ENVIRONMENTAL LITERACY TEACHER GUIDE SERIES

Changing Climate

A Guide for Teaching Climate Change in Grades 3 to 8

NATIONAL GEOGRAPHIC

1 The Climate System and Greenhouse Effect

by Lindsey Mohan and Jenny D. Ingber

"Climate is what you expect, weather is what you get."
Robert A. Heinlein

Earth's global climate is changing, bringing numerous changes to the planet and the organisms that live on it. Validated records from instruments around the world show that our global temperature increased by around one degree Celsius (almost two degrees Fahrenheit) during the second half of the 20th century. Consequences of this observed warming include substantial melting of glaciers, rising sea levels, and increased risk of drought, wildfires, and plant and animal extinctions.

In order to make well-informed decisions that will enable humans and other organisms to continue to thrive on Earth into the future, today's students need to have at least a basic scientific understanding of our planet's climate system and the role that humans are playing in changing it.

The climate system encompasses a complex set of processes that affect conditions around the world. One of the most important features of the climate system—the **Greenhouse Effect**—is necessary for life on Earth. However, human-induced amplification of this natural phenomenon is now causing a range of changes throughout Earth's system.

In this chapter we consider the differences between climate and weather, look at the climate system in more detail, discuss what it means for climate to change, and take a closer look at the Greenhouse Effect and what students know about this important phenomenon.

Our Experience of Climate

Weather and **climate** are a part of our daily lives. Throughout history, human settlement patterns and

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.a 3.2.b	
Grade 4		
Grade 5	5.4.a 5.4.c-d	
Grade 6	6.3.d 6.4.a-b,d-e	
Grade 7	7.6.a 7.6.f	
Grade 8		

migration routes show that climate has a profound influence on where humans live and how they interact with Earth. Historically, populations in milder climates have thrived relatively easily compared to those that settled in more extreme polar or desert regions. A region's climate controls the types of plants and crops that can grow there and, in turn, the types of animals that the plant life can support. Today, we still see an effect of climate in the "snowbird effect," the annual retreat of retired people from northern latitudes to more southerly ones that allow them to avoid harsh winter conditions.

Our experience of climate is often confused with our experience of weather. Weather is the observable state of the atmosphere at a given time and place. You can step outside your door to see what your weather is right now. If you check a thermometer and note how it feels outside, you can come up with a fairly complete description of your current weather. Weather is highly variable: it can change within minutes and be different in places that are only a short distance apart from one another. Measurements of temperature, precipitation, wind, humidity, and pressure are all a part of weather.

Climate, unlike weather, is a *concept* rather than an observable phenomenon. To make a complete description of your current climate, you would need to consult historical weather records and calculate average values for parameters such as temperature and precipitation.

Climate is the long-term average of weather conditions experienced at a location over a period of 30 years or more. **Climatologists** often use the last three decades (for instance, from 1981 to 2010), or the 100-year period from 1901 to 2000, as a base period to calculate average climate values. Descriptions of climate sometimes focus exclusively on average temperatures, but average values for precipitation and other weather parameters are also part of a location's climate.

The natural vegetation that thrives in a place can be a good indicator of its climate. For instance, if you see desert vegetation in a location, you can infer that its climate is hot and dry. If a place has the lush vegetation of a rain

CHAPTER OVERVIEW

Weather is the current state of the atmosphere at a given time and place. Climate, on the other hand, is the statistical average of weather over a long period. This distinction gave rise to the common phrase, "climate is what you expect, weather is what you get."

Understanding climate change involves understanding both climate norms and deviations from that norm over time. When changes start becoming usual across many decades, one can say an area's climate is changing.

The Greenhouse Effect is necessary for life on Earth, but students struggle with understanding this effect, and the gases responsible for the life-sustaining conditions on Earth. Students also confuse the Greenhouse Effect with climate change and with ozone depletion.

forest, you can deduce that its climate is warm and wet. Latitude, elevation, and proximity to features such as mountains, deserts, and bodies of water are the major factors that control a location's climate. In general, places at low latitudes and elevations are warmer than high latitudes and elevations. Being close to or far from different types of geographic features can affect climate in a range of ways.

Weather is the observable state of the atmosphere at a given time and place. Climate is the long-term average of weather conditions a place has experienced.

Two girls shelter themselves from the rain in Bali, Indonesia.

Calculating Climate. The climate for a location on a specific day of the year can be calculated from long-term records of weather. For example, you could look up the average temperature observed on June 1 in each of the last 30 years, and then average the values together. Similarly, you could look up precipitation amounts, humidity levels, cloud cover, and wind speeds observed on that date over the previous 30 years and calculate average values for each of those parameters. The set of average values you end up with from this exercise would be a valid description of the climate for that location on June 1. (Climatologists also calculate other statistics from the records, including measures that indicate how much the individual values vary from the average.)

The 30 separate temperatures you found in the records would span a range of values, reflecting the natural variability of weather over time. For instance, the weather on June 1 of some years may have been cool and stormy. Other years, the date may have been unusually warm. Because climate descriptions report the arithmetic mean, or average, of all the temperatures, the resulting average represents all the conditions that occurred. The value you calculate shouldn't be considered as a prediction of the temperature for the next June 1, but in a stable climate, the average from the past 30 years would provide a good idea of the next value.

Students (and adults!) who don't understand the difference between weather and climate can develop incorrect ideas about climate when they experience warmer-than-average or cooler-than-average weather. Daily weather rarely matches the long-term average values for climate, but some people mistakenly believe that any deviation in weather from the average climate is evidence of a cooling or warming climate. When measurements of extreme weather are averaged into a 30-year period that defines climate though, each event accounts for just 1/30 of the calculated average, so single weather events are not considered as indicators of climate, no matter how unusual they may be.

A convenient way to communicate how weather compares to climate is to express weather measurements as the difference between observed conditions and the long-term average, or "normal" value, of the same conditions. Values that represent the difference between observed weather and normal climate values are called **anomalies.**

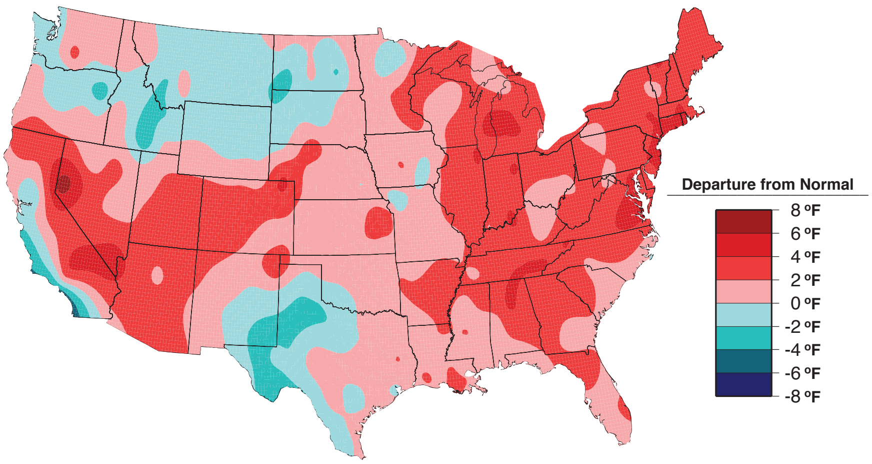
When the Unusual Becomes Usual

Scientific organizations such as the Intergovernmental Panel on Climate

Scientists study many of the same variables to learn about weather and climate, and climate is determined by long-term averages of these variables.

JULY 2010 TEMPERATURE ANOMALIES

Departures from the 1971—2000 Normal



This map shows how much warmer or cooler locations in the contiguous United States were during July of 2010 compared to their average temperatures during July from 1971 to 2000.

Red areas on the map show locations that were warmer than average, and blue areas show locations that were cooler than average (National Climatic Data Center, U.S. Climate at a Glance).

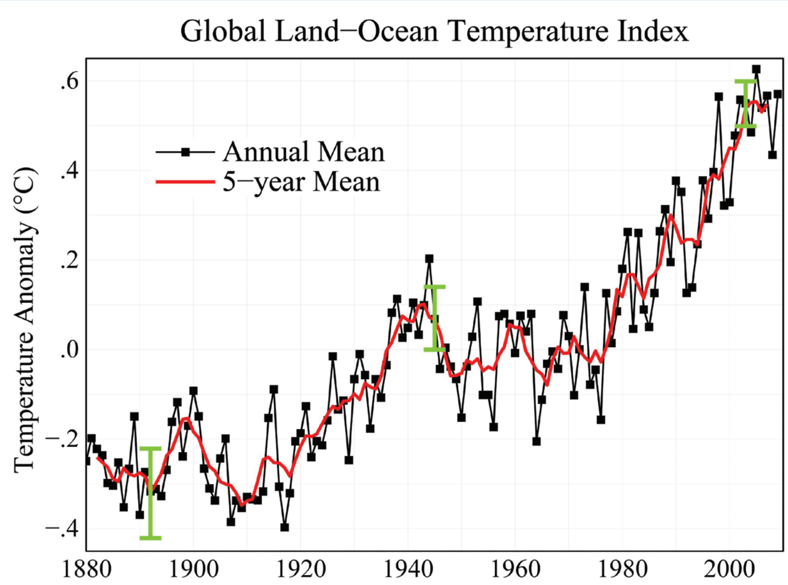
Change (IPCC) and the UN Framework Conventions on Climate Change (UNFCCC) have developed carefully worded definitions for ***climate change.*** Using the common elements of these organization's definitions, climate change is a change over time in the location's climate, indicated by changes in patterns of average temperature, precipitation, and other parameters, or the variability of these patterns. To be considered as climate change, observed changes need to be larger than changes that can be attributed to natural variation, and the change must persist for an extended period, usually decades or longer.

For educators, a useful way to describe climate change is *when the unusual becomes the usual.* This statement reflects the fact that when climate changes, the new conditions (the unusual) become more common that the historical average conditions (the usual). When the unusual becomes usual over time, statistical averages, scientific evidence, and anecdotal stories told by local residents will converge to tell the same story—the climate has changed.

A valid way to identify a changing climate is to calculate climate averages for a base period of at least 30 years, and then compare those values to averages calculated for an earlier or later period of the same length. Mathematical techniques can reveal if differences between the averages from two different periods are large enough to be "statistically significant," or if they are so small that they don't represent real change.

Consider that most of Florida has a subtropical climate: It is generally warm and wet, with a good chance for afternoon thunderstorms in the summer. Occasionally, a single summer or a string of three or four summers might be cooler than normal, with fewer thunderstorms than average. This situation would not mean that Florida's climate is no longer subtropical. If, however, Florida's annual average summer temperatures were lower than normal for 20 or 30 years, its long-term average temperature would be lower than in the past, and people would recognize that its climate was changing to become more temperate.

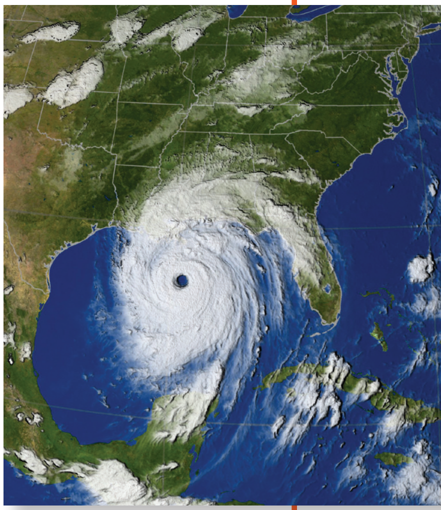
GLOBAL TEMPERATURE



Scientists have graphed global temperature averages each year, and the average over time shows a general trend toward warming temperatures.

Student Thinking

Climate and Weather



It is challenging to untangle our experience of weather from our experience of climate. Students may use the terms *weather* and *climate* interchangeably, or they may perceive extreme weather events as indicators of climate change. For example, when Hurricane Katrina hit New Orleans and the Gulf Coast in 2005, many people considered the storm as evidence of a changing climate. However, historical records show that locations in the Gulf commonly experience several hurricanes per century and that some years have more of these monster storms than others. Though the number of hurricanes that made landfall in the Gulf during 2005 was significantly larger than the historical average, it remains to be seen if this trend will persist into the future.

	Common Student Ideas	Scientific Ideas
Climate* versus *weather	The terms *climate* and *weather* can by used interchangeably	*Climate* is the average (mean) of climate variables over 30 years or more. *Weather* is the observable state of the atmosphere at a given time and place.
Weather	Unusually hot days, droughts, and strong hurricanes, are associated with global warming, and unseasonably cold or rainy days are evidence that global warming is not happening.	Extreme weather conditions, when averaged with conditions recorded over a time span of 30 or more years, have only a small effect on measurements that represent climate.
Climate predictions	Climate is long-term weather and cannot be predicted as weather cannot always be predicted accurately.	Predictions for climate and weather are both based on quantifiable physical systems. Computer models for both these systems represent reality accurately enough to facilitate increasingly accurate predictions for future weather and climate.

Ask Your Students

1. What is the difference between climate and weather?
2. If you have a really snowy winter, does that mean your climate is changing? Why or why not? In what ways might distinguishing weather from climate help students better understand climate change?
3. Why can scientists make predictions about climate, even though weather forecasters are sometimes wrong about their weather predictions?

The Climate System

When talking about climate, most people think about the climate of a familiar region. They can visualize how rainy their region is during summers, and know what type of weather to expect in the winters. Understanding the climate of a single place—likely the place where they live—is the first step in comprehending the enormity of what is meant by global climate. Climate is studied and measured at a very large scale, ultimately encompassing the entire Earth system, and over long periods of time, from decades to centuries.

Earth comprises five overlapping, interacting materials called spheres. These include

- **atmosphere**—gases that surround Earth's surface
- **biosphere**—all of the living organisms on Earth that live both in the water and on the land
- **cryosphere**—frozen water on Earth, found as accumulations of snow and ice in glaciers, sea ice, and ice sheets such as those found in Antarctica and Greenland
- **geosphere**—the rocky part of Earth, including mountains, rocks, and soil, as well as layers of molten material inside the planet
- **hydrosphere**—all the water on the planet, on the surface , underground, and in the air

Matter and energy are constantly changing forms and moving among these five spheres. Probably the most familiar example of matter moving through these spheres is demonstrated by the water cycle. Water can move from the hydrosphere to the atmosphere through evaporation, then condense and fall back to Earth as snow, becoming part of the cryosphere. Once the snow melts and flows into a river, it is part of the hydrosphere again. If an animal drinks it, the water becomes part of the biosphere. Water

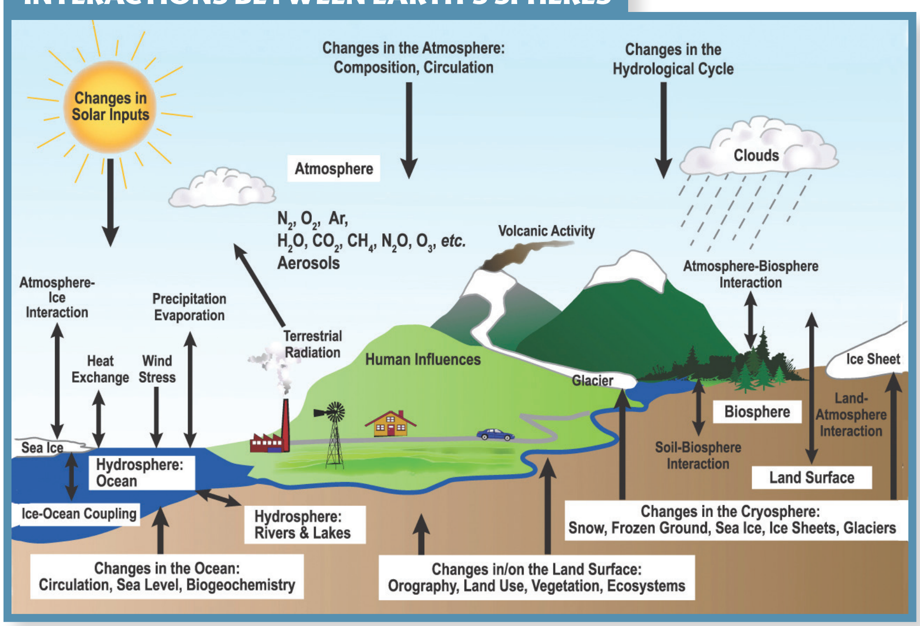
A storm develops off the coast of Eleuthera, the Bahamas, circulating water through the atmosphere and hydrosphere.

doesn't always move through the cycle linearly. Rather, it can move to more than one other sphere at several steps, and processes can move it in both directions through the cycle. This complexity is representative of a system.

The reason climate is discussed as a "system" is because of the dynamic, continuous movements of matter and energy among its different components. Looking at all of the spheres on Earth and the way matter and energy moves among them provides a convenient way to understand the climate system.

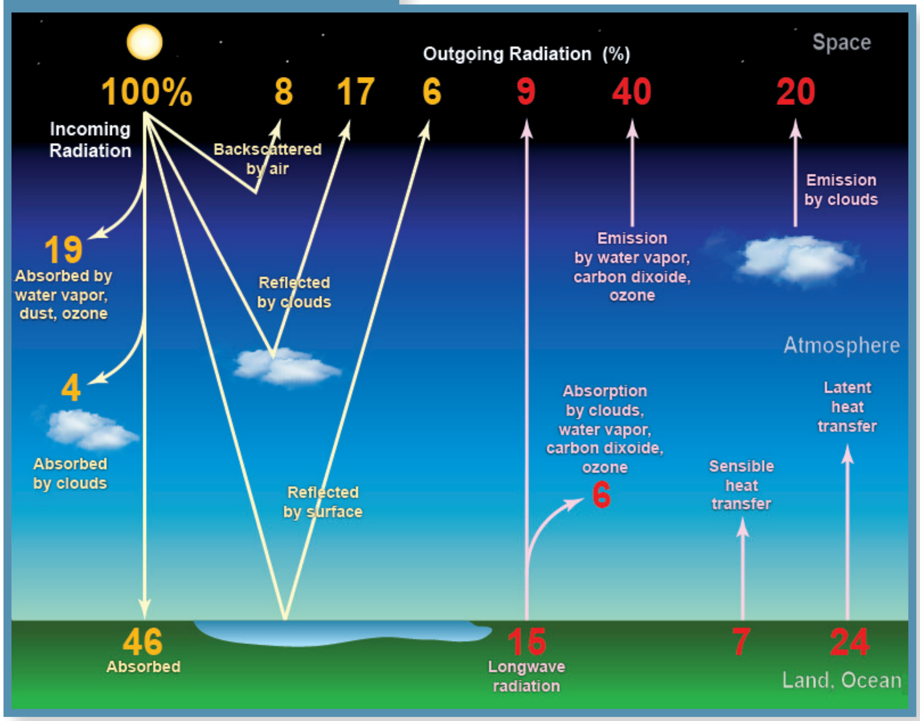
To describe the cause of present-day climate change, one can tell a simple, but helpful story about how materials have moved through Earth's spheres over time. Over hundreds of millions of years, large amounts of carbon, once located in our atmosphere, were incorporated into growing plants and sequestered in the biosphere. Eventually, the plants died, and the carbon they contained was transformed into fossil fuels such as coal and oil in the geosphere. Now, humans are retrieving these fossil fuels and burning them to power transportation and industry, returning huge amounts of carbon back to our atmosphere in a fraction of the time the carbon took to accumulate in the biosphere. The increasing amount of carbon in the atmosphere has increased the amount of heat energy the atmosphere absorbs and releases at Earth's surface. The result of changes in the atmosphere is a series of ongoing and cumulative changes in the cryosphere, hydrosphere, biosphere, and geosphere. Collectively, these changes are known as global climate change.

INTERACTIONS BETWEEN EARTH'S SPHERES



This illustration details the different interactions between the Earth's spheres. Notice that each sphere interacts with others in multiple ways, creating a complex web of relationships.

EARTH'S ENERGY BALANCE



A sample energy balance shows how scientists quantify the incoming and outgoing radiation.

Teaching Tip

One way to help students understand energy is to encourage them to create an energy story line. An energy story line traces how energy changes form as it interacts with matter on or near Earth's surface. When teaching about Earth's global energy balance, help students build a story about how the sun's energy changes forms when it interacts with air and land surfaces. An example storyline might look like this:

The sun's rays give off solar radiation.

Rocks, soil, and water convert light energy into heat energy.

Differences in heat energy at Earth's surface result in wind, or kinetic energy.

Kinetic energy of wind turns turbines, ultimately changing into electrical energy.

Electrical energy turns into light energy and heat when people turn on lightbulbs.

Earth's Energy Balance

We burn fossil fuels such as oil, natural gas, and coal to obtain the energy that was trapped in the chemical bonds of those fuels. However, the primary source of the vast majority of energy on Earth is the sun. The sun continuously emits energy into space in the form of electromagnetic radiation. When this energy reaches Earth's atmosphere and surface, it interacts with matter in the air, ocean, land, and life. In these interactions, solar radiation from the sun can be converted into other forms of energy such as heat and chemical energy. For example, **photosynthesis** in plants converts solar radiation into chemical energy by incorporating it into the bonds of carbon-based sugar molecules. Rocks and soils can absorb solar radiation and convert it to infrared radiation, or heat—which explains why Earth's surface gets warm when it's in direct sunshine. The heat energy emitted by Earth interacts with gases in the atmosphere, creating differences in the density of air at different locations and resulting in winds.

Examining the balance between incoming solar radiation (energy from the sun) and outgoing longwave radiation (the heat given off by Earth's surface) will help us understand our planet's climate system. We will explore this balance in the context of Earth's **energy budget.**

As energy from the sun reaches our planet, some of it is reflected out to space; the remaining energy enters Earth's system and interacts with gases in the atmosphere and materials at the planet's surface.

Most of the energy that arrives as ultraviolet (UV) rays, gamma rays, and x-rays interacts with gas molecules in Earth's upper atmosphere and is released in a different form. One result of these interactions is that Earth's surface is protected from these life-damaging forms of energy. Without this shield of gases, life would probably not exist on Earth.

Incoming radiation that moves through the upper atmosphere can also be reflected back into space. That is why clouds, ice, and large desert areas are so bright in a picture of Earth from space: these materials are reflecting solar energy away from the planet.

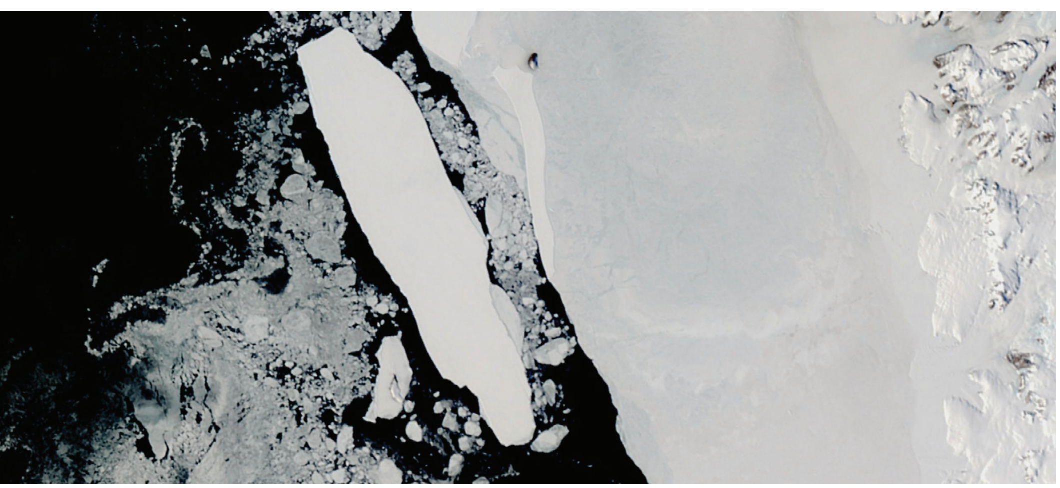
When incoming radiation is absorbed by materials at Earth's surface, some of the radiation is reemitted as infrared radiation, or heat. Heat is invisible to our eyes, but we can feel it, and it continues to interact with other materials at or near Earth's surface, including gases and aerosols in the atmosphere. **Global radiative balance** is a concept that has been studied and explained by physics. It states that any system that is in balance must emit exactly as much energy as it receives. To be in balance then, Earth must emit the same amount of energy (mostly as heat) into space as it receives as solar radiation from the sun.

Albedo Effect. ***Albedo*** is a term that describes the amount of incoming radiation that is reflected by matter. Surfaces that are highly reflective, such as a mirror, or light in color, such as snow, have high albedos. Darker materials such as plants and dark soils have lower albedos. These low-albedo surfaces absorb more of the solar energy that hits them than the higher albedo surfaces do. Albedo is a practical concept. For example, people in hot, sunny regions often choose light colors for their clothes because light colors absorb less energy in direct sunlight than dark colors, ultimately keeping them cooler.

On a large scale, albedo has important implications for climate change. Snow and ice are highly reflective surfaces. Up to 95 percent of the solar radiation that hits bright white surfaces of fresh snow and ice is reflected back from the surface, and this energy is essentially unchanged. When ice melts, though, a surface of liquid water has a lower albedo, so it absorbs a higher percentage of incoming solar radiation. As a consequence of the decrease in albedo as water changes from a solid to a liquid, the more ice that melts, the more energy becomes available to melt more ice.

Earth's Natural Greenhouse

Our atmosphere plays an important role in maintaining Earth's energy balance. The way different gases in it interact with incoming and outgoing radiation is key to understanding how life on Earth exists.



Water and ice have different albedo. The image shown shows water that will absorb more incoming radiation compared to snow or ice that will reflect more radiation.

For the most part, gases in the atmosphere allow incoming solar radiation to pass through and reach Earth's surface. As Earth emits this energy as heat, however, some gases in the atmosphere interact with the energy in ways that keep some of the energy near Earth's surface instead of releasing it into space. These gases—referred to as greenhouse gases—absorb heat energy and reemit it in all directions, sending some of it back toward space but returning much of it to other molecules in the atmosphere or materials at Earth's surface. Life, as we know it, is dependent on this process. The phenomenon is known as the Greenhouse Effect, named for its similarity to processes that allow greenhouses to be effective environments for growing plants when outside temperatures are too cold.

Water vapor is the most abundant greenhouse gas on Earth. We refer to the amount of water vapor in the air as humidity. Our experiences in humid and arid climates can help us understand how greenhouse gases relate to temperature changes.

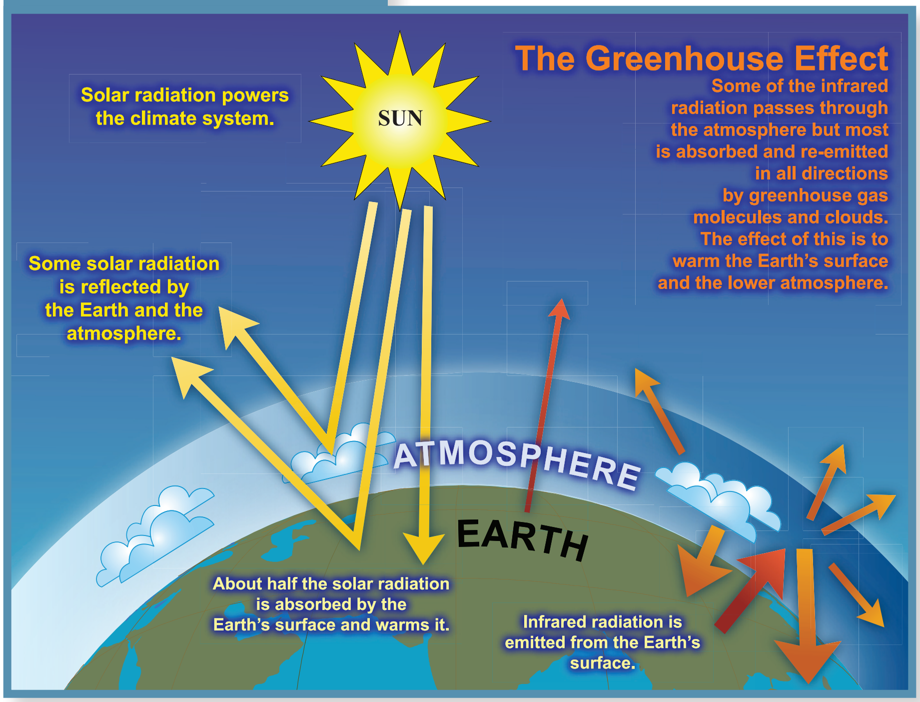
Deserts generally have low humidity. Have you ever been to a desert region and noticed how much cooler it gets at night compared to the day? In contrast, regions that have high humidity don't experience as large a difference in their daytime and nighttime temperatures. Summer days in deserts across the American Southwest can top 43°C (109°F), but nighttime temperatures can drop into the 20s C (70s F) as outgoing radiation escapes to space. However, residents of Florida, for example, often experience humid summer days during which temperatures reach 32°C (90°F). Though heat energy has an opportunity to escape all through the night with no additional solar radiation coming in, morning temperatures are usually still around 27°C (81°F). The large amount of water vapor (high humidity) in the air in this region essentially "traps" much of the outgoing infrared radiation by absorbing it and continually reemitting it to its surroundings. The amount of water vapor in the air varies greatly over time and space.

Beginning in the 1930s, scientists led by Dr. Guy Stewart Callendar, and later, in the 1950s, scientists led by Dr. Charles Keeling, began to monitor concentrations of greenhouse gases in our atmosphere. Dr. Keeling began monitoring carbon dioxide levels at NOAA's Mauna Loa Observatory in Hawaii in 1957, and the monitoring continues today. Mauna Loa was selected because of its large distance from land and cities that may influence the mixture of gases in its samples. Data collected at Mauna Loa—sometimes referred to as the Keeling curve for the shape it makes on a graph—shows that carbon dioxide levels increased from approximately 315 ppm (parts per million) in the atmosphere in 1957 to roughly 390 ppm in 2010. Data collected at the South Pole and other stations around the world agree with findings from Mauna Loa.

Increasing Carbon Dioxide in the Atmosphere. For the past several thousand years, humans have been reducing the amount of Earth's land that is covered by forests to obtain fuel and increase the area they have for building cities, growing crops, and raising animals. As forests have decreased, their ability to absorb carbon dioxide from the atmosphere has decreased. During this period, however, Earth was experiencing a gradual, natural cooling trend.

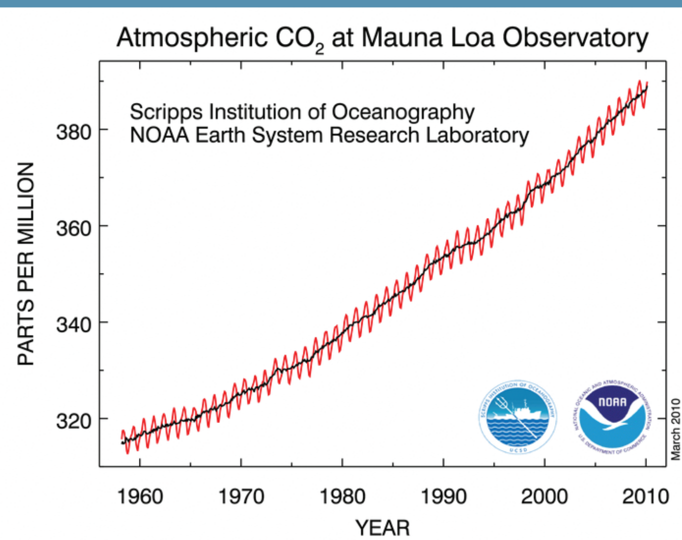
In recent years, the rapid increase in the amount of atmospheric carbon dioxide entering the atmosphere has been attributed to human use of fossil fuels. Rising levels in other greenhouse gases such as methane and nitrous oxide are also attributable to human activities. Scientists do not know for certain when human actions began to influence atmospheric carbon dioxide levels at the global level. However, it is now clear that the cumulative effects of increasing the amount of carbon dioxide through the burning of fossil fuels and decreasing the amount of carbon that the biosphere can remove from the atmosphere by clearing forests are attributable to human activities. It is important to note that Earth does experience natural warming and cooling trends caused by changes in the Sun or volcanic activity, but present-day climate change is mostly attributed to human activities.

THE GREENHOUSE EFFECT



The Greenhouse Effect describes how our Earth maintains habitable temperatures by the balance between incoming and outgoing radiation.

CARBON DIOXIDE MEASUREMENTS



This graph shows measurements of atmospheric carbon dioxide levels from the Mauna Loa Observatory in Hawaii, a location that has measured CO_2 levels since the late 1950s.

Student Thinking

Greenhouse Gases

Students struggle to understand gases as a form of matter. While students may be able to recite that matter comes in three forms—solid, liquid, and gas—they treat gases as quite different from solids and liquids. It can be a challenge for students to understand that although gases are invisible, they have mass and take up space. Many students have difficulty understanding the effect of greenhouse gases because they don't have a strong grasp of gases as real, tangible materials (Gowda et al. 1997; Jacoksson & Saljo 2009). When looking at greenhouse gases in particular, they may believe that these gases are bad because they are linked to climate change (Andersson & Wallin 2000). Most greenhouse gases are natural and necessary for life on Earth.

Scenario

You have just finished a lesson on greenhouse gases and want to see if your students learned the main concepts. You ask the class to discuss the following question as a summary to the day's lesson.

Question

Are greenhouse gases—carbon dioxide in particular—good or bad?

Scientific Answer

Greenhouse gases are essential to life on Earth (see **Earth's Natural Greenhouse,** page 17). This means that greenhouse gases are needed in the atmosphere to regulate temperatures to sustain life. While water vapor is the most important greenhouse gas, carbon dioxide is also important because of its necessary role in photosynthesis. An amplification of greenhouse gases, as is seen today, can alter atmospheric temperatures.

Student Answers

Sarah: I think carbon dioxide is a bad gas, even though it's helping us. So in different ways, it's a bad gas because it does so many bad things to us. But it's helpful if you have the right proportion of it, if you go overboard.

Thomas: I know there are greenhouse gases that aren't necessarily good for us. And a big one I think is carbon dioxide cause it's not that great for us.

Jacob: Because greenhouse gases pollute the world like carbon dioxide.

Joyce: It's good and bad, because trees get carbon dioxide and they need it, and they give us oxygen, but carbon dioxide is also bad because when we inhale it, it's bad for our bodies.

What Would You Do?

1. What patterns do you notice in students' answers?
2. How would you reteach the lesson to ensure more students understand the difference between naturally-occurring greenhouse gases, and amplified greenhouse gases?

Pictures of Practice

Greenhouse Gases: Good or Bad?

The struggle to understand greenhouse gases arises because of challenges in learning about gases, as well as challenges in learning the difference between the natural Greenhouse Effect and an enhanced Greenhouse Effect. While many people understand that the Greenhouse Effect is natural, they may also associate greenhouse gases with global warming, and, therefore, label these gases as bad. Yet, life on Earth evolved in a certain way because of how these gases regulate Earth's temperature.

Students: Grade 6

Location: South Gate, California (an urban community)

Goal of Video: The purpose of watching this video is to see students share ideas about the role of greenhouse gases on Earth.

Classroom Context

Ms. Walker, a sixth-grade teacher, engages her students in a discussion about the role of greenhouse gases in our atmosphere. Ms. Walker teaches in a large, urban school district, and her students in the video qualify for gifted and talented (GATE) placement. Ms. Walker explained that while this class was primarily GATE students, there was still a wide range of understanding among students with respect to science. Her students share both correct and incorrect ideas about science topics throughout the year, and the same was true during her unit on climate change. The lesson on greenhouse gases occurred in the middle of her two-week unit on climate change.

Video Analysis

Greenhouse gases are necessary for life on Earth because they help regulate Earth's temperature. However, some students may associate greenhouse gases with global warming, and, therefore, say that greenhouse gases are bad. At the beginning of the video, Ms. Walker predicts that some of her students will believe greenhouse gases are "bad" for the environment. She believes her students have made the link between these gases and global warming but still misunderstand how these gases regulate Earth's natural greenhouse. In the preinterviews Emily confuses the natural Greenhouse Effect with the amplified Greenhouse Effect (global warming). During the classroom discussion, Emily begins the discussion by saying she thinks greenhouse gases are bad because they get trapped in the atmosphere. Christopher describes greenhouse gases as being good for plants, and Amaya chimes in that greenhouse gases are both good and bad, but only Valeria seems to understand that greenhouse gases regulate Earth's temperature. Eliazar particularly struggles with understanding greenhouse gases and the Greenhouse Effect, as seen when the teacher quizzes him at the end of the lesson.

Reflect

How could you help students understand greenhouse gases and the Greenhouse Effect?

Think about how you would respond in a situation in which students believe greenhouse gases are bad. How would you convince them that greenhouse gases are natural and necessary? Why do you think Eliazar continues to have questions about greenhouse gases? For your instructional plans, consider teaching about the natural greenhouse effect before introducing students to amplified warming and climate change.

Representations of Science

Analogies for Greenhouse Effect

The Greenhouse Effect was named for its similarities with what we observe with greenhouses. The plastic or glass roof and siding of garden greenhouses have properties that are similar to greenhouse gases in our atmosphere. The transparent roof allows incoming solar radiation to enter the greenhouse, yet blocks outgoing infrared radiation (heat) from exiting. The result is a net warming inside the greenhouse, which enables plants to grow during times when exterior temperatures are too cool. When temperatures become too warm inside the greenhouse, the gardener can open vents in the greenhouse, allowing some of the warmed air and excess infrared radiation to escape.

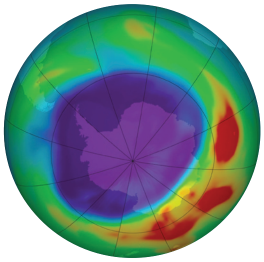
A garden greenhouse provides a tangible, real-world example to help students make sense of abstract phenomena, such as the Greenhouse Effect, that involve invisible gases interacting with invisible radiation. Educators can even find a local greenhouse to take students to visit, or students may bring in their own experiences about greenhouses to share with their peers. Leveraging these experiences and using the concrete analogy of a gardening greenhouse are useful strategies for helping students understanding the general concepts of the Greenhouse Effect.

However, the greenhouse analogy can also lead to unexpected misconceptions among students. Like all analogies, the greenhouse has its limits. The interior of greenhouses are also warm because they provide shelter from outside weather, especially wind, which is not captured in the analogy. Likewise, greenhouses have vents that can be opened and closed depending on the desired temperature.

Climate Change and the Ozone Hole

Ozone is a gas found in Earth's upper atmosphere, as well as closer to its surface. Like the oxygen molecules we depend upon for breathing, ozone is composed solely of oxygen atoms. The difference is that oxygen molecules have two oxygen atoms and ozone molecules have three. In our upper atmosphere, ozone provides a critical service for life: It acts as Earth's natural sunscreen and blocks some of the ultraviolet radiation that comes from the sun, shielding us from damaging rays. Beginning in the late 1970s scientists began to measure ozone and found that the thickness of the **ozone layer** in the upper atmosphere was lower over the southern polar region during the months of September through January. This phenomenon is now referred to as the **ozone hole**. Scientists discovered that **chlorofluorocarbons** (CFCs) and similar chemicals were causing ozone molecules in that region to break down. In 1987, countries from around the world signed the Montreal Protocol, agreeing to restrict their emissions of these chemicals. Over the past 25 years, scientists have observed a reduction in the concentrations of the substances that were depleting ozone, and they expect the ozone layer to recover over time.

At lower altitudes, close to Earth's surface, ozone gas is a hazard to the health of people and other organisms. Ozone has been linked to problems with asthma and other respiratory issues in humans, and it affects the health of crops and other plants. Ozone at this level in the atmosphere is a key component of "smog" that plagues cities, with emissions coming mostly from industrial processes and cars.



The ozone hole occurs over Antarctica and is actually a thinning of ozone in the upper atmosphere.

In one study of student understanding of climate change, a student described causes of climate change in this way: "Driving trucks releases carbon dioxide like hairspray, which puts holes in our ozone. Electricity also puts holes in our ozone." (Mohan et al. 2009). Other students have claimed that carbon dioxide breaks down the ozone layer or that cars cause the ozone hole. These are fairly prominent misconceptions among both youth and adults and, therefore, deserve particular attention when teaching about climate change.

Pictures of Practice

Greenhouse Gases and the Ozone Hole

Teachers use analogies, metaphors, and models to teach about how things work in the world. The greenhouse analogy, for example, provides a visible image to help students understand an abstract concept such as the Greenhouse Effect. By having students discuss what happens in a greenhouse, teachers can help them make sense of how radiation, or heat, could be trapped inside the atmosphere like heat trapped inside a greenhouse. However, this analogy can lead to another misconception about climate change that is connected to confusion about global warming and ozone depletion.

Students: Grade 6

Location: South Gate, California (an urban community)

Goal of Video: The purpose of watching this video is to see how the greenhouse analogy brings out misconceptions about the ozone hole.

Classroom Context

Previously, Ms. Walker taught her students about climate change in detail, but many students were struggling with understanding greenhouse gases and how they influence temperature in the atmosphere. Prior to the current lesson, some students had mentioned the ozone hole during discussions, claiming that greenhouse gases cause the ozone hole. Ms. Walker set this concept aside to continue her work on the greenhouse effect but, at the end of the week, realized that her students still had misunderstandings about the phenomena.

Video Analysis

The greenhouse analogy provides a concrete, real-world representation to help students make sense of the greenhouse effect, which can seem like an abstract concept. Like the Earth's greenhouse gases, the garden greenhouse structure absorbs radiation that would normally escape into the air around the greenhouse. In this video, you will see Ms. Walker review the greenhouse analogy with her students. The students had already learned about how gardening greenhouses work, and Ms. Walker used this discussion as a reminder. With help from Emily, Ms. Walker describes the gardener as opening up windows to let out excess heat from the greenhouse. She goes on to explain that there are no "windows" in the atmosphere that we can open to let the heat out. Cristabel, however, asks, "Why can't greenhouse gases escape through the ozone hole?" During her reflection, Ms. Walker shares her surprise by Cristabel's question, stating that they had never talked about the ozone in previous classes.

Reflect

If Cristabel said this in your classroom, what would be your next step?

Think about the trade-offs of the greenhouse analogy and how this analogy led to Cristabel's confusion. If you had been in Ms. Walker's shoes, how would you respond in this situation? How can your instructional plans take into account the potential drawbacks of the greenhouse analogy, as well as students' misconceptions about greenhouse gases and the ozone hole? Consider having your students do activities in which they contrast the ozone hole with climate change, so they learn the important differences.

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Teaching Resources:

California Education and the Environment Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm

Carbon Dioxide Measurements and Data: http://www.esrl.noaa.gov/gmd/ccgg/trends/

Ozone hole data and updates: http://ozonewatch.gsfc.nasa.gov/index.html

NASA animations: http://www.nasa.gov/centers/goddard/earthandsun/climate_change.html

NASA Exploring Albedo Activity: http://eosweb.larc.nasa.gov/EDDOCS/scierbe.html

National Geographic Climate and Weather Videos: http://video.nationalgeographic.com/video/player/science/earth-sci/climate-weather-sci.html

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