Weather and Seasons
Content Background Document

1. Introduction

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As we begin our content exploration of weather patterns on Earth, take a moment to consider what you already know about this topic. You're probably very familiar with weather in your area. Is it sunny all the time, or do you often have fog each morning that clears away by afternoon? What about rain? Do you live in an area that has a large amount of rainfall or doesn't have much rain at all? You've probably watched a meteorologist on TV give the weather forecast for your area (or for a place you're traveling to) and used that information to plan what to wear the next day or to pack for a trip. Or perhaps you check a favorite website to get daily weather updates.

But how deep is your understanding of the processes that cause weather patterns in certain areas? Do you understand what causes certain places on Earth to be hotter than others or to have more rain or wind? Can you connect the energy we receive from the Sun to the flow of energy through atmospheric and oceanic processes? Can you explain why some places near the ocean have more moderate temperature patterns over the course of a day or a year, or why higher elevations experience cooler temperatures on average than lower elevations? Can you explain why the daily weather is so variable when the energy we receive from the Sun, based on Earth's orbit and rotation, is so regular and predictable?

This document will challenge you to broaden and deepen your understanding of weather on Earth. It will also support and further your own learning about the underlying factors that lead to different weather patterns around the world. The content that follows will focus on how the Sun's energy causes uneven heating on Earth's surface and how this energy is transferred through oceans, land, and the atmosphere to cause the weather we experience every day. The goal of this exploration is for you to develop a conceptual understanding of these ideas so you'll be able to teach your elementary students more effectively.

The following content was written with you, the teacher, in mind. The subject matter is tied to the lessons you'll be teaching, but the concepts are presented at a higher level to equip you with the tools and background you'll need to guide student learning. Students at the kindergarten level are just beginning their weather journey by observing and recording weather data and thinking about the weather patterns they observe. A deeper understanding of the processes involved in causing weather patterns will enable you to consider students' ideas and support their learning in a more comprehensive way.

The goal of this lesson series is for you and your students to emerge with (1) accurate understandings of the atmospheric conditions commonly referred to as "weather" (e.g., sunny, cloudy, rainy, hot, or cold); (2) an ability to observe and measure weather; (3) ways to analyze weather data in order to study weather patterns, and (4) an understanding that weather patterns vary throughout the day, from month to month, and from place to place. The lessons in this unit on weather explore fundamental science ideas that connect student understandings and experiences with daily weather to weather patterns that are unique to a given place. This helps students recognize that weather isn't a random, day-to-day event but occurs in predictable patterns at certain times of the day or year or in specific locations. It is essential that students grasp this concept at an early elementary level in order to understand the disciplinary core ideas they'll encounter in the upper-elementary and middle-school grades regarding the systems on Earth that cause these patterns.

Throughout this lesson series, we assume that most kindergarten students will have some understanding of weather. They will know, for example, when it's cloudy or sunny, hot or cold outside, or windy. But they may not know that all of these factors are typically referred to as "weather," and they will probably never have collected data to identify and analyze weather patterns. Most students will likely be familiar with the idea of temperature even if they've never used a thermometer to collect temperature data. They might understand that weather is different in different places, but they likely won't be able to describe these differences beyond saying, "It's colder there" or "We get more sunlight than that place."

By the end of the lesson series, students will have (1) observed and studied various weather patterns on Earth; (2) collected weather data to use as evidence that weather patterns vary throughout the day, from month to month, and from place to place; (3) constructed graphical representations to help them better understand and identify weather patterns; and (4) strengthened their mathematical skills, including counting skills, number sense, measurement, and math reasoning.

2. Getting Started: Understanding Weather and Climate

Have you ever wondered whether *weather* and *climate* are just two different words that describe the same thing (what it's like outside)? If they truly are distinct concepts, how can we distinguish them?

Let's clarify the key differences between climate and weather. *Climate* is an *average* of atmospheric conditions in broader geographic regions over longer periods of time, such as a year, a decade, a century, or even longer. *Weather* involves changes in the atmospheric conditions we experience over relatively short periods of time, such as hours, days, or weeks. Weather can be a passing afternoon thunderstorm, a cold front, or a persistent heat wave. It's a snapshot of atmospheric conditions at a particular time and place.

A smart student once said, "Climate helps you decide what clothes to buy; weather helps you decide what clothes to wear." In other words, climate is what you *expect*, but weather is what you *get*.

A combination of atmospheric factors determine both weather and climate. Temperature and rainfall are the primary factors that determine weather and *long-term* climate. For example, studying the range of temperatures in a particular location can help us predict the weather we might experience on a *daily* basis, studying the range of temperatures *throughout the year* is essential for understanding the long-term climate of that location. The amount and frequency of precipitation are also important for understanding weather and climate. In particular, it's important to know the average yearly rainfall a place typically receives, but it's also important to know whether the rainfall occurs frequently in small amounts or occurs less often but in larger amounts. Other factors, such as wind speed and direction, cloud cover, relative humidity, and the frequency of unusually strong storms like hurricanes and typhoons, are also important in determining the weather and climate of a specific place.

3. Uneven Heating of Earth's Surface

The single force that controls all of the factors we just discussed that relate to weather and climate is the Sun's energy. The total amount of solar energy that reaches Earth and its transfer throughout Earth's systems is what ultimately drives the weather and long-term climate in a given place. The Sun's energy causes water to evaporate and rise into Earth's atmosphere. Then as water cools in the atmosphere, clouds form and rain pours down. The Sun's energy warms air masses, resulting in air-pressure differences that create wind. The Sun’s energy causes temperature variations in both shallow and deep ocean water, contributing to ocean currents that affect climate patterns like El Niño and La Niña. The Sun’s energy drives violent storms like tornados and hurricanes, which cause enormous devastation to life and property.

The rest of our discussion will focus on the big idea that Earth’s surface is heated unevenly, and as a result, we see different weather and climate patterns all over the world. First, we’ll explore how incoming solar energy heats Earth unevenly. Then we’ll discuss atmospheric and oceanic processes that transfer energy around Earth, causing the different weather conditions we see in our everyday lives.

4. The Sun Powers Our Earth

The story of weather and climate begins with the Sun. Kindergarten students are familiar with the Sun, and they know it provides Earth with light. But they probably don’t realize that the Sun also provides Earth with energy. They can see the Sun’s light and feel its warmth on their skin, but they won’t learn about solar radiation until later grades. However, it’s important for students to understand that the Sun provides us with more than just light. Energy from the Sun warms our world and, in turn, causes the different weather patterns we experience.

STOP AND THINK

Why can you get sunburned from the Sun,
but not from sitting under a lamp? What causes sunlight to
affect our skin differently than a lightbulb?

4.1 How the Sun Transfers Heat

Understanding how heat energy moves around is important because this is ultimately what powers our weather. Heat energy moves from one place to another in three ways: by conduction, convection, or radiation (see figure 1). It may surprise you to know that the Sun doesn’t heat Earth directly, at least not in the way a stove heats soup or a furnace heats your house.

Conduction is the transfer of heat *between* substances, like when a spoon in a hot bowl of soup becomes warmer because heat energy is transferred from the soup to the part of the spoon in contact with the soup. Heat moves from particle to particle within the spoon until the whole spoon is warm. Even though the Sun is extremely hot, it can’t transfer heat energy by conduction to Earth, since there is very little matter in space for heat to travel through.

Another way heat travels is through *convection*. Convection is the dominant way heat moves in liquids and gases. As a liquid or gas is heated, it become less dense and rises, allowing cooler liquid or gas (which is more dense) to take its place. As this cooler liquid or gas begins to heat, it rises as well, while the previously heated gas or liquid begins to cool again and sink. This creates continuous circulation between cooler and warmer liquids or gases. Just as heat is transferred through conduction between objects, such as the hot bowl, the soup, and the spoon mentioned earlier, it moves throughout a liquid by convection. Rather than transferring heat between objects, such as from the soup to the spoon, convection moves heat *within* a substance, such as within soup or through oceans or the atmosphere. However, the Sun doesn’t transfer heat energy to Earth by convection either.

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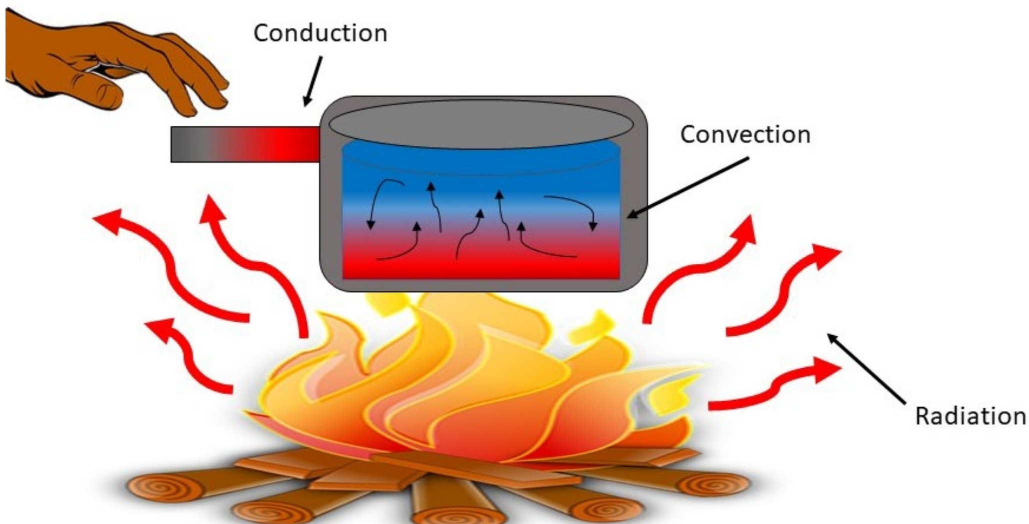

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Figure 1. Conduction, convection, and radiation

The Sun’s energy reaches Earth another way—through *radiation*. Radiation refers to a specific type of energy—electromagnetic waves—traveling through the nothingness of space without the aid of liquids, solids, or gases. There are many types of electromagnetic waves, including radio waves, microwaves, infrared light, visible light, ultraviolet light, X-rays, and even radioactive gamma rays. These waves, which are sequenced based on the amount of energy each wave carries, have been arranged on a chart called the *electromagnetic spectrum* (or *EM spectrum*) (see figure 2). The EM spectrum shows the range of wavelengths, from longer, lower-frequency wavelengths that carry smaller amounts of energy to shorter, higher-frequency wavelengths that carry larger amounts of energy.

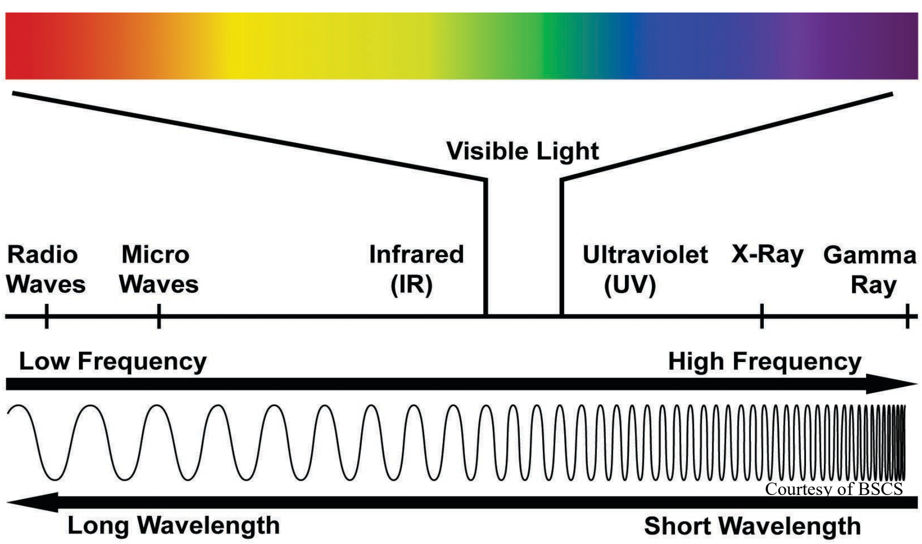

Figure 2. Only a small segment of the electromagnetic spectrum is visible light. The other segments of the spectrum aren’t visible to the human eye.

Most of the Sun's energy comes from three segments of the EM spectrum:

1. Infrared light (IR)
2. Visible light
3. Ultraviolet light (UV)

Each of these segments of the EM spectrum is called *light* even though we can see only those wavelengths categorized as visible light. Everything that has warmth radiates at least a little *infrared light*. Even though our eyes can't perceive infrared wavelengths, special glasses have been invented that enhance this segment of the EM spectrum so the human eye can "see" warmth.

Visible light is a very small segment of the EM spectrum. Cells at the back of our eyes are sensitive to this narrow range of wave energy. When these cells detect the wave energy, they send a signal to our brains that enables us to see it. For this reason, it's called *visible light energy*, or *visible light*. Different wavelengths in the visible EM spectrum constitute different colors of the rainbow. Red constitutes the lowest energy of visible light waves (closest to infrared—or below red—energy levels), and violet constitutes the highest energy of visible light waves (closest to ultraviolet—or above violet—energy levels).

Like infrared light, *ultraviolet light* is invisible to the human eye, although some animals have the ability to detect it. Ultraviolet light damages our cells and causes skin to tan or burn when it's exposed to sunlight for extended periods. Overexposure to ultraviolet light can also cause some forms of skin cancer. This is why we buy sunscreen that has a UV protection rating.

When infrared light, visible light, and ultraviolet light reach Earth's surface, the radiated electromagnetic wave energy is transformed into thermal energy. *Thermal energy* describes the motion of particles (atoms and molecules) that make up a substance. The thermal energy of a substance is determined by taking its temperature, so to speak, or measuring the average motion of the particles. When sunlight reaches a surface, some energy is absorbed, and the rest is reflected. What does it mean when a surface absorbs light energy? When sunlight reaches a sidewalk, for example, the energy is transferred to the particles (atoms and molecules) that make up the sidewalk, increasing their motion. As these particles move faster, the temperature of the sidewalk increases. How much an object's temperature increases depends on (1) the *intensity* of light striking the surface, (2) the *length of time* the light shines on the object, and (3) the *amount* of light the object absorbs and reflects.

So if energy from the Sun warms Earth day after day and year after year, why does Earth's surface not become hotter and hotter? The reason is that as Earth *receives* energy from the Sun (mostly in the form of visible and ultraviolet light), it simultaneously *radiates* energy back into space, mostly in the form of infrared light. On average, the energy Earth reflects back into space balances out the energy it absorbs from the Sun; so in general, the temperature of Earth stays about the same. For a number of years, many scientists and citizens have been concerned about rising temperatures on Earth—referred to as *global warming*—caused by changes in Earth's atmosphere that trap absorbed energy from the Sun and keep it from radiating back into space. The causes of global warming resulting from atmospheric changes are complex and exceed the scope and purpose of this document. Students may raise questions about this issue as they study the Sun's effect on climate, so be prepared to engage them in a scientific discussion.

4.2 Temperatures on Earth Vary in a Predictable Pattern

You don't even have to think about it in North America. When you travel north, you instinctively know that temperatures generally get cooler. When you head south, you know it's time to get out your bathing suit and suntan lotion! However, if you lived in the Southern Hemisphere, you might drive north instead of south for sun and fun. How can that be? The temperature of any place on Earth's surface tends to vary depending on how far north or south of the equator it is. Areas closer to the equator generally have warmer climates, while areas farther away from the equator generally have cooler climates (see figure 3).

STOP AND THINK

How would you explain the reason for cooler temperatures farther from the equator?
What factors do you think contribute to temperature differences across the globe?

You might notice another pattern besides warm temperatures at the equator and frigid temperatures in polar regions. Closer to the equator, for example, the air temperature is pretty much the same all year round, but farther away from the equator, temperature variations between the summer and the winter are greater. This consistent pattern of temperature variations at different times of the year constitutes *seasons*. The coldest time of year in North America is *winter*, and the warmest time of year is *summer*. The transition from summer to winter is *fall*, and the transition from winter to summer is *spring*. Many students think that every place on the planet experiences summer the way North America does, and they don’t realize that June, July, and August are considered *winter* months in the Southern Hemisphere.

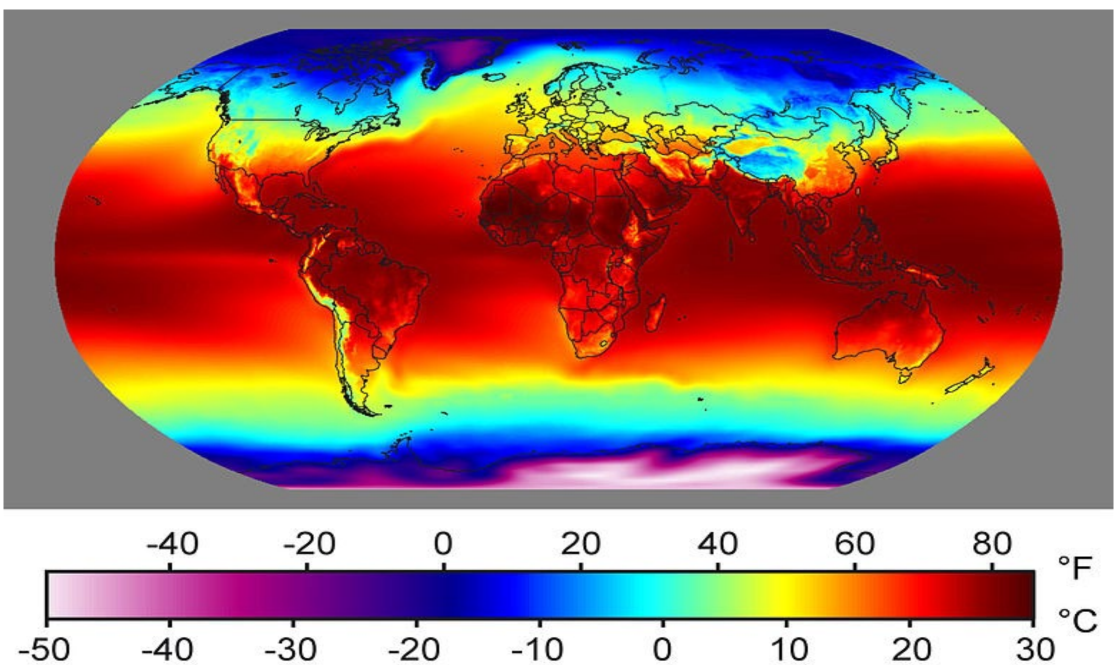

Image created by Robert A. Rohde/Global Warming Art

Figure 3. Average mean temperatures around the world

To complicate things further, the tropics experience few seasonal shifts in temperature; instead, rainfall patterns change from summer to winter. Some locations in the tropics experience a dry season during the summer and a very rainy season during the winter, with very little change in temperature, so people who live there have a completely different notion of weather in the winter and summer.

STOP AND THINK

Why do you think the Southern Hemisphere and the Northern Hemisphere experience opposite seasons? Why do seasonal temperature variations overall become more pronounced farther away from the equator? What do you think are the primary factors that contribute to seasons?

As noted earlier, the extent to which light energy increases an object's temperature—in this case Earth's temperature—depends on (1) the *intensity* of light striking the surface, (2) the *length of time* the light shines on the object, and (3) the *amount* of light absorbed and reflected. Other factors, particularly elevation and proximity to the ocean or another large body of water (such as the Pacific Ocean), influence a region's temperature patterns as well. Both elevation and proximity to water relate to how solar energy is distributed around Earth. We'll discuss this in more detail later.

Measuring Temperature

Kindergarten students don't understand the numerical scales—Fahrenheit or Celsius—we typically use to measure temperature, but in this lesson series, they observe how hot or cold it is outside and learn to measure temperature using thermometers.

Scientists define *temperature* as a measure of the kinetic energy of matter. All matter is made up of tiny particles in constant motion. Motion means that the particles have kinetic energy. The average kinetic energy of the molecules of a substance is its temperature. When we describe an object as having a high temperature, we mean that its molecules have a high average kinetic energy. Likewise, if an object has a low temperature, its molecules have a low average kinetic energy. In other words, *the kinetic energy of a substance relates to how much heat it has. That heat, or energy, is measured as the temperature of the substance.*

Thermometers are tools that help us measure temperature. In this lesson series, students use a real thermometer and might be curious about how they work. Students at the early elementary level should be able to understand the following about how thermometers work:

- Most thermometers have long, thin glass tubes filled with liquid (that is usually red).
- As the air around the thermometer gets warmer, the liquid rises higher in the tube.
- As the air around the thermometer gets cooler, the liquid falls lower in the tube.

Scientists, however, would say in a more accurate way that all thermometers work by detecting changes in some property of matter resulting from changes in internal energy. Since most materials expand when heated and contract when cooled, the most commonly used type of thermometer detects these changes. Old-style standard thermometers contained a liquid sealed in a glass tube. Alcohol and the liquid metal mercury were often used in these types of thermometers because they expanded and contracted at a uniform rate. Heating caused the liquid in the glass tube to expand and rise, and cooling caused the liquid to contract and fall. Today, digital thermometers have replaced mercury thermometers. Digital thermometers measure temperature using different types of sensors that detect changes in temperature.

Scientists often use a temperature scale based on absolute zero called the *Kelvin scale*. The lowest point on this scale is absolute zero. *Absolute zero* is the theoretical point at which the molecules of any matter would stop moving or have no kinetic energy.

Just as length and distance are measured using the metric and decimal systems, temperature is measured using either the Fahrenheit or the Celsius scale, named for the scientists who developed them. On the Fahrenheit scale, the freezing point of water is 32 degrees, and the boiling point of water is 212 degrees. On the Celsius scale, the freezing point of water is 0 degrees, and the boiling point of water is 100 degrees. In this lesson series, the thermometers students use will be based on the Fahrenheit scale, since most temperature information they're exposed to uses this scale (e.g., weather forecasts, newspapers, digital clocks and other devices).

4.3 The Intensity of Light Striking Earth's Surface Influences Heating Patterns

Have you ever considered that the shape of Earth affects its climate? The fact that Earth is round impacts light intensity at any given place on the planet. *Intensity* refers to how much of the Sun's energy reaches a particular spot. Remember that the Sun is about 150 million kilometers (92.9 million miles) away from Earth and sends out a fairly constant supply of energy. You could imagine those rays of energy as parallel lines or arrows coming from the Sun to Earth. When the Sun is directly overhead, those arrows would strike Earth just about straight on, but when the Sun isn't directly overhead, sunlight hits Earth's surface at a less direct angle (see figure 4).

Courtesy of BSCS

Figure 4. When the Sun is overhead, its rays strike Earth's surface more directly, but when the Sun isn't overhead, its rays strike Earth at a less direct angle.

This is easy to envision if you think about the Sun rising in the morning and the rays hitting your house at a less direct angle. As the Sun climbs higher in the sky, its rays gradually shift and increase in intensity until they're directly overhead. In the afternoon, the Sun's rays again strike your house at a less direct angle and become less intense as day turns to nighttime. This change in the angle of the Sun's rays as they hit Earth from east to west occurs every day, and you can actually feel the changes in intensity. In the morning and evening, when the Sun hits Earth at the lowest angle, you feel less heat because the light energy is less intense. At noon, when the Sun is highest in the sky, the light energy is more intense, and you feel more heat.

STOP AND THINK

Why do temperatures vary from the equator to the poles?
What does Earth's round shape have to do with this temperature variation?

To gain a deeper understanding of what happens when sunlight strikes Earth's surface at different angles, let's visualize the variations in intensity when light strikes a *flat surface*. Then we'll apply this idea to Earth's *curved surface*. If you point a flashlight directly at a flat surface, it shines a concentrated circle of light on a specific area. But if you tilt the surface at an angle, the circle of light becomes an oval with a larger surface area than that of the circle (see figure 5). Intensity decreases when light hits an angled surface because the light spreads out over a larger surface area. The amount of light energy coming from the flashlight doesn't change; it just spreads out as it hits the surface at an angle. So the *same amount* of light energy is spread over a larger amount of space.

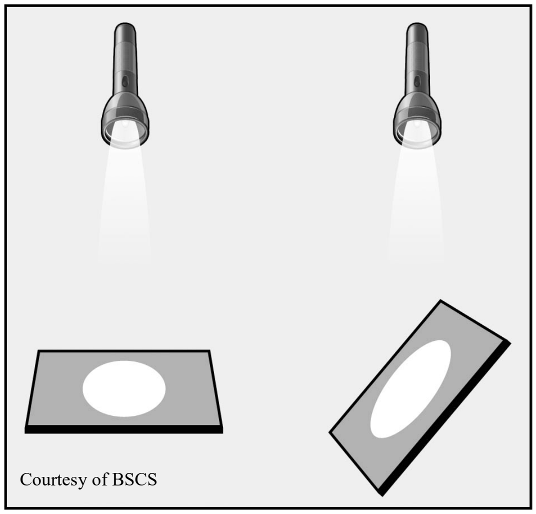

Figure 5. Light striking a surface directly is more concentrated—or intense—than light striking a surface at an angle.

Now let's apply this idea to the curved surface of Earth at various positions from north to south. To orient ourselves, let's initially assume that the Sun is directly overhead at the equator. (As we'll find out later, this occurs only twice a year, but it's a good starting point for considering how Earth's spherical shape impacts temperature.) The most direct (and most intense) sunlight strikes Earth at the equator. As you move farther away from the equator, the sunlight strikes Earth at a less direct angle, and the intensity of the light energy decreases (see figures 6 and 7). In other words, the light energy hitting Earth's surface north or south of the equator is more spread out, like light from a flashlight when it hits an angled surface.

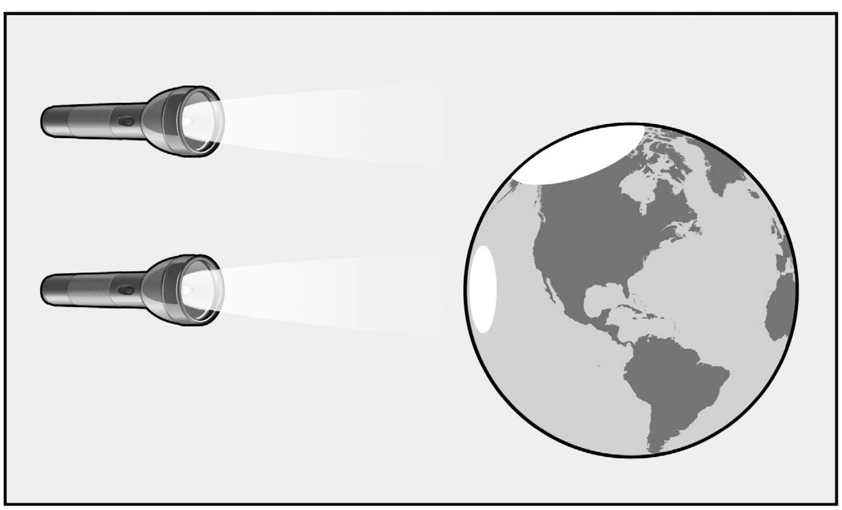

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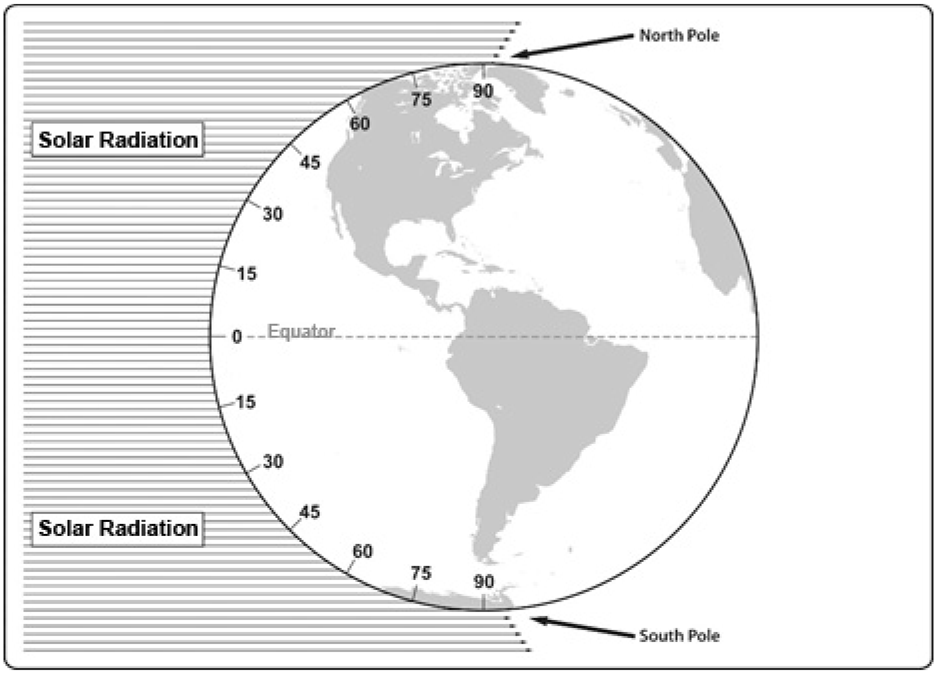
Figure 6. Light energy is less intense (more spread out) as sunlight strikes Earth's surface at less direct angles farther away from the equator.



Art adapted with permission from Dr. Lawrence Woolf, General Atomics Sciences Education Foundation

Figure 7. Solar radiation (rays of sunlight) strikes Earth's surface at different angles according to latitude. Solar radiation is more intense near the equator and less intense (more spread out) at the poles.

STOP AND THINK

To figure out the amount of light intensity in a location close to the equator, count the number of lines (rays of sunlight) hitting Earth in that segment, such as between the equator and latitude 15° N. How many rays of sunlight are in this segment?

Misleading Distances

Have you ever noticed that the distance light travels from the Sun to the equator is slightly less than the distance it travels from the Sun to the poles? Students' everyday experiences with heat and light suggest that the farther you are from the source, the less intense the light or heat will be. This idea can reinforce the misconception that distance from the Sun causes the temperature variations from the equator to the poles. However, the distance from the Sun to the equator versus the poles might be compared to sitting 4 feet from a very warm campfire or sitting 4¼ feet from the campfire. That extra quarter inch makes almost no difference in the intensity of warmth you feel. The actual difference in distance between the Sun and the equator versus the Sun and the poles is about 6,376 kilometers (3,863 miles)—compared to the *total distance* from Earth to the Sun of about 150 million kilometers (92.9 million miles)!

4.4 The Duration of Light Striking Earth's Surface Influences Heating Patterns

The angle of sunlight is one reason temperatures vary on Earth, but it's only part of the story. Remember the factors that contribute to how much an object heats up when it encounters electromagnetic waves? The first factor was the *intensity* (angle) of sunlight striking the surface; the second factor was the *length of time* the light shines on the object; and the third was the *amount* of light the object absorbs and reflects. The first factor (intensity or angle of light) explains why colder regions are generally farther from the equator and warmer regions are generally closer to the equator. But it doesn't explain why locations in the Northern Hemisphere experience cold months at the same time locations in the Southern Hemisphere, like Australia, parts of Africa, and South America, experience hot months. It also doesn't explain why our counterparts in the Southern Hemisphere are enjoying the peak of ski season while we're sunbathing at the beach in August! When we consider this additional twist in the climate story, we realize that latitude—distance from the equator—doesn't fully explain temperature variations at different times of the year in different locations.

The other part of the story relates to our second factor: the *length of time* light shines on an object. It seems as if every location on Earth would experience half a day of sunlight and half a day of darkness, but think about where you live. Do you ever experience 12 hours of daylight and 12 hours of nighttime? Unless you're reading this document at the equator, day and night are 12 hours long only twice a year—once in the spring and once in the fall. We call those particular days the *spring equinox* and the *fall equinox*.

Notice that part of the word *equinox* sounds a bit like the word *equal*, and in fact, during each equinox, night- and daytime hours are equal all over the world. If every location on the planet received 12 hours of sunlight *all the time*, then the length of time the Sun shines north or south of the equator wouldn't vary at all. It would be the same everywhere. But the length of our days and nights does vary, which is where Earth's tilt and orbit come into play.

STOP AND THINK

During what part of the year are the days longer than the nights in your location? Is the relationship between hours of daylight and temperatures on Earth?

4.5 Earth's Tilt and Orbit

To complete the picture, we need to consider the position of Earth on its axis (an imaginary line between the North and South Poles). In figure 7, this imaginary line is pointing straight up and down in relation to the Sun. But in reality, the axis tilts at a 23.5-degree angle. As Earth orbits the Sun, its axis always tilts in the same direction—in general, toward the North Star, also known as *Polaris*. This means that part of the year, the Northern Hemisphere is tilted toward the Sun, and the direct rays of the Sun (which during the spring equinox on March 21 are directly over the equator) strike Earth somewhere north of the equator. In fact, by the time June 21 (the summer solstice) rolls around, the Sun's rays are directly overhead at latitude 23.5° N. That latitude might ring a bell. It's the *Tropic of Cancer*, which marks the northernmost point on the globe where the Sun is directly overhead at noon—and your shadow would be directly under your feet. This means that all locations north of the Tropic of Cancer receive more intense sunlight—light striking Earth at a more direct angle—between March 21 and September 21. Thus, temperatures in the Northern Hemisphere are warmer at this time of year.

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As Earth makes its orbit around the Sun, the tilt continues to point in the same direction (see figure 8). In December, the North Pole will point away from the Sun, and the South Pole will point toward the Sun. During the winter solstice (on December 21), the direct rays of the Sun will hit Earth 23.5 degrees south of the equator at a latitude called the *Tropic of Capricorn*. So between September 21 and March 21, the Southern Hemisphere receives more concentrated solar energy than it does between March 21 and September 21, and the light the Northern Hemisphere receives is more spread out (less intense) because the Sun's rays hit the northern half of the world at a less direct angle. This results in cooler temperatures in the Northern Hemisphere between September 21 and March 21.

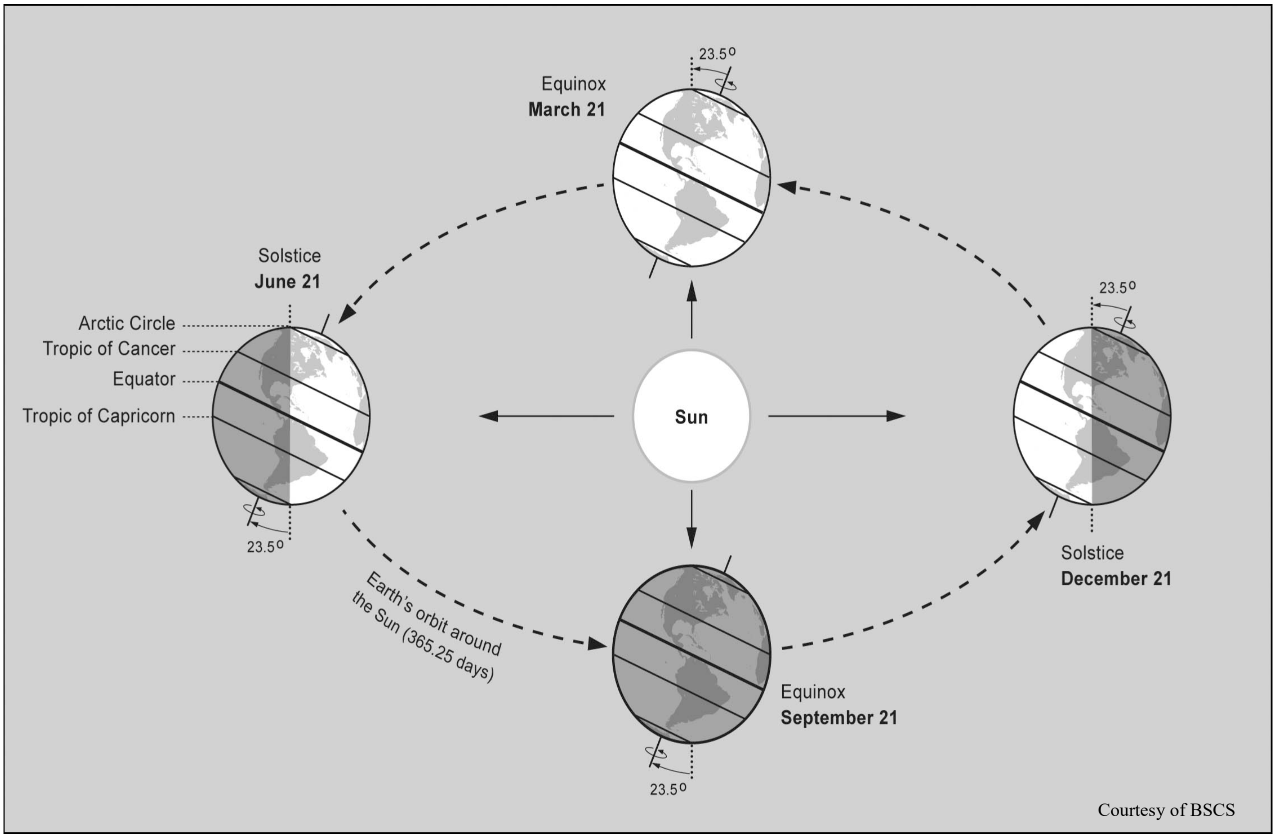

Figure 8. Earth's tilt and orbit around the Sun cause the Sun's rays to hit Earth's surface at varying angles at different times of the year based on latitude.

In addition to variations in the intensity of sunlight in winter and summer, the tilt of Earth on its axis also causes variations in the number of daylight hours and hours of darkness (nighttime). As we noted earlier, days are longer in the Northern Hemisphere during the summer, which means there's not only more intense sunlight, but the Sun's rays hit Earth for a longer period of time than in the winter months, increasing heat energy in that segment of the planet. You may have heard the expression "land of the midnight Sun." Look at figure 9, which shows day length on June 21. Can you see why the northernmost latitudes on Earth have daylight for a full 24 hours? The Sun never sets at these latitudes for a portion of the summer months because of Earth's continuous tilt toward the Sun during this period. Conversely, the North Pole experiences very little daylight during the winter months in the Northern Hemisphere (see figure 8). Study figure 8 closely to see how the position of Earth changes throughout its orbit around the Sun.

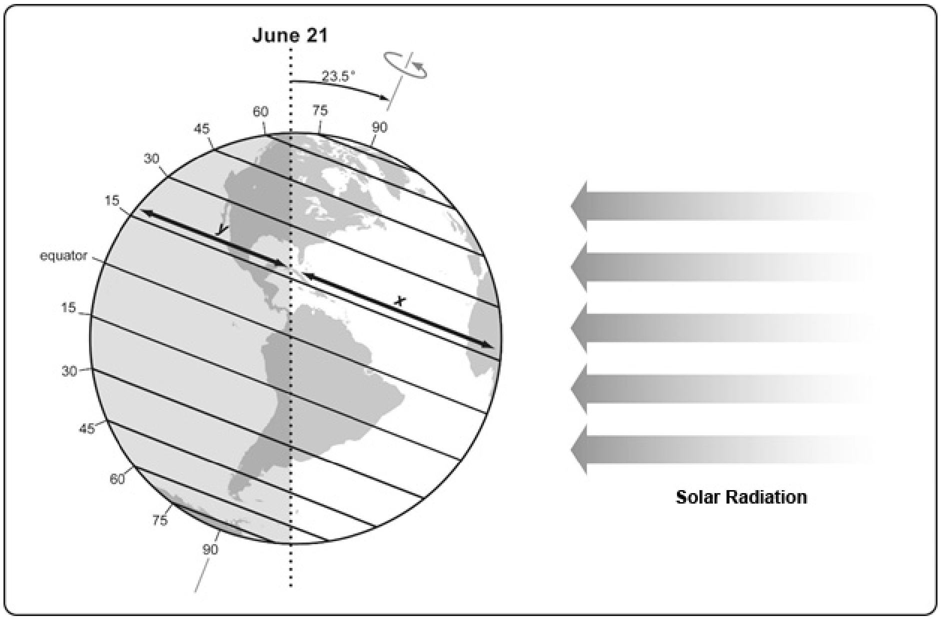

Figure 9. Length of day on June 21

STOP AND THINK

Look again at figure 9. What does this content representation illustrate about the relationship between the Sun and Earth, as well as the angle of light and the length of days? What misconceptions might this representation reinforce?

So while Earth's spherical shape causes different locations on Earth to experience varying intensities of sunlight based on latitude, Earth's tilt and orbit cause variations in the intensity and duration of sunlight throughout the year. As mentioned earlier, the equator receives direct sunlight only twice a year—during the spring and autumn equinoxes. From March to September, direct sunlight strikes between the equator and 23.5° N, and from September to March, direct sunlight strikes between the equator and 23.5° S.

5. Putting It All Together: Incoming Solar Energy and Uneven Heating

In this section, we discussed how intensity and duration of the Sun's energy influence temperature patterns on Earth based on latitude and time of year (seasonal shifts in direct sunlight based on Earth's tilt and orbit). But is one of these factors more important than the other, or do they play equally important roles in the temperature patterns we see on Earth?

Let's consider Nome, Alaska. Nome is located in a part of the world that receives 24 hours of sunlight at the height of summer. Does the length of time Nome receives light and heat from the Sun mean that it's warmer than areas that get just 12 hours of sunlight—like at the equator? Of course not. Even though the equatorial regions spend much less time soaking up the Sun's rays, they're still warmer than Nome, Alaska, because solar radiation (light energy) is more *intense* at the equator. Although the additional hours of sunlight keep temperatures warmer in Nome than they would be if daytime hours were shorter, the sunlight is much more spread out and therefore less intense at that latitude than it is at the equator.

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Both intensity and duration of sunlight play equally important roles in the uneven heating of Earth's surface. The intensity of sunlight changes as Earth orbits the Sun, and the duration of sunlight changes over the course of the year as the Sun's energy heats different portions of Earth's surface for varying lengths of time. However, although intensity and duration explain why some places experience hotter temperatures than others, these factors represent only part of our weather and climate story. A third factor also plays a significant role in climate and weather: the ability of an object to absorb and reflect heat. In the following section, we'll discuss this factor and how it influences oceanic and atmospheric flow patterns on Earth.

6. The Movement of Energy around Earth

We know that solar energy heats our world, and that variations in the intensity and duration of sunlight hitting planet Earth cause uneven heating. Temperature patterns influence weather on Earth, but they aren't the only influence. When solar energy reaches Earth, it becomes part of a complex system that transforms the Sun's energy and transfers it all over the world, causing the movement of air and water that influences the weather we experience.

To comprehend this system, we must first understand how different materials on Earth's surface absorb, store, and reflect solar radiation, and how varying rates of absorption and reflection influence oceanic and atmospheric flow patterns on Earth. The movement of air from areas of higher pressure to areas of lower pressure also influences the directional flow of winds and surface ocean currents around the world. The Coriolis effect adds a twisting direction to the flow of air and water, which further complicates the picture. All of these factors combine to create wind and ocean-current patterns that influence weather and climates on Earth's surface.

6.1 How Objects Absorb and Reflect Solar Radiation

First, let's discuss how different earth materials absorb, store, and reflect solar radiation and how this impacts a region's weather and climate. Some materials are good reservoirs of heat energy because it takes a lot of heat to change their temperature. Other materials warm up quickly but release their heat energy just as quickly. Liquid water is a substance that holds heat well. Regions with an abundance of vegetation also tend to hold more heat energy than areas with no vegetation. But deserts and ice fields, bare rock, and concrete cities are less able to retain the Sun's energy and consequently have greater temperature swings from day to night. Water heats slowly and releases heat slowly because the Sun's energy has to penetrate the surface and distribute heat over a depth of several meters. By contrast, land heats more intensely and quickly and releases heat more quickly because the Sun's energy has to penetrate only a few centimeters of rocks and soil.

STOP AND THINK

Have you ever walked along a beach on a summer afternoon and noticed that the sand is unbearably hot, while the water feels refreshingly cool? If you return to the same beach at night, you find yourself walking across cool sand into water that feels warm by contrast. The sand absorbs and releases the Sun's heat faster than water, so the temperatures of sand are more extreme than water temperatures.

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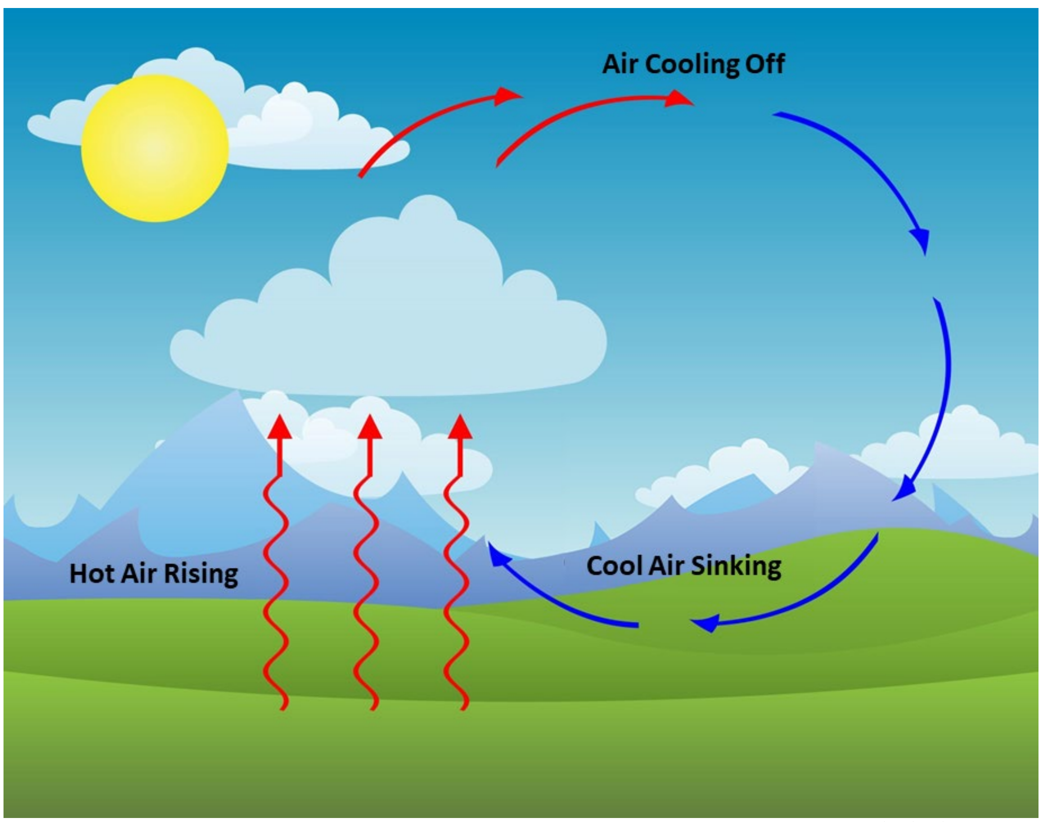
Certain surfaces reflect more sunlight than others—primarily based on the color of those surfaces. For example, a vast parking lot covered in black asphalt will absorb more sunlight than a vast ice field that reflects more of the Sun's energy. Clouds reflect 95% of solar energy, whereas forests or oceans reflect only about 10% of the Sun's energy and absorb the rest.

6.2 Churning Air

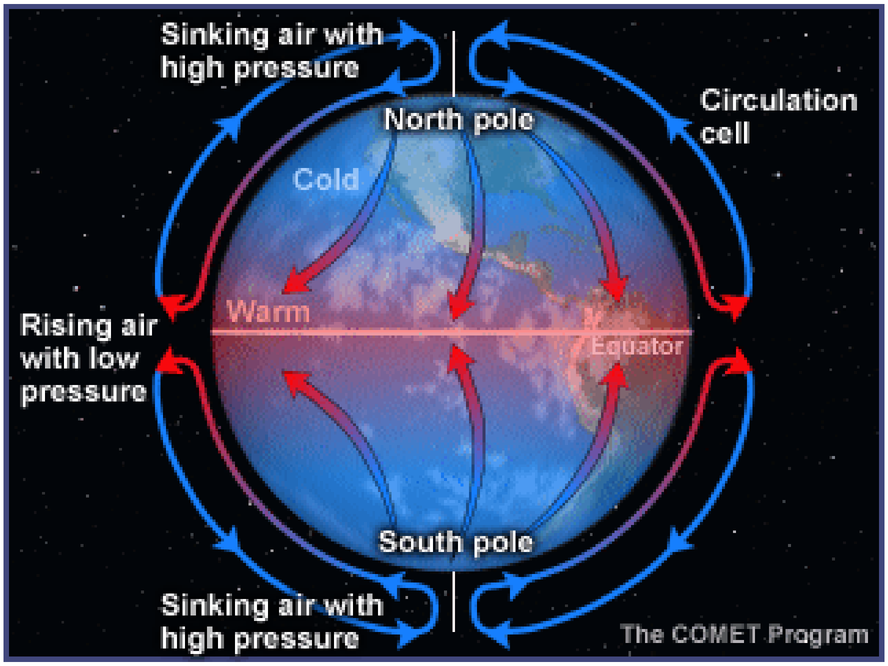
The atmosphere is churning all the time. Like a sea of air, the atmosphere flows with its own currents. Various types of surfaces, such as oceans, bare land, and forests, have different pressures and temperatures that cause the air masses above them to move. For example, the air above land tends to heat and cool quickly like the land does. Because oceans heat and cool much more slowly than land, the air masses above the ocean surface experience more moderate fluctuations in temperature. (We'll discuss the moderating effect of oceans later.) The heating and cooling of surface air causes the air to move.

Although we won't dig into the molecular level in this document, it's important to remember that air is made up of tiny particles of different gases, including carbon dioxide, oxygen, and nitrogen. As we discussed earlier, *convection* is the transfer of heat within a liquid or a gas. As air heats up, the gases expand and rise, and the cooler, denser air above it sinks (see figures 10 and 11). This creates a continuous circulation of air even though we rarely see this cycle in action.



Courtesy of Cal Poly Pomona

Figure 10. Air expands and rises as it heats up and then sinks as it cools and condenses.



Courtesy of Comet.NCAR.edu

Figure 11. On a planetary scale, the differential heating of air creates large convection cells that influence our atmosphere.

6.3 What Is Wind, and What Causes It?

Simply put, wind is moving air. In almost all cases, unequal heating in the atmosphere (temperature variations) causes this movement of air. These temperature variations (the kinetic energy of molecules) cause differences in air pressure. Cooler air is associated with higher air pressure, and warmer air is associated with lower air pressure. Because areas of higher air pressure are more dense (or heavier), they tend to replace areas of lower air pressure. Therefore, when cooler air moves into an area of lower pressure, the warmer air rises, and the cooler air replaces it. As the warmer air rises higher in the atmosphere, it begins to cool and sink toward Earth, where it warms up again. Through this process, a complete three-dimensional semisphere of circulating air is created. What we call *wind*, however, is the horizontal flow of moving air, with directional shifts influenced by Earth's rotation. In this lesson series, students will only describe the windy weather outside, but they may ask what causes the wind.

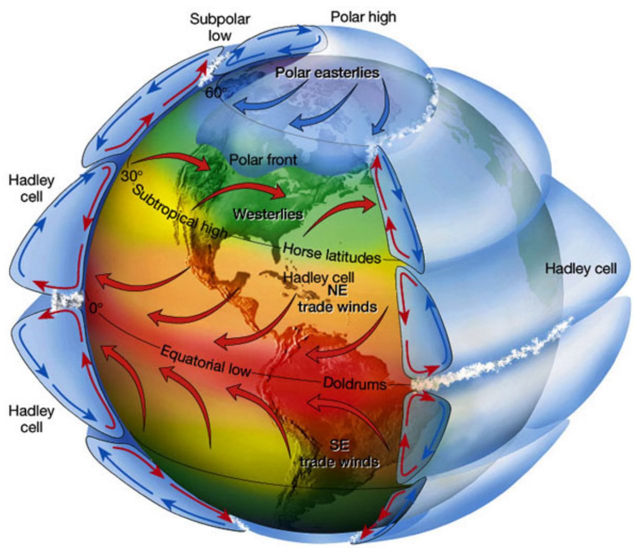
A larger pattern of wind moves across the entire Earth. These *global winds* are described as follows:

> *While many winds are caused by local conditions, there is a pattern of winds that covers the entire earth. It is caused by the uneven heating of Earth. The belt of hot air around the equator is a low-pressure area. Caps of cold air at the poles are high-pressure areas. If the earth did not turn, one giant convection cell would carry cold air from the poles to the equator. Another giant convection cell would carry warm air from the equator to the poles. But the earth is turning. It turns once every 24 hours. Because of this movement, places on the equator move at a speed of 1,600 kilometers an hour. A place very near one of the poles, however, is hardly moving.*
>
> *… Anything moving over the earth follows a curving path caused by the earth's rotation.… Air moves in a curved path between the equator and the poles. … Near the equator is a belt of air that is strongly heated by the sun's nearly vertical rays. This heated air rises, thus creating a belt of low pressure called the* doldrums *(**dole**-drumz).*

The air in this belt moves mostly upward. There are only weak winds nears the earth's surface. … The rising air currents from the doldrums turn north and south toward the poles as they become upper-level winds. This movement, or circulation, of air between the equator and the poles, combined with the effects of the earth's rotation, produces a series of wind belts in each hemisphere.… The winds belts describe an overall picture of the movement of air in the earth's atmosphere. (Ramsey, Gabriel, McGuirk, Phillips, & Watenpaugh, 1986).

The Coriolis Effect

The movement of air masses and ocean currents is also influenced by the Coriolis effect, which results from the rotation of Earth on its axis. The Coriolis effect causes a twisting motion in the flow of water and air on Earth.

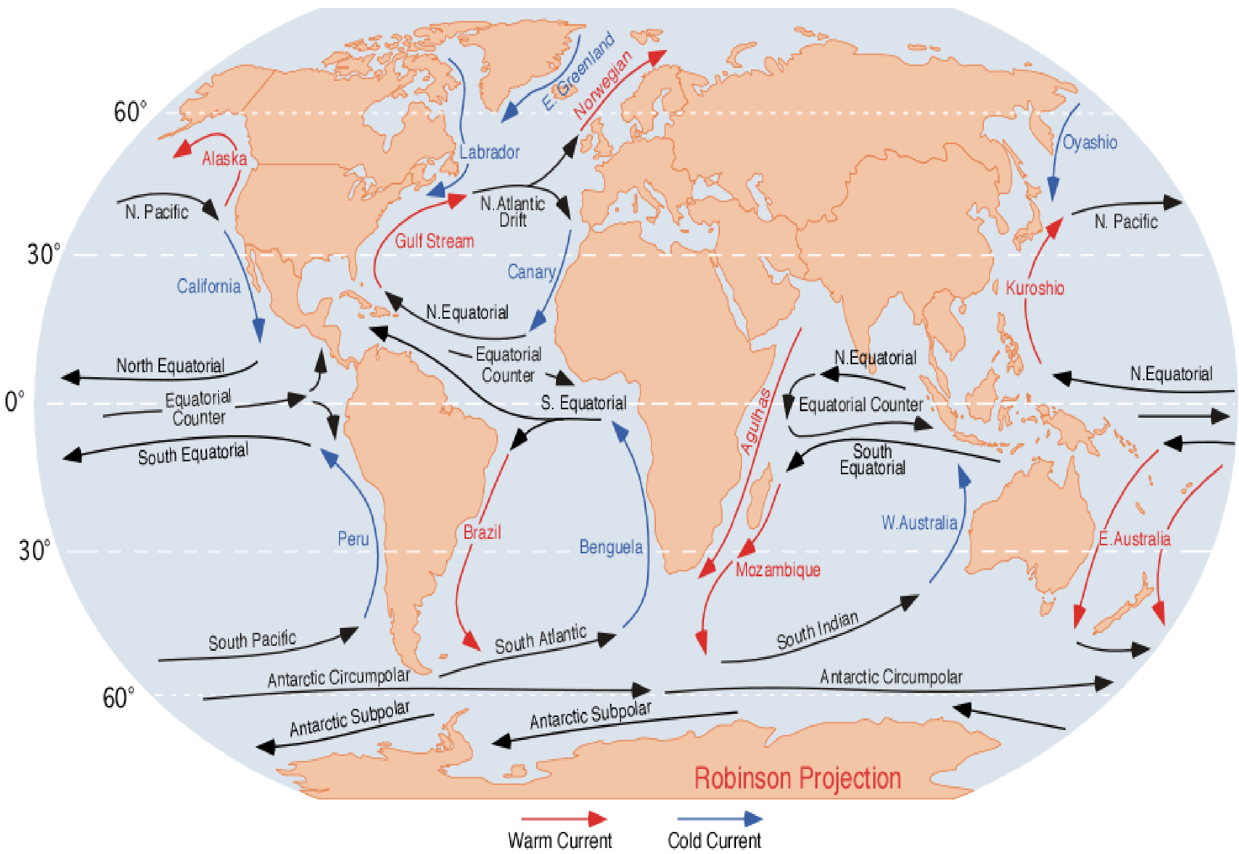


Courtesy of Lutgens and Tarbuck

6.4 The Moderating Effect of the Oceans

The materials on Earth's surface heat unevenly, causing the air above those materials to heat unevenly as well. However, oceans are slowly absorbing and releasing solar energy all the time, and since water has the ability to hold on to the Sun's energy for longer periods of time, oceans and other large bodies of water have a moderating effect on the weather and climate of adjacent land masses. Air that sit's over an ocean tends to have the same temperature as the ocean, which doesn't change drastically from one season to the next. When this air moves, it can change temperatures on the land nearby. A good example of this is San Francisco. During the winter months, the warmer air that sits over a warm ocean moves onto land and keeps the city mildly warm. However, San Francisco is a chilly city during the summer months because the cooler air sitting over a cool ocean blows over the land and lowers the air temperature.

Ocean temperatures influence the temperature of air above the water, but it's also important to note that oceans don't have a uniform temperature or salinity. This causes movement in oceans called *currents*. Three key factors influence ocean currents: gravity, winds, and differences in temperature and salinity. The gravitational pull between Earth and the Moon causes *tidal currents*, winds or sea breezes cause *surface ocean currents* (see the "Sea Breezes" sidebar on the following page), and differences in water density, controlled by temperature (*thermo*) and salinity (*haline*), cause *deep ocean currents*. The process that drives deep ocean currents is referred to as *thermohaline circulation*. Thermohaline circulation begins in Earth's polar regions, where water gets very cold. As sea ice is formed, the surrounding seawater becomes saltier, which increases its density. As this saltier, colder water becomes heavier (denser), it starts to sink. Warmer surface water is then pulled in to replace the sinking water, and this warmer water eventually becomes cold and salty enough to sink. This process sets in motion the global circulation of water (see figure 12).



Courtesy of Dr. Michael Pidwirny/Wikimedia Commons

Figure 12. The global circulation of water

Sea Breezes

Breezes typically form along a coastal area because of varying rates of heating between land and water. Land heats and cools more quickly than water, causing shifting breezes during the day and night. During the day, the air above land heats quickly and expands, causing the air pressure to decrease. Air over nearby oceans or bodies of water, has a higher pressure. As this air moves toward land, it causes a sea breeze. At night, the air over land cools quickly, becoming denser with higher pressure. As this dense, cool air moves toward the ocean, it creates an offshore breeze. The unequal heating of land and water is one of the major causes of wind movements across the globe. If you live near a coastline, engage students in noticing the movement and direction of sea breezes.

7. The Water Cycle

Our weather story is almost complete! We've discussed the uneven heating of Earth's surface and how it influences ocean currents and air circulation around the world, so we now have a better idea of how temperature and currents work. But the final part of our story involves a process called the *water cycle*.

The air around us contains in microscopic particles of water called *water vapor*. If you live in a humid location, you've probably felt water in the air. If you live in a dry area, you may never have realized that water is in the air around you.

When the tiny water particles in the air come in contact with something cool, they clump together to form drops of water. This process is called *condensation*. When tiny water particles warm up and move into the air, the process is called *evaporation*. People often think that when liquid water evaporates, it disappears, but in fact, the small particles of water evaporate into the air.

Water evaporates and condenses all the time in nature. Water is constantly on the move. It either goes into the air (evaporates) or comes out of the air (condenses). The pattern of water movements on Earth is called the *water cycle*. The movement of water is responsible for much of the weather on Earth. When rain or snow is falling, water is moving out of the air as it condenses. When it's a sunny day, water is evaporating and moving into the air.

The water cycle begins with the evaporation of seawater from the oceans (see figure 13). Oceans are Earth's primary reservoir for water, holding more than 97% of all the water on the planet. As this evaporated water enters the atmosphere, it moves around with air currents. As water particles rise into the atmosphere and cool, they condense, forming clouds that create rain or other frozen forms of precipitation like snow or hail. Most of Earth's precipitation falls right back into the ocean, but some of it moves over land, where it soaks into the ground to become groundwater or flows over Earth's surface into streams and rivers. Plants use some of this water as well, and some evaporates back into the air. Eventually the rainwater or snowmelt makes its way back to the oceans, and the water cycle begins again.

But why does water move? The short answer is because of thermal energy or heat. When liquid water is heated enough, it changes from a liquid to a gas. Heat causes the liquid water particles to move faster and spread farther apart. When this happens, some of the liquid particles closest to the surface of the water become a gas called *water vapor*. For example, when the Sun warms the water in lakes, rivers, oceans, and even puddles, the water gradually evaporates or changes from a liquid to a gas.

When the air that contains water vapor cools, this causes the water particles to lose thermal energy (heat) and move closer together. When this happens, the water vapor (gas) changes to liquid water. If water continues to lose energy (or heat), it will eventually change from a liquid to a solid. In other words, it will become ice.

How does all of this apply to weather? As moist air—air filled with water vapor—rises away from the warm surface of Earth, the air and water vapor cool. When the water vapor becomes cool enough, it condenses into tiny liquid-water droplets that form clouds. When a lot of water in the air condenses, the water droplets in the clouds become larger and heavier and eventually fall from the clouds as rain.

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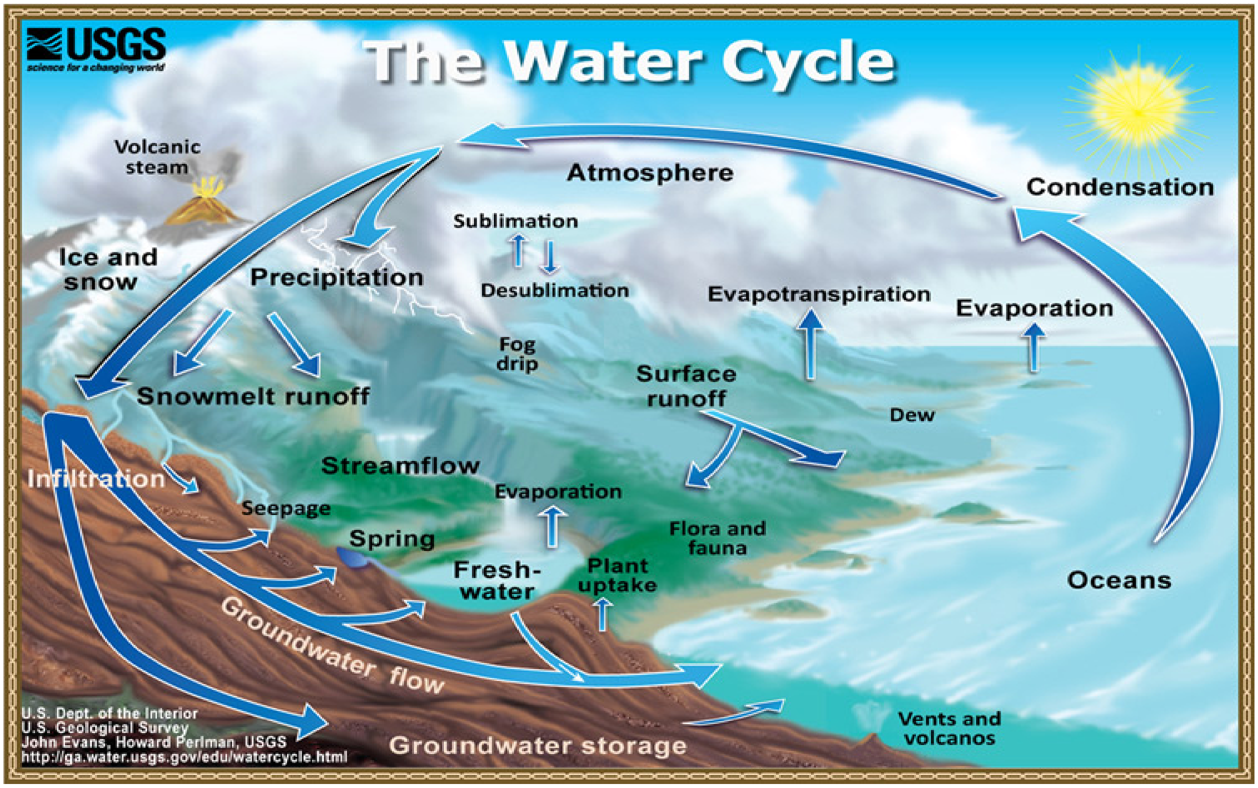

Photo courtesy of USGS.com

Figure 13. The water cycle

Precipitation

Precipitation is water in either a liquid or solid form that falls to the ground. There are four types of precipitation: rain, snow, sleet, and hail.

Precipitation begins in clouds. Clouds are collection of tiny droplets of liquid water suspended in the air. These tiny droplets may range from 0.002 to 0.1 millimeters in diameter. In clouds where large amounts of moisture are present, water droplets may join together. When these droplets reach 2.0 to 6.5 millimeters in diameter, they may fall as rain.

Hail forms when droplets of liquid water freeze in layers around a small nucleus of ice. Hailstones grow larger as the rising and falling air currents that occur during severe thunderstorms toss them up and down. Sleet forms when raindrops fall through a layer of air below 0 degrees Celsius and freeze. Sleet usually falls during the winter. In summer, sleet melts and falls as rain. Snow forms when water vapor changes directly to a solid. Snowflakes are usually six-sided crystals that appear in many different patterns. For snow to form, the air temperature must be below freezing.

8. The Influence of Regional Geography on Weather

Another factor that influences regional weather and climate is *elevation*. Higher elevations tend to be cooler than lower elevations regardless of the time of year. Air is less dense at higher elevations; consequently, air particles (molecules) are more spread out, lowering the average air temperature. A process called *adiabatic heating and cooling* also affects temperatures in the mountains. As air rises over the mountains, it expands and cools. This causes the water vapor in the air to cool and condense into liquid-water droplets that form clouds. As air pockets on the other side of the mountains begin to sink, the water droplets in the air compress and heat up again, causing the clouds to become water vapor once more. Adiabatic heating and cooling explains why the leeward sides of mountain ranges often experience a different climate than the windward sides.

9. Weather Patterns and Forecasting

A combination of latitude, the tilt and orbit of Earth, air and ocean currents, and regional geography and elevation can be used to explain our weather. But these factors vary all over Earth, causing unique weather patterns in some places that are different from others. While Southern California experiences mostly sunny, moderate weather because of its latitude and proximity to the cool currents of the Pacific Ocean, other places, such as Detroit, Michigan, experience more drastic seasonal shifts in temperature and precipitation.

Weather data can be observed and measured using a variety of instruments, including thermometers, rain gauges, anemometers (to measure wind force and speed), and hygrometers (to measure humidity). Using this data, we can better understand the weather around the world and forecast future weather based on the predictable patterns of winds and ocean currents, global and local temperature patterns, and the amount of water in our air. Forecasting weather allows us to plan ahead for what we might wear to work, how we might pack for a trip, or how we can avoid severe weather when it's likely to occur.

This lesson series doesn't go into the processes that cause weather on Earth, but it does engage students in observing, recording, and analyzing weather data to determine the patterns that exist in our weather. Students will observe and record the weather they see, learn how to measure temperature with thermometers, and create content representations, such as charts and graphs, to show weather patterns. These activities will help students understand that weather varies throughout the day, from month to month, and from place to place. This understanding will equip them to begin explaining the processes on Earth that cause weather patterns.

Severe Weather

Many Americans use the word *storm* when referring to a small area of severe weather, such as a thunderstorm or snowstorm. Meteorologists also use this word to describe large-scale weather systems that include fronts or areas where air masses collide. Fronts are frequently areas where violent and dramatic weather changes occur. We describe these violent changes as thunderstorms, snowstorms, dust storms, and other forms of severe weather.

Storms and severe weather events, such as lightning, tornadoes, hurricanes, and blizzards, aren't part of this lesson series, but students have firsthand experience with these phenomena and often find them fascinating.

Lightning and thunder are products of a *thunderstorm*. As the unstable air rises and falls within a thunderstorm, electrical energy builds up and is then discarded between positively and negatively charged areas. This discharge of electrical energy, called a *lighting stroke*, happens when the attraction between positive and negative charges becomes stronger than the air's resistance to electrical flow. Lightning can occur within a cloud, between clouds, and between a cloud and the ground. The air around a lightning strike is very hot, with temperatures reaching as high as 50,000 degrees Fahrenheit. The heating and cooling of air around a lightning strike causes thunder. As the hot air cools, a shock wave is created, and we hear this shock wave as a thunderclap.

Tornadoes are violently rotating columns of air extending from a thunderstorm to the ground. Products of severe thunderstorms, tropical storms, and hurricanes, tornadoes form when strong, veering winds occur in the lowest mile of the atmosphere. Changes in wind direction and increasing wind speeds cause a spinning effect in the lower atmosphere. As air rises within a thunderstorm, the rotation changes from horizontal to vertical, causing a tornado to form. With wind speeds of 250 miles per hour or more, tornadoes can be up to a mile wide and carve destructive paths up to 50 miles long. They can last minutes or up to an hour depending on the strength of the storm. A *funnel cloud* is a violently rotating column of air that has not touched the ground and is not considered a tornado.

Hurricanes usually begin as storms over oceans in which the water is at least 80 degrees Fahrenheit. Water vapor rises quickly and begins rotating as winds increase. Hurricanes have an “eye” or an area of complete calm in the middle of the swirling winds. Not all storms over the oceans become hurricanes. For a storm to be considered a hurricane, it must produce sustained winds of at least 74 miles per hour (mph). Tropical systems that produce winds of 39 to 73 mph are classified as *tropical storms*. Systems that produce winds under 38 mph are classified at *tropical depressions*. Hurricanes produce large amounts of rain and can frequently spawn tornadoes. The most deadly aspect of hurricanes is the storm surge, or wall of water, that accompanies the hurricane as it makes landfall.

Winter storms, such as blizzards, can occur during the winter and springs months. Dangerous conditions, such as strong winds, extreme cold, ice, and heavy snow, often accompany these storms. The strong winds that occur during winter storms can cause blizzard conditions with wind-driven snow, snowdrifts, and life-threatening wind chill. Although snow is common during winter storms, another type of precipitation that can occur is sleet, which consists of raindrops that freeze into ice before reaching the ground.

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