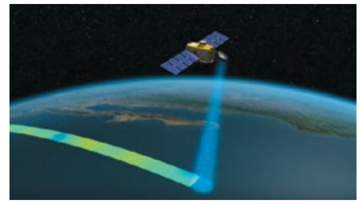
To measure the mass of land ice, scientists use satellites to measure slight changes in Earth's gravitational tug. More mass leads to a higher gravitational force on the satellites. Measurements of the force allow researchers to calculate the mass of glaciers and ice sheets.





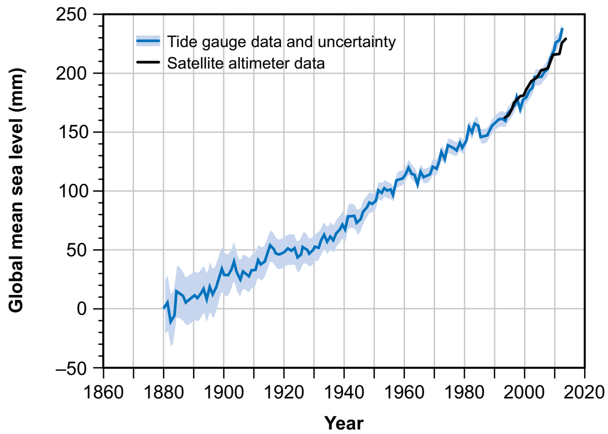
Source: NASA

Satellite Altimetry: Measuring the Height of the Sea

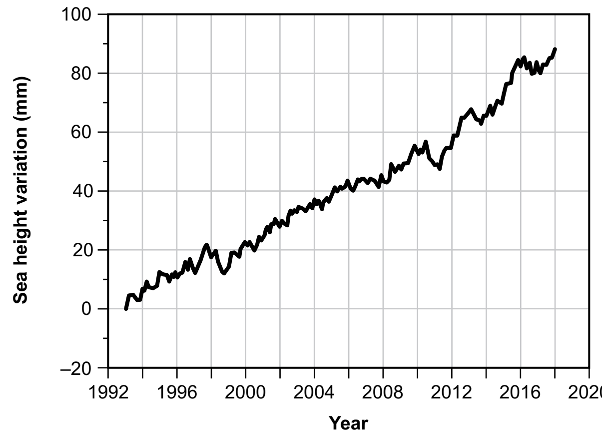


Satellites use radar to track the height of the sea. They measure the time it takes a radar pulse to travel from the satellite, reflect off the sea, and return. The travel time can be used to calculate the distance to the sea and its height. Before satellites were in use, sea level was measured with tide gauges attached to piers around the world.

Sea Level from Tide Gauges and Satellite Altimetry



Sea Level from Satellite Altimetry

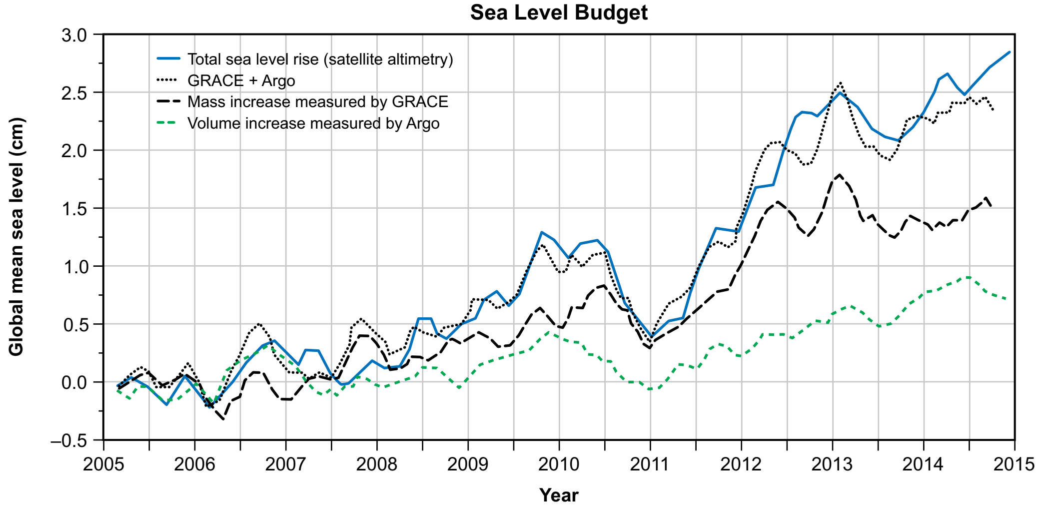


Source: NASA Goddard Space Flight Center and CSIRO

Sea Level Budget

Sea level rise due to thermal expansion of the ocean (green, short-dashed line) is measured by Argo; sea level rise due to land ice melt (black, long-dashed line) is measured by GRACE. The combination of these two contributions (black, dotted line) matches well with global sea level rise measurements by satellite altimetry (blue, solid line).

Sea Level Budget



Source: Wei Feng and Min Zhong/Creative Commons

Appendix F: Transportation Fact Cards

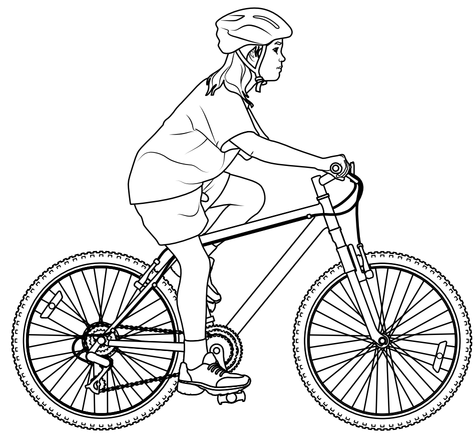
Activity 4

Walking

Walking is the simplest, most environmentally friendly form of transportation. The amount of carbon dioxide emitted due to breathing is very small. The cost, for footwear and appropriate clothing, is so low as to be negligible compared with other forms of transportation. Most people walk at about 5 km/h.

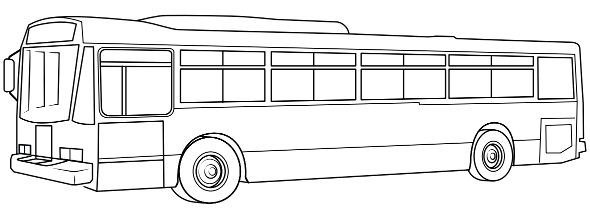
Cycling

Cycling is an inexpensive, low-carbon form of transportation that is often efficient over short distances. Cycling produces tiny amounts of carbon dioxide due to the breathing of the rider. The manufacturing process has a carbon cost of 240 kg of carbon dioxide per bicycle. It costs about 8¢ to ride a bicycle per kilometre due to repairs and maintenance needs.



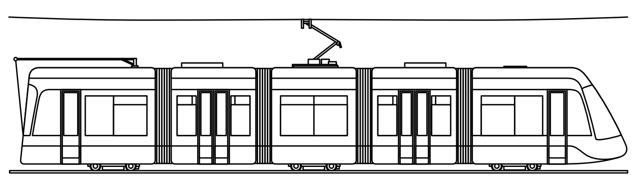
Bus

A bus can transport about 40 people from one destination to another. Manufacturing a bus releases 50 t of carbon dioxide into the atmosphere. Driving a bus releases 75 g of carbon dioxide into the atmosphere per kilometre of travel. It costs 37¢ per kilometre to operate a bus. A bus ticket costs about $3.



Light Rail

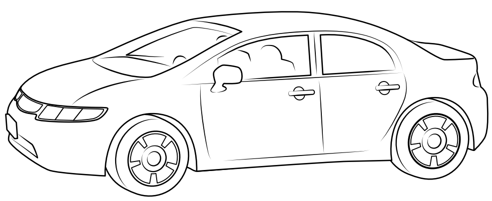
Light rail vehicles are trains that move along fixed tracks. Found in larger cities, they can hold about 100 people. Manufacturing a light rail car plus its tracks releases approximately 338 t of carbon dioxide into the atmosphere. Operating a light rail vehicle releases 323 g of carbon dioxide per kilometre of travel and costs around 33¢ per kilometre. A light rail ticket costs about $3.



Cars

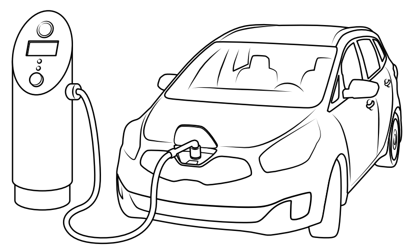
Gasoline-Powered Car

Cars powered by gasoline are one of the most common modes of transportation worldwide. They burn gasoline fuel to create high-pressure gas, which pushes on cylinders. This motion is transferred to the car's wheels, which turn, making the car move. Manufacturing a car releases about 4.2 t of carbon dioxide. Operating a car releases 250 g of carbon dioxide per kilometre of travel. A new car costs about $20 000 and 69¢ per kilometre to drive (for fuel and maintenance).



Electric Car

Electric cars are powered by a large battery. They use electricity to create rotational motion, which is then transferred to the wheels to make them move. Their manufacture releases about 5.8 t of carbon dioxide. Operating an electric car does not directly release any carbon dioxide into the atmosphere per kilometre of travel. However, it may indirectly release some carbon dioxide if the electricity is generated by fossil fuels. A typical electric car generates about 11 g of carbon dioxide for every kilometre of driving. A new electric car costs $40 000 initially and 50¢ per kilometre to drive (for charging and maintenance).



Snowmobile

A snowmobile is a gasoline-powered vehicle designed to travel on snow. An average snowmobile emits 4.7 g of carbon dioxide per kilometre. A new snowmobile costs about $10 000 to buy and approximately 15¢ per kilometre to drive (for fuel and maintenance).

Appendix G

Appendix G: Calculations Used for My Yearly Carbon Dioxide Footprint

Activity 5

Travel by Car

Average fuel efficiency is about 10.7 L/100 km.
Assuming 39 school weeks/year
Burning gasoline creates 2.3 kg of CO_2/L
Annual CO_2 factor = 0.107 L/km × 194 school days/year × 2.3 kg of CO_2/L
= 47.7 kg of CO_2/km

Travel by Bus

Average fuel efficiency of a bus is 40 L/100 km. (This average includes city and school buses)
A bus carries about 40 riders.
Fuel consumption is 0.01 L/km/rider
Burning diesel creates 2.7 kg of CO_2/L.
Annual CO_2 factor = 0.01 L/km/rider × 194 school days/year × 2.7 kg of CO_2/L
= 5.24 kg of CO_2/km

TV, Computer, and Lighting

Generation of electricity on average in Canada creates 0.225 kg of CO_2/kWh.
Newer television uses about 18 W.
Annual CO_2 factor = 0.018 kW × 365 days/year × 0.225 kg of CO_2/kWh
= 1.5 kg of CO_2/hour

Desktop computer uses about 150 W.
Annual CO_2 factor = 0.150 kW × 365 days/year × 0.225 kg of CO_2/kWh
= 12.3 kg of CO_2/hour

Laptop computer uses about 60 W.
Annual CO_2 factor = 0.060 kW × 365 days/year × 0.225 kg of CO_2/kWh
= 4.9 kg of CO_2/hour

Regular light bulbs are 60 W.
Annual CO_2 factor = 0.060 kW × 365 days/year × 0.225 kg of CO_2/kWh
= 4.9 kg of CO_2/hour

Low-energy light bulbs are 8.5 W.
Annual CO_2 factor = 0.0085 kW × 365 days/year × 0.225 kg of CO_2/kWh
= 0.7 kg of CO_2/hour

Water Heating

Estimated water input temperature: 13°C
Water output temperature: 46°C
Temperature rise = 46°C – 13°C = 33°C
Electrical water heater's efficiency is about 92%.
Assuming a shower uses 62 L of hot water
Assuming a bath uses 120 L of hot water
4.184 kJ of energy raises 1 L of water 1°C.
Energy required to heat 1 L of water by 33°C is (4184 J/°C)(33°C) = 138 072 J = 38.35 Wh
Annual CO_2 factor (shower) = 62 L/shower × 38.35 Wh/L × 52 weeks/year × 0.001 kW/W × 0.225 kg of CO_2/kWh/0.92
= 30.2 kg of CO_2/weekly shower

Annual CO_2 factor (bath) = 120 L/bath × 38.35 Wh/L × 52 weeks/year × 0.001 kW/W × 0.225 kg of CO_2/kWh/0.92
= 58.5 kg of CO_2/weekly bath

Assessment

Assessing Global Competencies

The following rubric highlights the key global competencies to evaluate as students complete an activity. It is not essential to evaluate all the competencies at once. Rather, at certain points during an activity, you may choose to evaluate one or more of the competencies. You may evaluate a small sampling of students for one activity and other groupings of students for subsequent activities.

Global Competencies Activity Rubric

	Level 1	Level 2	Level 3	Level 4
Critical Thinking and Problem Solving	- demonstrates limited ability to acquire, process, analyze, and interpret information during completion of the activity	- demonstrates some ability to acquire, process, analyze, and interpret information during completion of the activity	- demonstrates good ability to acquire, process, analyze, and interpret information during completion of the activity	- demonstrates advanced ability to acquire, process, analyze, and interpret information during completion of the activity
Innovation, Creativity, and Entrepreneurship	- demonstrates limited ability to turn ideas into action, lead, take risks, think unconventionally, and test new strategies, techniques, or perspectives	- demonstrates some ability to turn ideas into action, lead, take risks, think unconventionally, and test new strategies, techniques, or perspectives	- demonstrates good ability to turn ideas into action, lead, take risks, think unconventionally, and test new strategies, techniques, or perspectives	- demonstrates advanced ability to turn ideas into action, lead, take risks, think unconventionally, and test new strategies, techniques, or perspectives
Self-Directed Learning	- demonstrates limited awareness of student's own process of learning, with regard to motivation, perseverance, resilience, and self-regulation	- demonstrates some awareness of student's own process of learning, with regard to motivation, perseverance, resilience, and self-regulation	- demonstrates good awareness of student's own process of learning, with regard to motivation, perseverance, resilience, and self-regulation	- demonstrates advanced awareness of student's own process of learning, with regard to motivation, perseverance, resilience, and self-regulation
Collaboration	- rarely provides suggestions and ideas to the group - rarely listens to and values the suggestions or ideas of others - rarely assumes shared responsibility for the completion of the activity	- sometimes provides suggestions and ideas to the group - sometimes listens to and values the suggestions or ideas of others - sometimes assumes shared responsibility for the completion of the activity	- usually provides suggestions and ideas to the group - usually listens to and values the suggestions or ideas of others - usually assumes shared responsibility for the completion of the activity	- always provides suggestions and ideas to the group - always listens to and values the suggestions or ideas of others - always assumes shared responsibility for the completion of the activity
Communication	- demonstrates limited ability in expressing thinking and understanding using various means: reading and writing, viewing and creating, listening and speaking - demonstrates limited ability in using a variety of media appropriately, responsibly, safely, and with regard to digital footprint	- demonstrates some ability in expressing thinking and understanding using various means: reading and writing, viewing and creating, listening and speaking - demonstrates some ability in using a variety of media appropriately, responsibly, safely, and with regard to digital footprint	- demonstrates good ability in expressing thinking and understanding using various means: reading and writing, viewing and creating, listening and speaking - demonstrates good ability in using a variety of media appropriately, responsibly, safely, and with regard to digital footprint	- demonstrates advanced ability in expressing thinking and understanding using various means: reading and writing, viewing and creating, listening and speaking - demonstrates advanced ability in using a variety of media appropriately, responsibly, safely, and with regard to digital footprint
Citizenship	- demonstrates limited ability in understanding diverse worldviews and perspectives - demonstrates limited appreciation for the diversity of people and perspectives, and for the value of a more sustainable future for all	- demonstrates some ability in understanding diverse worldviews and perspectives - demonstrates some appreciation for the diversity of people and perspectives, and for the value of a more sustainable future for all	- demonstrates good ability in understanding diverse worldviews and perspectives - demonstrates good appreciation for the diversity of people and perspectives, and for the value of a more sustainable future for all	- demonstrates advanced ability in understanding diverse worldviews and perspectives - demonstrates advanced appreciation for the diversity of people and perspectives, and for the value of a more sustainable future for all

Name: ______________________________ Date: ______________________________

Self-Assessment

Scientific Investigation Skills

After completing an activity, read the following statements. For each statement, if applicable, write the rating that best represents your contribution.

Rating Scale
1. Rarely 2. Sometimes 3. Usually 4. Often

Initiating and Planning

___ I formulated questions.

___ I made predictions.

___ I planned experiments to answer my questions and test my predictions.

___ I tested predictions by determining relationships between variables in my activity.

Performing and Recording

___ I made observations.

___ I gathered, organized, and recorded information from my activity.

Analyzing and Interpreting

___ I analyzed the data or information from the activity.

___ I identified patterns and relationships to draw conclusions.

Communication

___ I was able to communicate with others my ideas, procedures, results, and conclusions.

___ I communicated verbally, in writing, and with labelled diagrams.

Self-Assessment

Scientific Knowledge and Skills

After completing an activity, read the following statements. For each statement, if applicable, write the rating that best represents your contribution.

Rating Scale
1. Rarely 2. Sometimes 3. Usually 4. Often

Knowledge and Understanding

___ I gained knowledge from the activity.

___ I learned new terms from the activity.

___ I understand the concepts and the process of science explored in the activity.

Thinking and Investigation

___ I identified the problem being investigated and asked questions to help study the problem.

___ I gathered, recorded, and analyzed data and was able to draw conclusions from the data.

Communication

___ I expressed myself verbally, in writing, and with labelled diagrams.

___ While communicating, I used scientific information and terms learned from completing the activity.

Application

___ I applied knowledge and understanding to familiar problems presented in the activity.

___ I transferred knowledge to unfamiliar situations presented in the activity.

Glossary

Aerosols: tiny particles of matter suspended in the air, primarily sulfates and soot

Altimetry: the technique of measuring sea level relative to the centre of Earth

Anthropogenic: caused or produced by humans

Climate models: complex mathematical algorithms that simulate the climate using quantitative data

Forcing factors: variables that alter Earth's energy balance

Feedback mechanisms: changes to the climate that amplify or diminish further changes

Gravimetry: the technique of measuring mass using an instrument called a gravimeter

Greenhouse gases (GHGs): any gases that absorb infrared radiation (e.g., carbon dioxide, methane, nitrous oxide, chlorofluorocarbons (CFCs))

Heat capacity: the amount of energy needed to change the temperature of a substance

Infrared: describes radiation that has a wavelength longer than those of visible light and shorter than those of microwaves, usually perceived as heat

Proxy: a physical process that can be used to reconstruct past temperatures

Surface albedo: the fraction of light reflected by a surface. White surfaces (e.g., snow) have a high albedo; forests and oceans have a low albedo

Temperature anomaly: the difference in temperature for a location relative to an average from a baseline period

Thermal expansion: an increase in volume caused by increased temperature

Ultraviolet: describes radiation that has a wavelength shorter than those of visible light and longer than those of X-rays

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