The Sun’s Effect on Climate:
Content Background Document

1. Introduction

As we begin exploring the Sun’s effect on Earth’s climate and seasons, take a moment to consider what you already know about this topic.

You probably have a basic picture in your mind of the relationship between Earth and the Sun. For example, you may know that night and day occur because Earth spins on its axis every 24 hours, and that Earth orbits the Sun every 365.25 days. (You’re probably also aware that we make up the extra quarter day each year that it takes Earth to revolve around the Sun by having a leap year with 366 days.) And you almost certainly know that the Sun not only provides Earth with heat and visible light but also emits different kinds of energy waves, such as ultraviolet light that can lead to sunburn if you’re out too long in unfiltered sunlight.

If someone were to ask you why there are seasons, you might say it has something to do with the way Earth tilts on its axis. But how deep is your understanding of the relationship between Earth and the Sun? Can you connect your understanding of the seasons to observations of the Sun’s path when it appears higher or lower in the sky at different times of the year? Can you explain why we experience summer in the Northern Hemisphere in June, July, and August while the Southern Hemisphere is experiencing the chill of winter? 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 daily weather is so variable when the energy we receive from the Sun, based on Earth’s orbit and spin, is so regular and predictable?

This document will challenge you to broaden and deepen your understanding of the Sun’s effect on climate and seasons. It will also support and further your learning about the underlying factors that lead to seasonal temperature variations, especially how Earth’s tilt and orbit influence the intensity of the Sun’s energy and seasonal temperature patterns. Understanding these factors will help you relate these concepts to the uneven heating of Earth’s surface referred to in the *Next Generation Science Standards* (NGSS Lead States, 2013). The goal of this exploration is for you to develop a conceptual understanding of climate so you’ll be able to teach your elementary students more effectively.

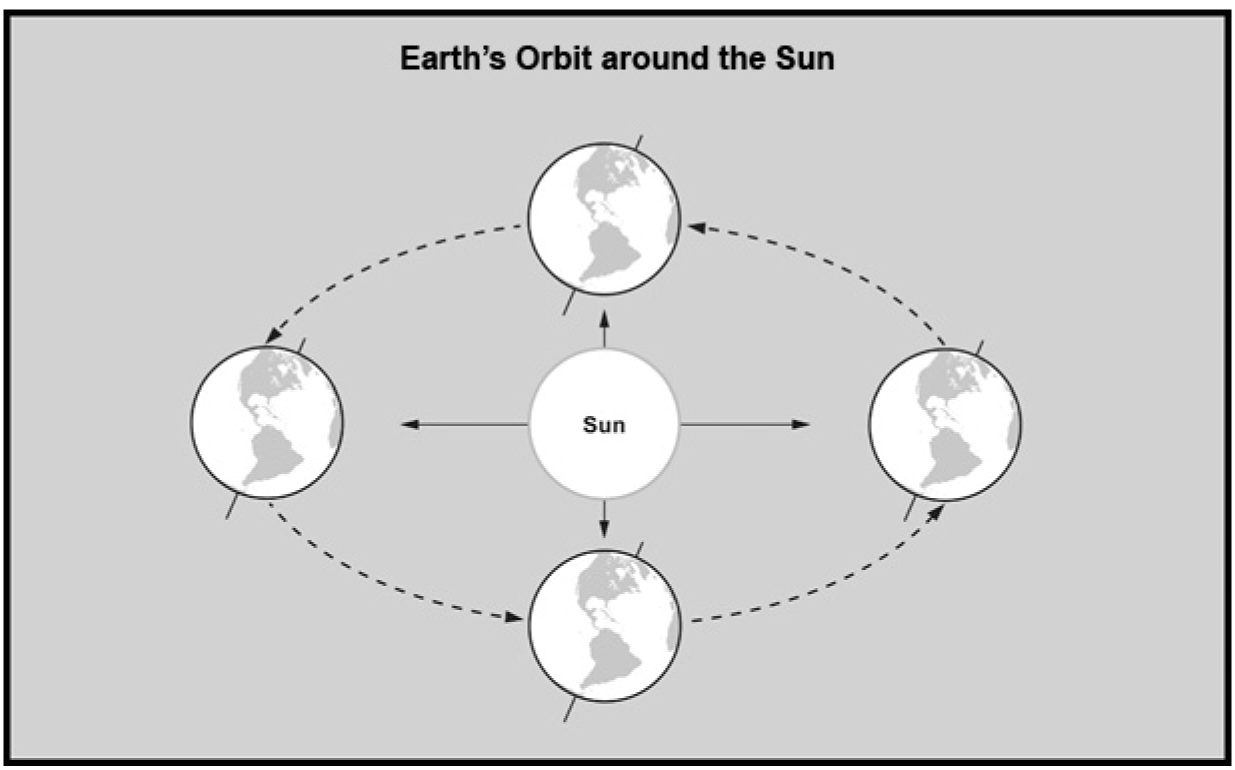
This content was written with you, the teacher, in mind. The subject matter is tied to the lessons you’ll be teaching, but the concepts are presented at a higher level to equip you with the tools and background you’ll need to guide student learning. After all, teachers should know more about science content than their students!

2. Getting Started: Understanding Celestial Motion

The goal of this module is for you and your students to emerge with (1) a clear mental image of how Earth moves in relation to the Sun, (2) an understanding of why this motion causes varying amounts of energy from the Sun to impact different locations on the planet in regular and predictable patterns, and (3) how this differential (uneven) heating influences Earth's climate and seasons. Most elementary science curricula fail to connect the fundamental science concept of motion in the solar system with climatic patterns and seasons on Earth, but this relationship is essential for developing students' understandings based on 6th-grade science standards and grade-level activities.

Throughout this series of lessons, it's assumed that most 6th-grade students have been introduced to the basic relationship between the Sun and Earth. According to Disciplinary Core Ideas for Earth and the Solar System in the *Next Generation Science Standards* (NGSS Lead States, 2013), expectations for 5th-grade students regarding Earth and the solar system include understanding that "the orbits of Earth around the sun and of the moon around Earth, together with the rotation of Earth about an axis between its North and South poles, cause observable patterns. These include day and night; daily changes in the length and direction of shadows; and different positions of the sun, moon, and stars at different times of the day, month, and year."

Most 6th graders will already have seen models of the solar system in which the Sun is static, and Earth not only rotates daily on its axis but also revolves annually around the Sun (see figure 1). It's difficult, however, for students to retain this abstract image of Earth in relation to other bodies in the solar system when their personal experiences support the idea that Earth is stationary, and the Sun and Moon move across the sky. Reinforcing these experiences are references to the Sun rising in the east and setting in the west. Using such terms as *sunrise* and *sunset* seems practical because, from our earthly perspective, the Sun does appear to rise and set, but this terminology only reinforces student misconceptions that the Sun moves while Earth stands still.



Courtesy of BSCS

Figure 1. Every year, or 365 days, Earth makes a complete orbit (revolution) around the Sun, and every 24 hours, Earth spins on its axis, marking day and night.

However, by 6th grade, students are beginning to make sense of celestial motion apart from their own experiences and perceptions. Students in early elementary school typically have a geocentric, or Earth-centered, understanding of the motion of objects in space, while students in upper elementary school and middle school are ready to learn about the motion of objects in space from a heliocentric, or Sun-centered, perspective. Before you begin teaching this unit, you'll want to make sure that both you and your students have a clear mental image of the Sun at the center of the solar system, with Earth revolving (orbiting) around the Sun every year or 365 days and rotating (spinning) on its axis every 24 hours, marking day and night. You might begin by asking your students these questions:

- Why do we start a new year every 365 days?
- Which objects moving in space cause us to experience a year on Earth?

To prevent confusion, the word *orbit* rather than *revolve* has been used in this document and the RESPeCT lessons to describe Earth's motion around the Sun. However, since many national and state standardized tests use the R words *revolution* and *rotation*, make sure your students know the difference between these terms by the end of the unit.

Students should also know that Earth's orbit is very nearly circular, even though in most textbook illustrations, it appears elliptical. Elliptical representations lead many students to believe that Earth is farther from the Sun at certain times of the year and closer at other times. As a result, students often hold a common misconception that seasons are caused by variations in Earth's distance from the Sun at different times during its orbit. For example, many students believe that Earth is closer to the Sun during the summer and farther away during the winter. But in fact, Earth's orbit is only *slightly* closer to the Sun around January 4 of each year. On this day, called Earth's *perihelion*, our planet is 147.5 million kilometers from the Sun. In contrast, around July 4—Independence Day in the United States—is Earth's *aphelion*, the day when our planet is farthest from the Sun at 152.6 million kilometers. The difference between Earth's perihelion and aphelion is 5.1 million miles. If that seems like a lot of miles, remember that compared to the total distance between Earth and the Sun, this only represents about a 3% change from January to July.

STOP AND THINK

Based solely on Earth's distance from the Sun, would you expect July or January to be the hottest month of the year? Why?

To make sense of the relationship between Earth and the Sun, students need to envision how other bodies in the solar system compare with Earth in size and distance from the Sun. At present, there are no really effective ways of representing these size and distance relationships in the classroom, which tends to reinforce student misconceptions rather than correct them. (No doubt you've seen models of the solar system mapped out from one end of a school playground to the other in an attempt to demonstrate scale and size.) Based on their own observations, students might think that the Sun and the Moon are about the same size and distance from Earth. But actually, the Moon is approximately one quarter the size of Earth, while the Sun is the size of 109 Earths! They merely appear to be the same size because the distances from Earth are so different.

If the diameter of Earth (about 12,756 kilometers) is used as a measuring tool, the Moon would be about 30 Earths away, while the Sun would be about 12,000 Earths away. To put it another way, the Sun is 400 times bigger than the Moon, but it's also 400 times farther away from Earth, so the Sun and Moon appear to be about the same size in the sky. While it isn't necessary for students to memorize statistics on planet size and distance, it is important for them to have a general sense of the *relative* size and shape of these celestial bodies (see table 1). One of the most strongly held misconceptions students—and adults —hold is that warmer summer temperatures are caused when Earth moves closer to the Sun at certain times of the year. To change this perception, we need to help students visualize why the *relative positions* of Earth and the Sun—not the distance between them—influence the seasonal temperature variations we experience on Earth.

Table 1. Relationship between Earth, the Moon, and the Sun in size and relative distance

Object in the Solar System	Approximate Distance from Earth in Kilometers	Number of Earths Away	Diameter in Kilometers	Number of Earths Across
Sun	150,000,000	12,000	1,392,000	109
Moon	384,000	30	3,500	0.27
Earth			12,756	1

Your students will likely bring prior knowledge about Earth's motion, size, and distance from the Sun with them as they investigate the Sun's effect on climate and seasons. But as you teach the RESPeCT lessons, you'll need to remind students that classroom models using lightbulbs, flashlights, globes, Styrofoam balls, and other materials to represent the size of Earth in relation to the Sun and Moon and the distance between them are inaccurate and distort the actual size and scale of these objects in space.

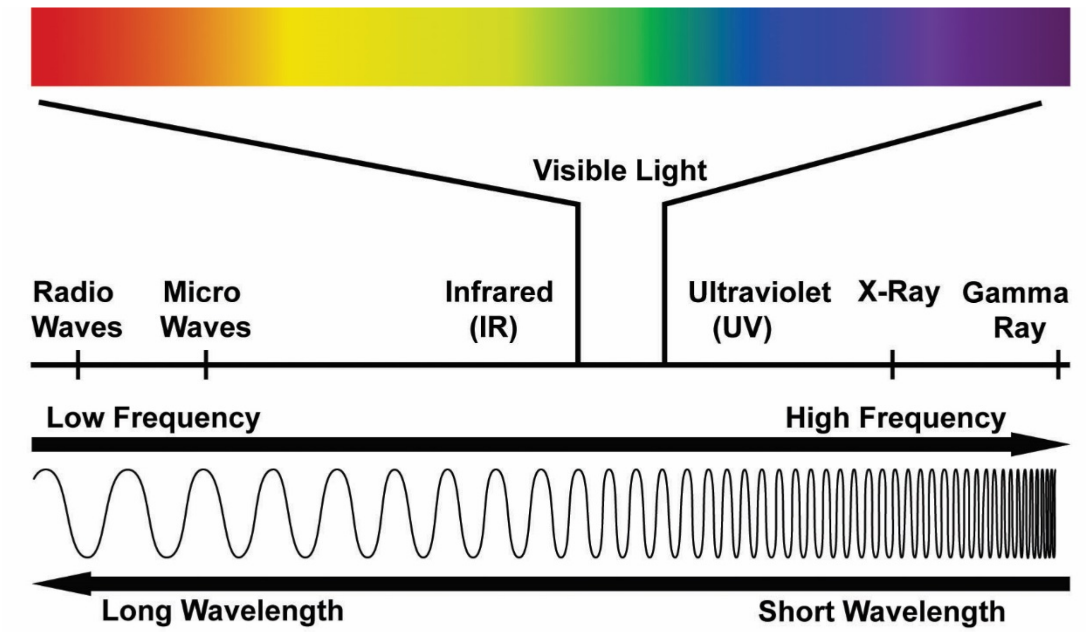
3. Three Kinds of Solar Radiation

Students are familiar with the Sun's energy because they see light and feel warmth on their skin. But not all of the Sun's energy reaches Earth as visible sunlight.

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, our moods, and the growth of plants differently than a lightbulb?

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. These are examples of *conduction* in which heat is transferred through matter from particle to particle, 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 and 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 to Earth by conduction, since there is very little matter in space for heat to travel through. So the Sun's energy must reach 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, 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.



Courtesy of BSCS

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
2. Visible light
3. Ultraviolet light

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.

Figure 3 compares three kinds of light energy from the Sun with light energy from a standard lightbulb. As you can see, a lightbulb emits more infrared light than visible light and very little ultraviolet light.

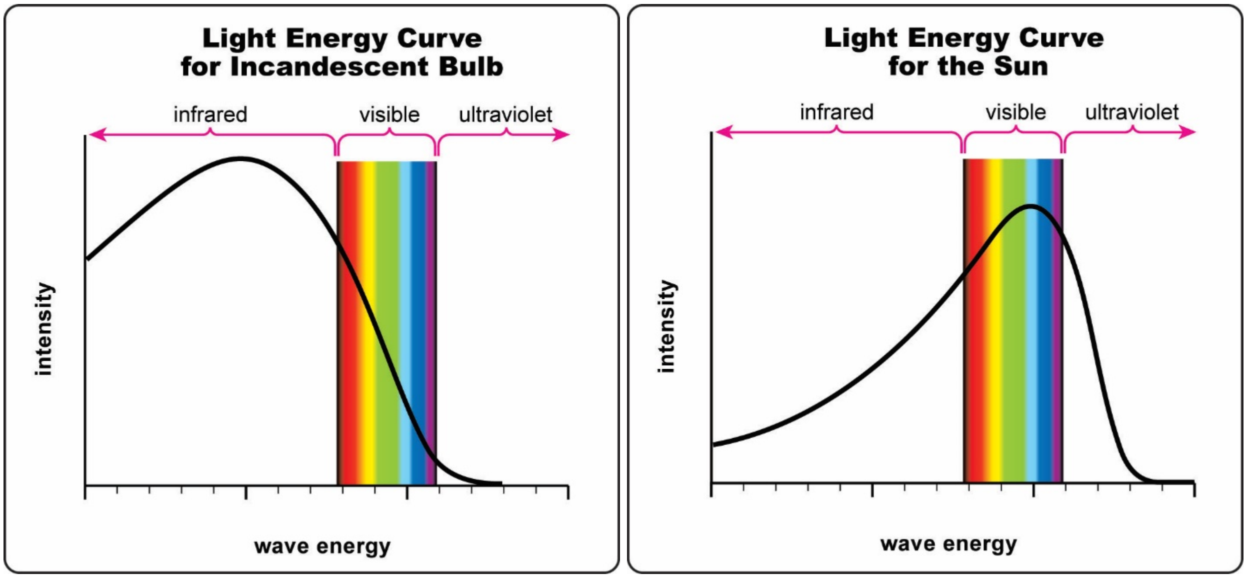


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Figure 3. Comparison of light energy emitted from an incandescent lightbulb and the Sun

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. Temperatures on Earth Vary in a Predictable Pattern

You don't even have to think about it. When you travel north, you instinctively know that temperatures generally get cooler. When you head south, 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.

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.

Global Warming, Climate Change, and the Greenhouse Effect

The terms *climate change*, the *greenhouse effect*, and *global warming* are often confused as referring to the same thing and are sometimes simply misunderstood. But these terms mean very different things.

Climate change is a measure of the long-term differences of weather patterns across the world over periods of decades to millions of years. Earth's climate has changed countless times throughout its 4.5-billion-year history, but these changes have often been very slow, with long periods of relative stability. Records indicate that Earth may have once, or even multiple times, been almost entirely covered in snow and ice. Some evidence also suggests that at other times in the past, Earth was exceptionally hot. Think of Earth's climate as a pendulum swinging back and forth from hot to cold roughly every 10,000 to 100,000 years.

The *greenhouse effect* is essential to the survival of living organisms on this planet. Almost all of us have experienced getting into our cars on a warm summer day and realizing that the interior is much warmer than the outside air. This is the greenhouse effect in action. Short-wavelength, visible light from the Sun filters through the car windows and is absorbed in the interior, causing an increase in temperature. The seats then radiate energy, but in the form of longer-wavelength, infrared light that can't escape through the glass as easily as the shorter wavelengths of visible light do. So the warmth is trapped inside the car. Earth's atmosphere behaves just like car windows. Some of the atmospheric gases, such as carbon dioxide, methane, and even water vapor, have the ability to trap infrared light (heat). Without the greenhouse effect, heat from Earth's surface would freely escape into space, causing Earth to become much cooler than it currently is, particularly at night. The greenhouse effect is not, in itself, a problem; rather, the accumulation of large quantities of greenhouse gases is of concern because the greenhouse effect becomes amplified, and too much of Earth's heat gets trapped, leading to an overall warming of the planet.

Finally, the term *global warming* is often used in reference to human-caused climate change. Since the end of the Industrial Revolution in the late 1800s, a significant increase in the burning of fossil fuels has released more carbon dioxide (CO_2) into the atmosphere, leading to a rise in Earth's temperature. This trend has been seen in temperatures recorded in many locations around the globe.

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.

In this short series of classroom lessons, we're going to focus entirely on the first and third factors, but in this document, we'll include information on the second factor as well. We hope that by the end of this unit, students will be able to explain how the intensity of sunlight hitting any given location on Earth impacts temperature patterns. Other factors, particularly elevation and proximity to the ocean or another large body of water (such as the Great Lakes), influence a region's temperature patterns as well. Both elevation and proximity to water relate to the amount of sunlight a surface—such as land, oceans, or the atmosphere—absorbs and reflects. We'll briefly discuss these other factors later on.

5. Earth's Shape: Different Points on a Sphere Receive Different Amounts of Solar Energy

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.

What's the Hottest Time of Day?

Just as a pot doesn't boil the moment you put it on a hot stove, the temperature of Earth's surface doesn't immediately increase when the Sun is directly overhead and the light energy is most intense. There's a delay. Depending on the time of year and the latitude, the lag can be as long as three or four hours. For example, the hottest time of day during a typical summer afternoon is midafternoon, not at noon when the Sun is directly overhead.

Similarly, the hottest day of the summer isn't the summer solstice (generally either June 21 or 22 in the Northern Hemisphere) when the Sun is highest in the sky. Because surface heating is delayed, the hottest day occurs much later depending on your location—usually in August in the Northern Hemisphere. And because Earth holds on to some of its warmth, the coldest month of the year isn't when the Sun is lowest in the sky (December 21 or 22 for the Northern Hemisphere), but later, often January or February.

In the lessons comparing temperatures in different cities, examples from January and July are used because they illustrate the seasonal differences between the Northern and Southern Hemispheres more dramatically than temperature averages from the solstice months of December and June.

To gain a deeper understanding of what happens when sunlight strike 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.

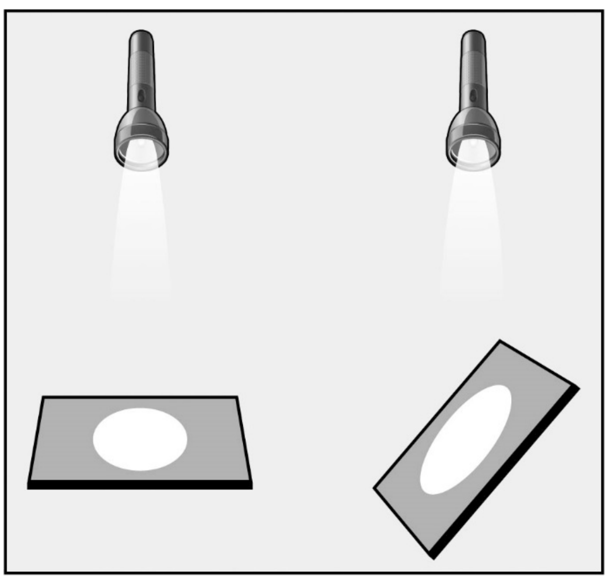

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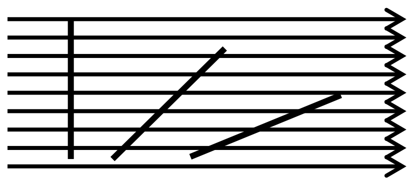
Figure 5. Light striking a surface directly is more concentrated—or intense—than light striking a surface at an angle.

STOP AND THINK

On which of the two lighted areas—the circle or the oval—do you think you would feel the most heat from the flashlight? Why?

Look at the diagram below and think of the arrows as rays of light leaving the flashlight. Note that each solid line crossing the arrows is the same length, but the light hits each line at a different angle. How many rays of light hit the upright solid line? How many rays of light hit the angled lines? This diagram effectively illustrates that the intensity of the light energy is greater when more rays of light are hitting a surface.



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 figure 6). 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.

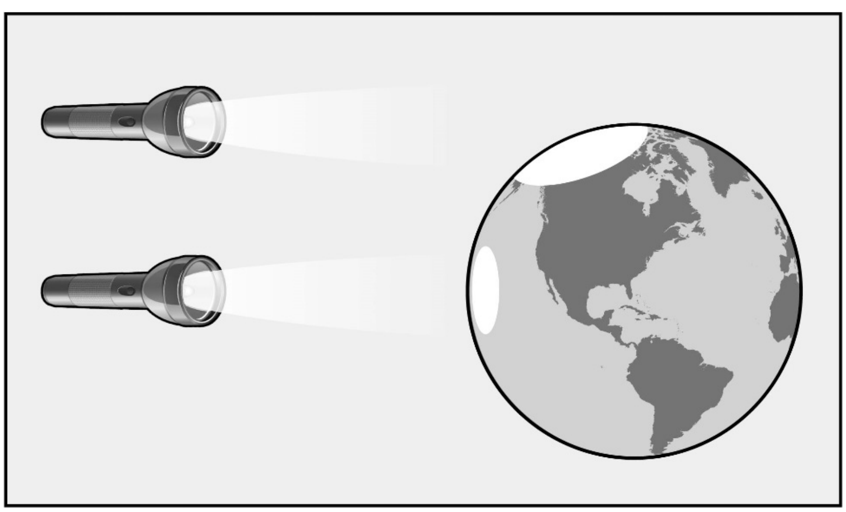


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Figure 6. Light energy is less intense (more spread out) as sunlight strikes Earth's surface at less direct angles farther away from the equator.

Figure 7 illustrates another way to determine variations in the intensity of light energy hitting different locations on Earth. The lines of solar radiation represent the parallel rays of the Sun hitting Earth. So if you want to figure out the amount of light intensity in a location close to the equator, count the number of lines (rays of Sun) hitting Earth in that segment, such as between the equator and latitude 15° N. Next, move a little farther north, between latitudes 30° N and 45° N. How many rays of sunlight are in this segment? Finally, make your way up to the polar regions between latitudes 75° N and 90° N and count the lines. How much solar energy (rays of Sun) is heating this part of the globe?

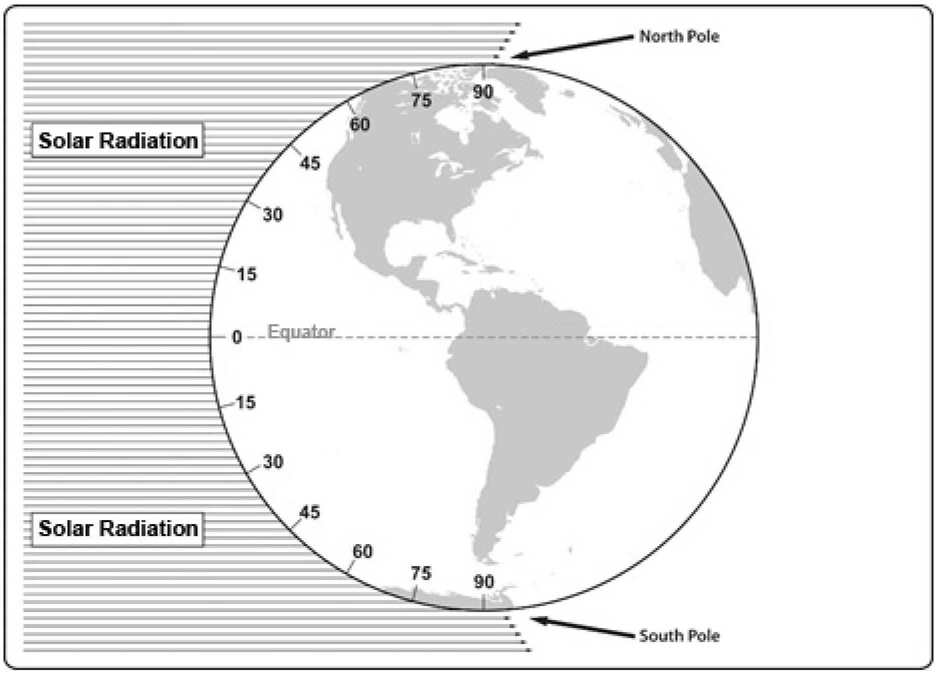

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Figure 7. The Sun's rays hitting Earth at different angles according to latitude

STOP AND THINK

Why do temperatures vary between the equator and the poles? What does Earth's curved shape have to do with these temperature variations?

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* of sunlight striking the surface; the second was the *length of time* the light shines on the object; and the third was the *amount* of light the object absorbs and reflects. Look again at figure 7. From this view, 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.

STOP AND THINK

During what part of the year are days longer than the nights in your location? During what part of the year do you experience fewer daylight hours than hours of darkness? Is the relationship between hours of daylight and hours of darkness the same everywhere on Earth? What do you know about day length in the summertime and wintertime in the far north, near the Arctic Circle?

Misleading Distances

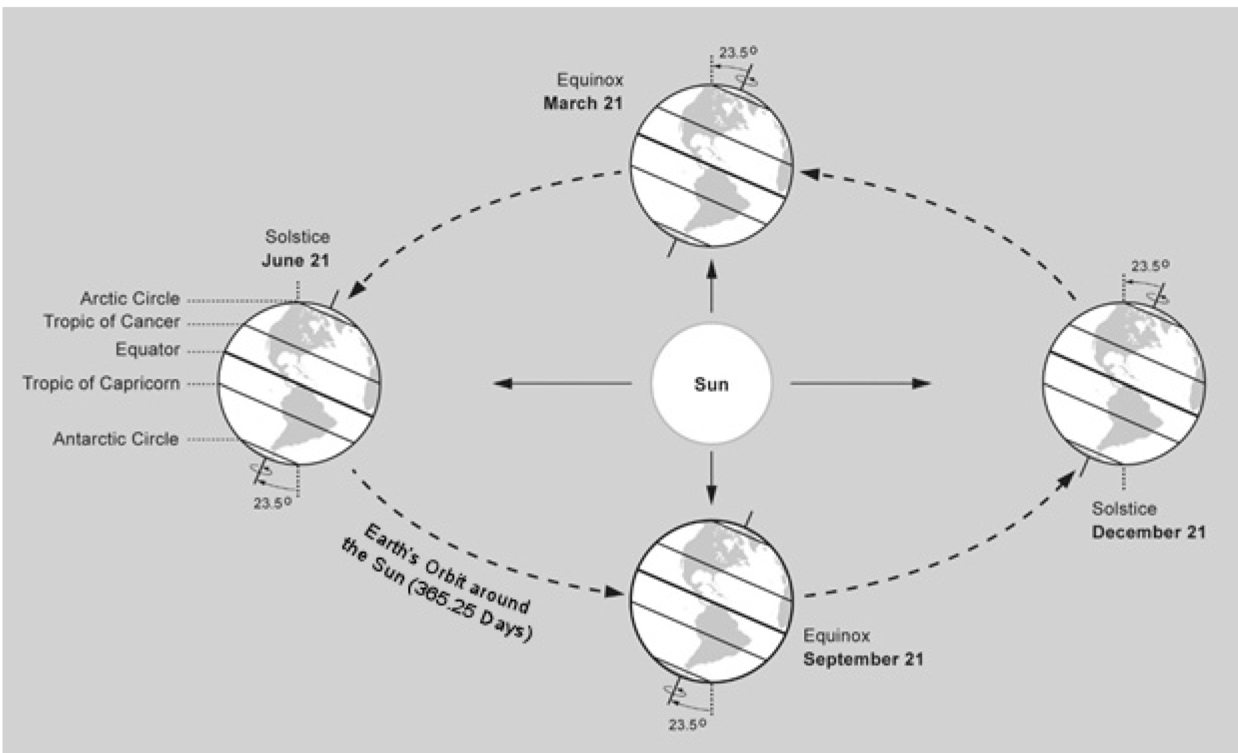
Have you ever noticed that the distance light travels from the Sun to the equator is slightly less than the distance it travels from the Sun to the poles? Students' everyday experiences with heat and light suggest that the farther you are from the source, the less intense the light or heat will be. This 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)!

6. Earth's Tilt

Figure 7 on the previous page explains why colder regions on Earth are generally farther from the equator and warmer regions are generally closer to the equator. But there's more to the story! Distance from the equator (latitude) doesn't explain why locations in the Northern Hemisphere experience cold months at the same time locations in the Southern Hemisphere, like Australia, Africa, and South America, experience hot months. Or 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.

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.

As Earth makes its orbit around the Sun, the axis continues to tilt 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 because the Sun's rays hit the northern half of the world at a less direct angle. Due to Earth's spherical shape, locations north and south of the equator receive varying intensities of sunlight, but 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.

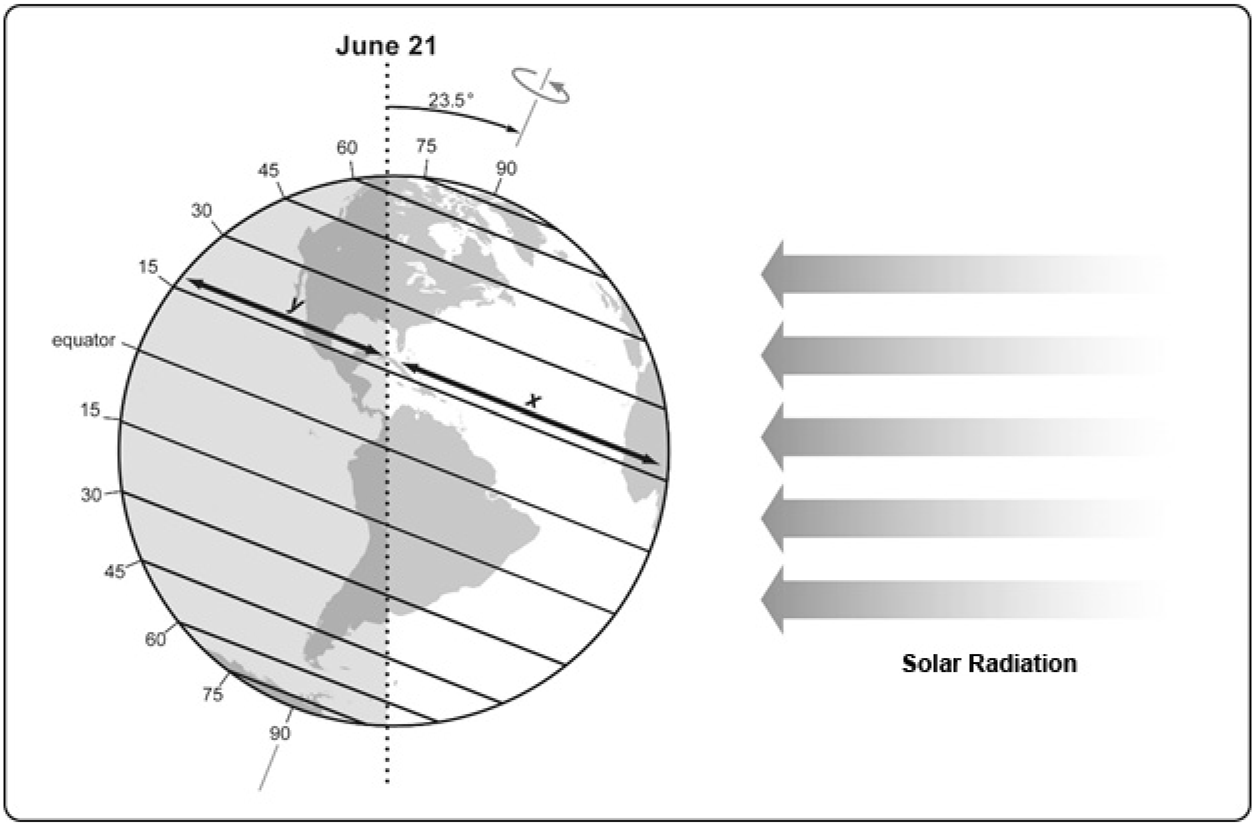


Courtesy of BSCS

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.

It's important to note that the solstices have different designations depending on your location on the planet. If you live in the Southern Hemisphere, for example, December 21 is the *summer solstice*, and June 21 is the *winter solstice*. Taking a more global view, many people now refer to these dates as the *June solstice* and the *December solstice*, eliminating any bias regarding the Northern or Southern Hemisphere.

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. 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.



Courtesy of BSCS

Figure 9. Day length on June 21

STOP AND THINK

How would figure 9 be different on December 21? Would the tilt of Earth change direction? Refer back to figure 8 to check your thinking.

7. Putting It All Together: The Sun's Effect on Climate and Seasons

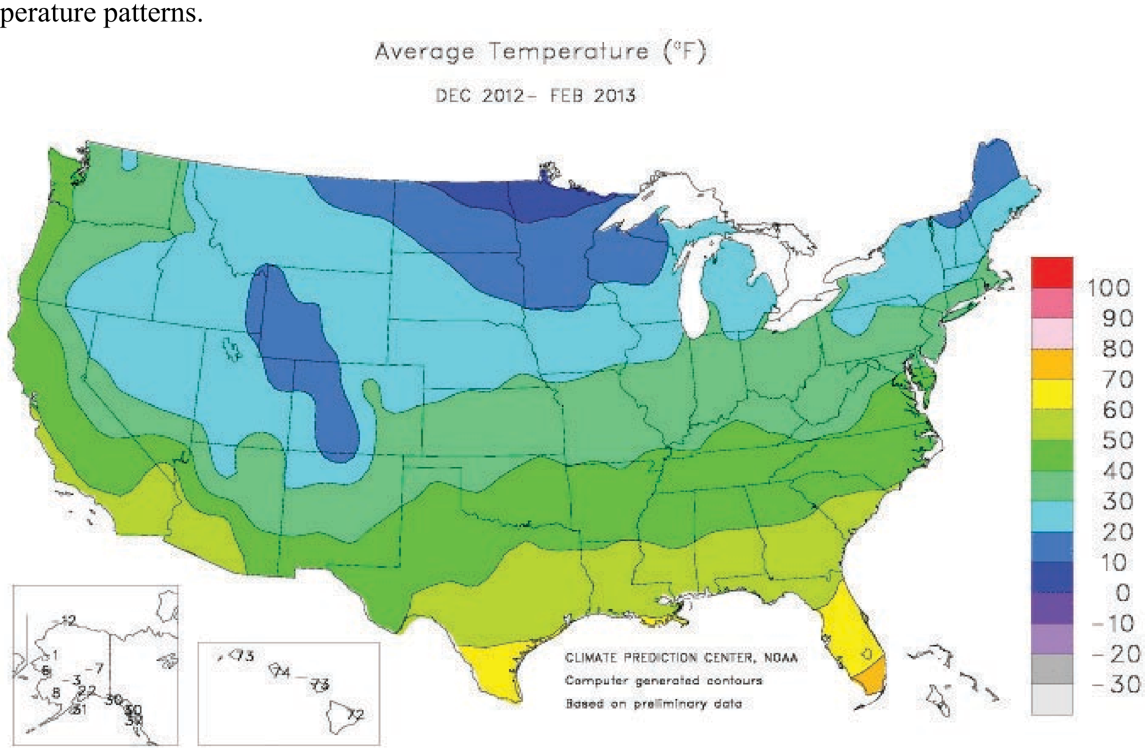
Now you know Earth's tilt isn't the only reason for seasonal temperature variations. Other distinct factors cause differential (uneven) heating of Earth's surface, including the angle at which sunlight strikes Earth's surface at various latitudes, the amount and intensity of light energy Earth receives as it orbits the Sun, and the length of daylight hours in different locations on Earth over the course of a year.

Is one of these factors more important than the other, or do they play equally important roles in seasonal changes? 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 only 12 hours of sunlight—like at the equator? Of course not. Even though 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. So 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.

Did you know that equatorial regions have very little seasonal change? If you think about the angle of sunlight, it varies only a little between the Tropics of Cancer and Capricorn—23.5° N (Tropic of Cancer) and 23.5° S (Tropic of Capricorn). The Sun is *almost* directly overhead at the equator all year long. In addition, the number of daytime and nighttime hours is always the same throughout the year—12 hours of daylight, and 12 hours of darkness (night). As a result, regions around the equator have a rainy season and a dry season, but they never have a true summer or a true winter, and temperatures don't vary the way they do north and south of the tropics. Because of the combined factors of intensity and duration of sunlight, as distance from the equator increases, seasonal temperature variations become more pronounced.

8. Other Factors That Influence Temperature

At this point, you might be thinking that similar latitudes would have similar temperature profiles. For example, if you're in San Francisco, California; Denver, Colorado; Kansas City, Missouri; and Washington, DC (all of which are at about latitude 38° N), you might expect to experience about the same amount of sunlight and therefore the same temperatures on any particular day. To a certain extent that's true. Figure 10 shows similar temperatures occurring in bands across the United States, but certain anomalies indicate once again that the relative position of the Sun and Earth don't fully explain a region's temperature patterns.



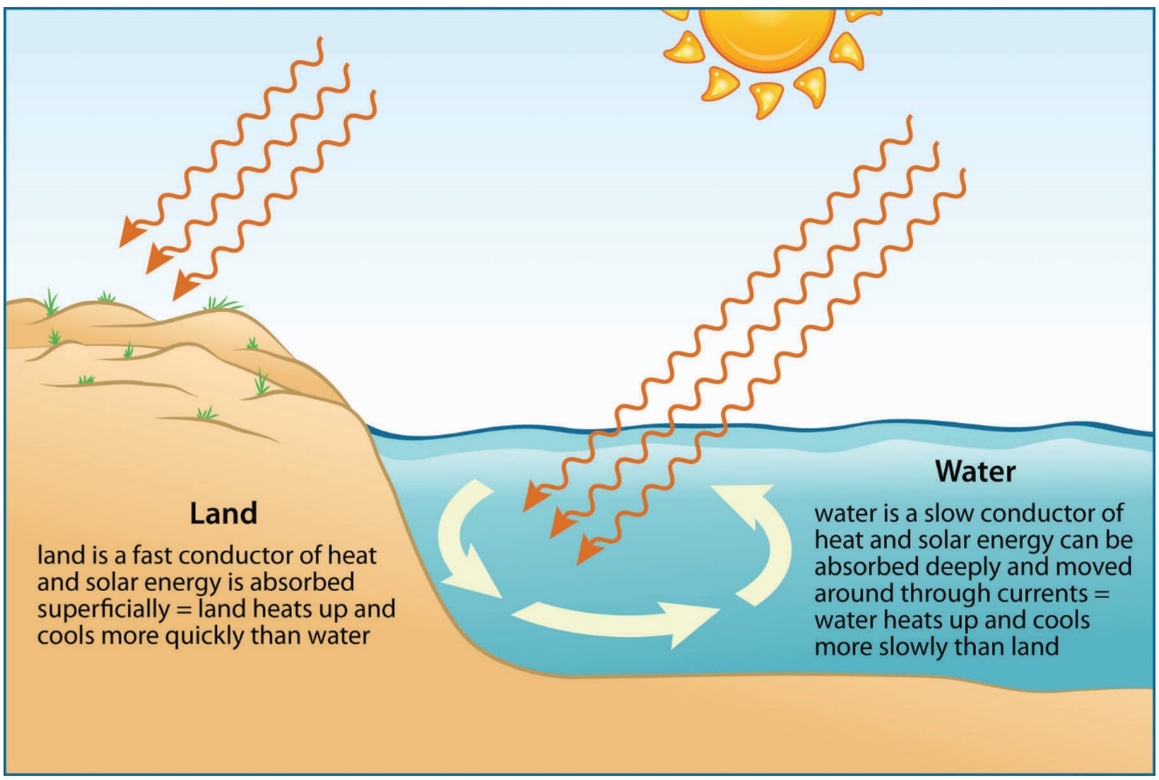
Courtesy of NOAA/National Weather Service

Figure 10. Average US temperatures between December and February, 2012–2013

STOP AND THINK

Look at the winter temperatures for the United States in figure 10.
Can you see evidence of the moderating impact of the ocean on the West Coast?
What about the East Coast? Can you identify places where high elevation
plays a role in the average temperature of a region?

Earlier it was mentioned that regional temperature patterns have something to do with *proximity* to an ocean or other large body of water. Coastal areas, where winds usually blow in from the ocean, have a smaller range of temperatures than interior areas of a continent that are far away from large bodies of water. Land warms up and cools off more rapidly than water, resulting in a broader range of temperatures, but the ocean has a moderating impact that keeps coastal areas cooler in the summer and warmer in the winter (see figure 11).



Courtesy of BSCS

Figure 11. Variations in rates of absorption and reflection of solar radiation between land and water

Another factor that influences regional climates 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 molecules are more spread out, lowering the average air temperature. The process of *adiabatic heating and cooling* also affects temperatures in the mountains. As air rises over the mountains, it expands and cools, and the water-vapor molecules it contains also cool, condensing into liquid-water droplets and forming clouds (see figure 12). As air pockets on the other side of the mountains begin to sink, the liquid-water droplets in the air compress and heat up, 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.

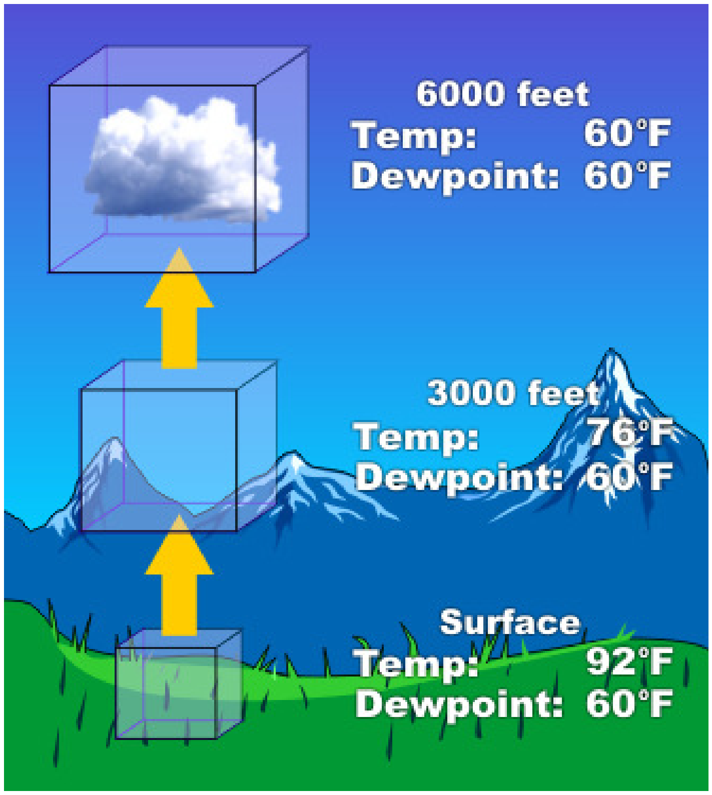


Photo courtesy of NOAA

Figure 12. As elevation increases, water vapor in the air expands and cools, forming clouds.

In this document, we've explored the reasons for temperature variations across Earth based on the intensity and duration of sunlight hitting the planet. The amount of warming and cooling any given location experiences is also related to the materials that make up Earth's surface. 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. Also, land surfaces behave quite differently from water surfaces. In general, the surface of any deep, expansive body of water heats and cools more slowly than the surface of a large body of land. 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.

9. Climate and Weather

Temperature is only one aspect of climate. The amount and frequency of precipitation matter too. For example, does rain fall often and in small amounts in certain areas, or does it tend to fall less often but in large amounts? Other factors, such as wind speed and direction, cloud cover, relative humidity, and the frequency of violent storms like hurricanes and typhoons, are also important in describing climate.

The Sun’s energy controls all of these climatic factors. It causes water to warm up and evaporate, and then as water-vapor molecules cool in the atmosphere, clouds form and rain pours down on the surface of Earth. The Sun’s energy warms air masses, resulting in air-pressure variations that create winds. It also causes variations in ocean temperatures at the surface and in deeper water, contributing to currents that influence climate patterns like El Niño and La Niña. The Sun’s energy drives violent storms like tornados and hurricanes, sometimes causing enormous devastation and loss of life.

How is climate different from 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 or days. Weather can be a passing afternoon thunderstorm, a cold front, or a persistent heat wave. Weather is 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*.

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