"Sun's Effect on Climate and Seasons"
Content Background for Teachers

Introduction

As we start our content exploration about the Sun's effect on climate and seasons, take a moment to think about what you already know about this topic.

You probably have a basic picture in your head of the relationship between Earth and the Sun, including the facts that night and day are the result of Earth's spinning on its axis every 24 hours and that Earth orbits the Sun every 365.25 days. (Every four years we have a "leap year" with 366 days to make up on our calendars for the extra quarter day each year that it takes to revolve around the Sun.) You most certainly know that the Sun provides Earth with both light and heat, and you're probably aware that in addition to visible light and heat, the Sun also provides different kinds of energy waves, such as the ultraviolet light that can cause sunburn if you're out too long in unfiltered sunlight. If someone were to ask you about the reason for Earth's seasons, you might say that it has something to do with the tilt of Earth 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 your observations of the path of the Sun as it appears higher or lower in the sky at different times of the year? Can you use your knowledge to explain why as we experience summer in the Northern Hemisphere—June, July, and August—the Southern Hemisphere experiences its lower average temperatures in the winter months? Can you explain why the polar regions—the lands with 24 hours of sunlight at certain times of the year—do not have higher average temperatures than the equator which receives 12 hours of sunlight and 12 hours of darkness year-round? For that matter, can you explain why the daily weather is so variable if 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 seasonal temperatures. It is written to support and further your own content learning about the underlying factors that lead to differences in seasonal temperatures, especially how the intensity of the Sun's energy and the length of day are influenced by Earth's tilt and orbit. It will help you understand how the factors that explain Earth's seasonal temperature differences relate to your science standards that talk about "uneven heating of Earth's surface." The goal is for you to develop a conceptual understanding of these ideas so you will be able to more-effectively teach elementary students.

The content is written with you, the teacher, in mind. It presents subject matter knowledge that is tied to the STeLLA model lessons you will be teaching, but it is at a level higher than what you will present in your classroom. After all, teachers should know more than what they teach their students!

Getting Started: Celestial Motions

The goal of this unit is for you and your students to emerge with (1) a good mental picture of the motion of Earth in relation to the Sun, (2) an understanding of why this motion results in different amounts of energy from the Sun reaching different locations on the planet in regular and predictable patterns, and (3) an understanding of how this "differential heating" results in patterns of climate and seasons. This unit explores a fundamental science concept that connects our understanding of motions of objects in the solar system to climatic and seasonal patterns on our planet.

In the unit, we will assume that most fifth-grade students have been introduced to the basic relationship between the Sun and Earth. In the Next Generation Science Standards, expectations for fifth grade include the concept "ESS1.B: Earth and the Solar System—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 students will have seen models of the solar system in which the Sun is static and Earth both rotates on its axis daily and revolves around the Sun annually (figure 1). It is difficult, however, for students to hold this abstract image of Earth in relation to other bodies in the sky when their daily experiences support the ideas that Earth is stationary and the Sun and Moon move across the sky. Their personal experiences are reinforced by the way we talk about the Sun as "rising in the east and setting in the west." Using terms such as *sunrise* and *sunset* is practical because the Sun appears to rise and set from our perspective standing on Earth's surface, but it strengthens misconceptions that the Sun moves while Earth stands still.

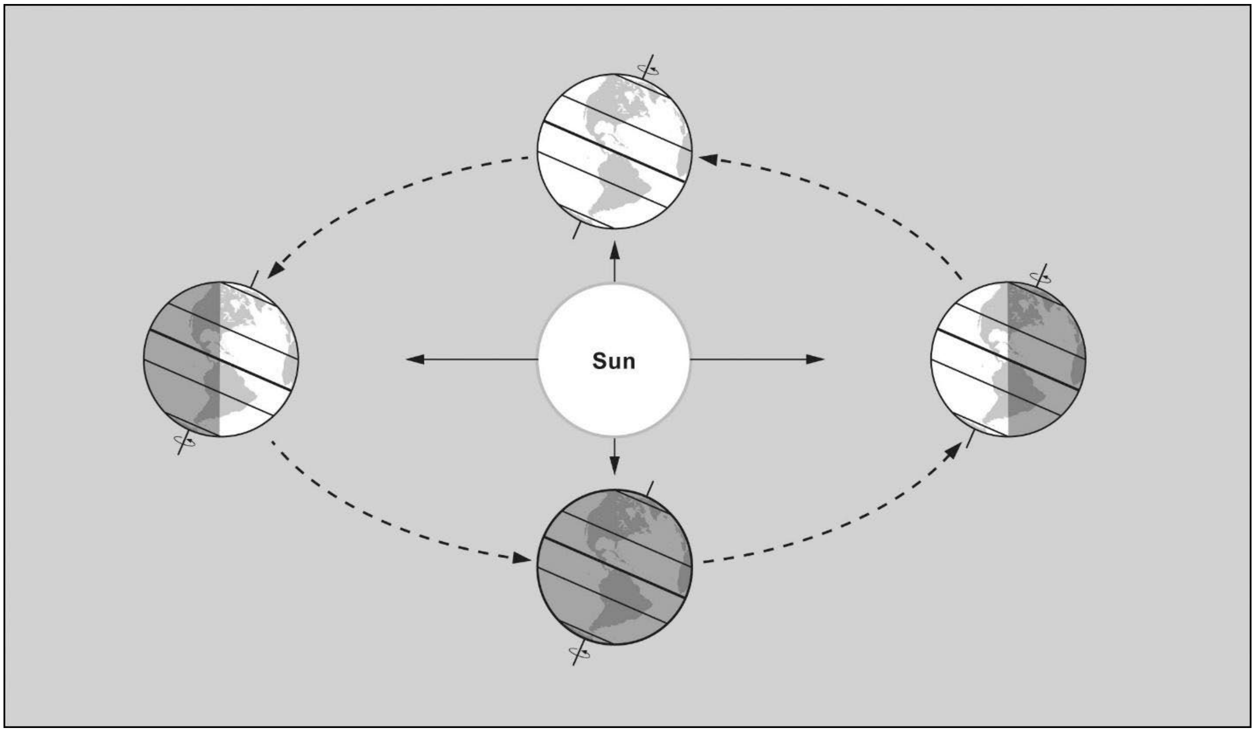


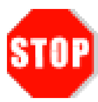
Figure 1: A complete orbit of Earth around the Sun creates our year, while Earth's spin on its axis results in the 24-hour cycle of daylight and nighttime.

However, somewhere about middle-school age, students are just beginning to make sense of celestial motion in ways that are not dependent on their own experience. Students in early elementary typically have a geocentric, or Earth-centered, perspective on the motion of objects in space, while students in upper elementary and middle school are prime to learn about the motion of objects in space from a heliocentric, or Sun-centered, perspective. You will want to be sure, prior to beginning this unit, that both you and your students have a good picture of the Sun at the center of our solar system, Earth revolving (orbiting) around the Sun every 365 days to make a year, and Earth rotating (spinning) on its axis every 24 hours to create daytime and nighttime. You might begin by asking your students these questions:

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

In this document (and throughout the classroom lessons) we will use the word *orbit* to describe Earth's motion around the Sun in order to avoid the confusion that can result when we use the two "R" words—revolve and rotate. Because many national and state standardized tests use those "R" words, you will want to make sure by the end of the unit that your students know how the terms *revolution* and *rotation* relate to Earth's orbit and spin.

Students should also know that Earth's orbit is very nearly a circle, even though in most textbook illustrations it appears to be a long ellipse. The image of an elliptical orbit leads many students to believe that Earth is farther from the Sun at certain times of the year and closer at other times—resulting in the common misconception that the seasons are caused by how close to or far away from the Sun we are at various times in our orbit. In fact, Earth is *slightly* closer to the Sun in its orbit on January 4 of each year. This day is called Earth's perihelion—when Earth is 147.5 million kilometers from the Sun. July 4 is not only known as Independence Day in the United States, it is also Earth's aphelion, the date each year when Earth is farthest from the Sun—152.6 million kilometers away. The difference between Earth's perihelion and aphelion is 5.1 million miles. If that seems like a lot of miles, remember that in comparison to the entire distance between Earth and the Sun, this is a very small amount, just about a 3-percent change from January to July.



STOP AND THINK: Based solely on the distance from the Sun, would you expect July or January to be the hottest month of the year? Why?

In order to make sense of our Earth-Sun system, students also need to have an idea about the size of the various bodies in the sky compared to their distances from us. We have no really good way of modeling those size-and-distance relationships in the classroom and tend to reinforce student misconceptions rather than clarify them with classroom models and diagrams. (No doubt you've seen an attempt to demonstrate size and scale on some school playgrounds with models of the solar system mapped out from one end of the play yard to the other.) Based on their own observations, students might think that the Sun and the Moon are about the same size and about the same distance from Earth. Actually, the Moon is about ¼ the size of Earth, while the Sun is the size of 109 Earths! They merely seem the same size in the sky because their distances from Earth are so very different. If we use the diameter of Earth as our measuring tool (about 12,756 kilometers), the Moon would be about 30 Earths away, while the Sun would be about 12,000 Earths away. To put this another way, the Sun is 400 times bigger than the Moon, but it is also 400 times farther away, so it appears to be about the same size in the sky. It is certainly not necessary for students to memorize any of these statistics related to size and distance, but it is important for them to have a general sense of the relative size and distance of these celestial bodies (figure 2). One of the most common misconceptions held by students—and adults—is that higher summer temperatures are caused by Earth being closer to the Sun at certain times of the year. In order to change this strongly held idea, students need to be able to visualize why the *relative positions of Earth and the Sun*—not their distance apart—impact the seasonal temperature differences we experience on Earth.

Object in the solar system	Approximate distance from Earth (km)	# of Earths "away"	Diameter (km)	# 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

Figure 2: Relative distance and size of Earth, Moon, and Sun

We may consider this information about the motions, sizes, and distances of Earth and the Sun to be prior knowledge that your students will bring to their investigation of the Sun's effect on climate and the seasons. However, the representations we use in the model STeLLA lessons—lightbulbs, flashlights, globes, and Styrofoam balls—do not provide an accurate representation of the relative sizes and distance between the Sun and Earth. As you teach the lessons, you will want to remind students that our classroom model distorts the sizes and scales of these objects in space.

The Sun provides light and heat.

Students are familiar with the energy of the Sun. They see its light and feel its warmth on their skin. But not all the Sun's energy is visible sunlight.

STOP AND THINK: Why can you get sunburn from the Sun but not from sitting in your classroom under a lamp? What is it about sunlight that affects our skin, our mood, and the growth of plants differently than a lightbulb?

Three Kinds of Solar Radiation

It may surprise you to know that the Sun doesn't heat Earth directly, at least not in the way that the stove heats your soup or a furnace heats your house. These are examples of heat being conducted from one substance to another. *Conduction* is the transfer of heat through matter from particle to particle, like when a spoon in a bowl of hot soup becomes warmer because the 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 to touch. Even though the Sun is very hot, heat from the Sun cannot travel by conduction to Earth because there is very little matter in space to travel through.

The Sun's energy arrives on Earth through another means—*radiation*. Radiation refers to the transfer of a specific type of energy—electromagnetic waves—traveling through the nothingness of space without the aid of liquids or solids or gases. Electromagnetic waves come in many types—radio waves, microwaves, infrared light, visible light, ultraviolet light, x-rays, even radioactive gamma rays—which can be sequenced by how much energy each wave carries. The collection of these different waves is known as the electromagnetic (EM) spectrum, shown in the figure 3 image that displays the range of wavelengths from longer wavelengths (lower frequency) that carry lower amounts of energy to shorter wavelengths (higher frequency) that carry higher amounts of energy.

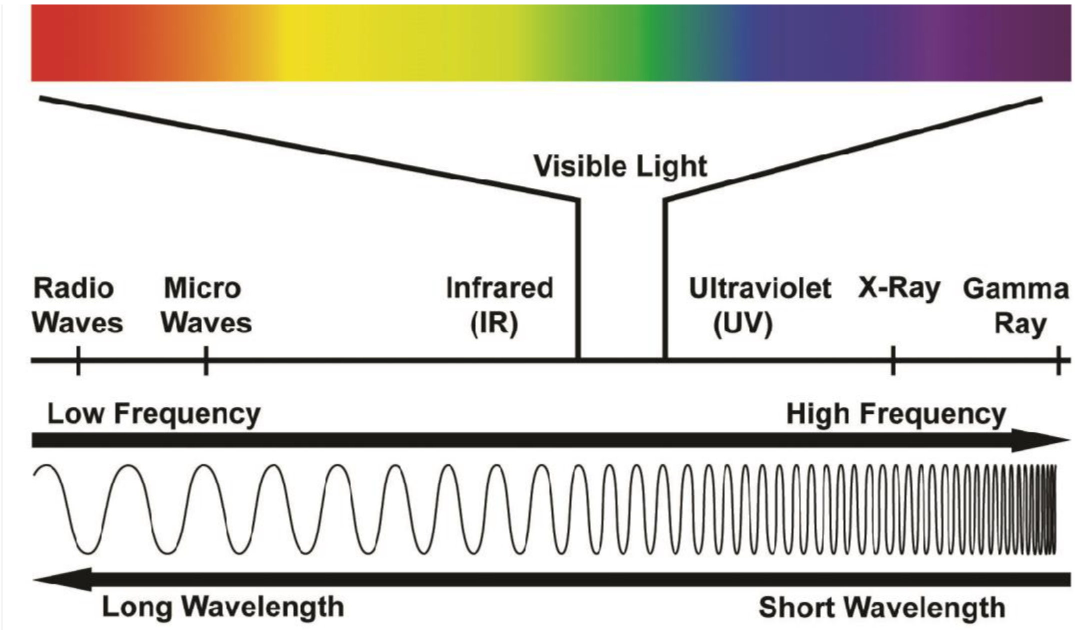
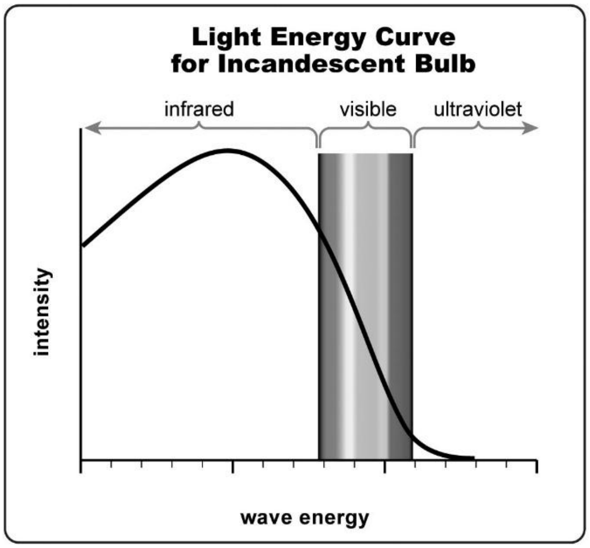


Figure 3: Notice that only a small range of the electromagnetic spectrum is visible light. The remaining portions of the spectrum are not visible to the human eye.

Most of the Sun's energy comes from three areas of the EM spectrum: infrared light, visible light, and ultraviolet light. We call each of these segments of the EM spectrum *light* even though we can only see those wavelengths categorized as visible light. Everything that has warmth radiates at least a little *infrared light*. Even though our eyes cannot perceive infrared light wavelengths, special glasses have been invented that enhance the infrared spectrum, allowing a person to "see" warmth. *Visible light* falls within a very small range of the EM spectrum. Cells in the back of your eyes are sensitive to this narrow range of wave energy. When those cells detect the energy reaching them, they send a signal to your brain. This gives you the ability to see. Thus, it is called visible light energy, or visible light. Different wavelengths in the visible spectrum constitute the different colors of the rainbow—red being the lowest energy of the visible light waves (and closest to the infrared—or below red—energy levels) and violet being the highest energy of the visible light waves (and closest to the ultraviolet—or above violet—energy levels). *Ultraviolet light* is also invisible to the human eye, although some animals have the ability to detect it. Ultraviolet light is damaging to our cells and is the part of sunlight that causes skin to tan or burn. Overexposure to ultraviolet light from the Sun can be a cause of some forms of skin cancer. Figure 4 compares the types of light coming from the Sun to those emitted by a typical lightbulb. You can see that the lightbulb emits more infrared light than visible light, and very little ultraviolet light.



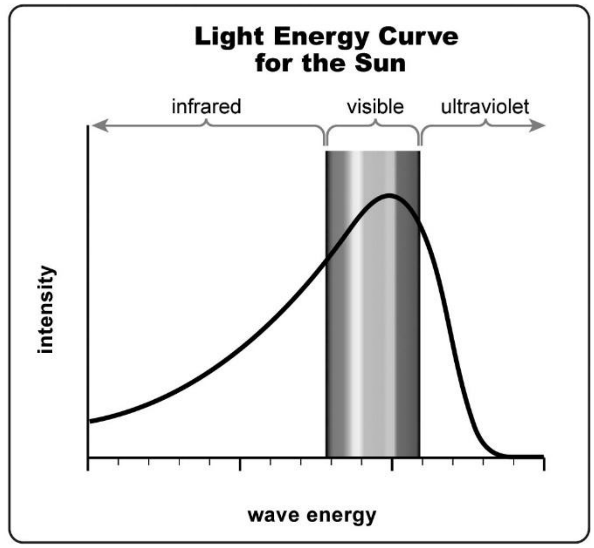


Figure 4: Light emitted from a lightbulb compared to light emitted from the Sun

When infrared light, visible light, and ultraviolet light reach surfaces on Earth, the energy is transformed from radiated electromagnetic wave energy into thermal energy. *Thermal energy* describes the motion of the particles (atoms and molecules) that make up a substance. We measure the thermal energy of a substance by taking its temperature—which essentially measures the average motion of the particles. When sunlight reaches a surface—like the sidewalk—some energy is absorbed, while the rest is reflected. What does it mean for light to be absorbed? The energy from the light is transferred to the object's particles (atoms and molecules), making the particles move more. As particles in the sidewalk move faster, its temperature increases. How much an object's temperature increases depends on (1) how intense the light striking the surface is, (2) how long the light shines on the object, and (3) how much of the light is absorbed or reflected.

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 at the same time that Earth *gets* energy from the Sun—mostly in the form of visible and ultraviolet light, it radiates energy back out into space—mostly in the form of infrared light. On average, the energy Earth absorbs from the Sun is balanced by the energy it emits back into space, so, in general, the temperature of Earth stays about the same. Today, many people are concerned about rising temperatures on Earth—global warming—caused not by more of the Sun's energy reaching the planet, but by changes in the atmosphere that keep Earth's radiated energy from escaping back out into space. The reasons for changes in the atmosphere leading to global warming are complex and go beyond the scope and purpose of this document, but students engaged in studying the Sun's effect on climate and the seasons may raise questions about global warming.

Global warming: The terms "climate change," "greenhouse effect," and "global warming" are often confused for one another and are sometimes simply misunderstood. 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 this change is often 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 over its history; there is also evidence that suggests that at other times in the past the planet has been 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 life on this planet. Almost all of us have experienced getting into our car on a warm summer day and realizing that the car's interior is much warmer than the outside air. This is the greenhouse effect in action. Short-wavelength visible light from the Sun goes through the car windows and is absorbed in the interior, causing an increase in temperature. The interior then radiates energy, but in the form of longer-wavelength infrared light which cannot pass back through the glass as easily as the shorter wavelengths of visible light do. The warmth is trapped inside the car. Earth's atmosphere behaves just like the car windows. Some of the gases in our atmosphere, such as carbon dioxide, methane, and even water vapor (called *greenhouse gases*), have the ability to trap infrared light (heat). Without the greenhouse effect, heat leaving Earth's surface would freely escape into space, leaving Earth much cooler than it is, particularly at night. The greenhouse effect is not, in itself, a problem; rather, it is the addition to the atmosphere of large amounts of greenhouse gases that is of great concern since the greenhouse effect becomes amplified and too much of Earth's heat gets trapped, leading to an overall warming of the planet at a very fast rate.

Finally, the term *global warming* is often used when referring to human-caused climate change. Since the end of the industrial revolution in the late 1800s, when we greatly increased the burning of fossil fuels which releases carbon dioxide, the temperature of Earth has rapidly increased, and this trend has been seen in temperatures recorded in many locations around the globe.

Temperatures on Earth vary in a predictable pattern.

We don't even have to think about it—when you go north, the temperatures generally get cooler. When you head south, get out your bathing suit and suntan lotion! However, if we lived in the Southern Hemisphere, we might think just the opposite ... let's drive north for sun and fun! The temperature of any place on Earth's surface tends to vary depending on how far north or south of the equator the place is. Closer to the equator, we generally have warmer climates, while farther away from the equator we have generally 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 in Earth's temperatures besides the warmth at the equator and frigid temperatures in polar regions. Close to the equator, the air temperature is pretty much the same all year, but farther away from the equator, the variation between temperatures in the summer and temperatures in the winter is greater. This regular pattern of temperature differences at different times of the year is our definition of *seasons*. We call our "cold" time of year *winter* and our "warm" time of year *summer*. The transition from summer to winter becomes our fall and the transition from winter to summer becomes our spring. Students might think that when they experience warm temperatures (summer) in North America that everywhere on the planet is also experiencing summer. They might not realize that the months of June, July, and August are considered winter months in the Southern Hemisphere.

STOP AND THINK: Why do you think the Southern Hemisphere has seasons opposite the Northern Hemisphere? Why do seasonal temperature differences overall become more pronounced the farther you get from the equator? What factors do you think contribute to the seasons?

You got a hint in answering questions about patterns of global temperature differences and patterns of seasonal temperature differences in the previous section. We said earlier that how much an object's temperature—in this case, Earth's temperature—increases when hit by the Sun's light energy depends on (1) how intense the light striking the surface is, (2) how long the light shines on the object, and (3) how much of the light is absorbed or reflected. In this short series of classroom lessons, we're going to focus entirely on (1) and (2) above. We hope that by the end of this unit students will be able to explain how, at any given location, the intensity of sunlight and the duration of sunlight hitting that area impacts how warm it will be. You might know that other factors, particularly elevation and the proximity to an ocean or other large body of water (such as the Great Lakes), also influence a region's temperature patterns. Both of these factors—elevation and proximity to water—are related to (3), the amount of sunlight that is absorbed and reflected by land, by oceans and other bodies of water, or by the atmosphere. We'll briefly describe these other factors later in this document.

Earth's shape: Different points on a sphere receive different amounts of solar energy.

Did you ever consider that the shape of Earth affects its climate? The fact that Earth is round affects the intensity of the light at any given place on the planet. By intensity, we mean how much of the Sun's energy reaches a particular spot. Remember that the Sun is very, very far away, and it sends out a fairly constant supply of energy. You could imagine those rays of energy as parallel lines or arrows coming directly from the Sun to Earth. When the Sun is directly overhead, those arrows would strike Earth just about straight on, but when the Sun is not directly overhead, the sunlight hits at an angle. This is easy to envision thinking about the Sun rising in the morning and the Sun's rays hitting your town at an angle; then, as it rises, the Sun's rays become more and more directly overhead—and more intense. As you move into the afternoon, the Sun's rays again strike at an angle and become less intense as the daytime 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 feel the changing intensity of the Sun. In the morning and evening, when the Sun is at the lowest angle, the Sun's rays are less intense and you feel less heating. At noon, you can feel the greater intensity of the Sun's energy when the Sun is highest in the sky.

Figure 5: When the Sun is directly overhead, the Sun's rays strike Earth straight on, but when the Sun is not directly overhead, the Sun's rays strike the surface at an angle.

What's the hottest time of day? Just as a pot doesn't boil the moment you put it on a hot stove, there is a delay between the time when the Sun's light is directly overhead (and therefore most intense) and when the temperature of the area is highest. 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 a typical summer day would be in the midafternoon, not at solar noon.

Similarly, the hottest day of the summer is not the summer solstice (generally either June 21 or 22 in the Northern Hemisphere) when the Sun is highest in the sky. Because of this delay in the heating of Earth, the hottest day occurs much later, depending on the location, usually in August in the Northern Hemisphere. And because Earth holds on to some of its warmth, the coldest day of the year is not when the Sun is lowest in the sky on the winter solstice (December 21 or 22 for the Northern Hemisphere), but later, often in January or February. In the classroom lessons comparing temperatures in different cities, we use examples from January and July because they illustrate the seasonal differences between the Northern and Southern Hemispheres more dramatically than if we use temperature averages from the solstice months of December and June.

To get a deeper understanding of what's happening as the angles of sunlight hitting Earth change, let's visualize these differences in intensities when light strikes a flat surface—and then transfer the idea to the curved surface of Earth. If you point a flashlight directly at a flat surface, it shines on a specific area and makes an intense circle of light. But if you shift or tip the surface to an angle with respect to the flashlight, the circle of light turns into an oval of light on the surface—and the surface area of the oval is larger than that of the circle (figure 6). The intensity of the light is reduced when hitting a surface at an angle because the light spreads out across a larger surface area. The amount of energy leaving the flashlight didn't change; it just spread out over a larger area as it hit the surface at an angle.

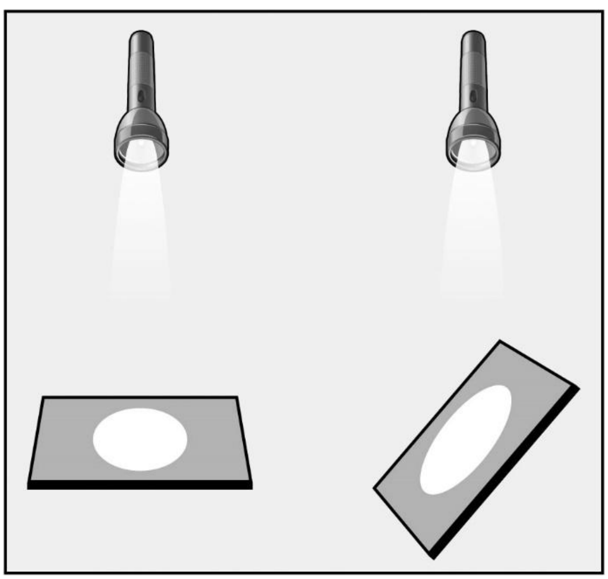
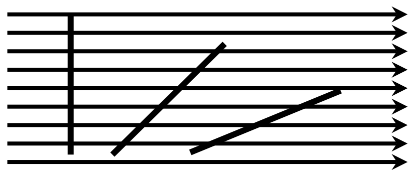


Figure 6: Light striking a surface straight on is more concentrated—or intense—than light striking a surface at an angle.

STOP AND THINK: If light from the flashlight created heat, on which of the two lighted areas—circle or oval—do you think you would feel the most heat? Why?

Look at the following image and think about the arrows as rays of light leaving the flashlight. Note that each solid line across the arrows is the same length, but the light rays hit each line at a different angle. How many rays of light hit the vertical line? How many rays of light hit the lines that are at an angle? The more rays of light that touch a surface, the greater the intensity of the energy hitting that surface.



Now, let's take this same idea of light spreading out as it hits a surface at an angle and transfer it to our round Earth at various positions from north to south. To get ourselves oriented, let's initially consider that the Sun is directly overhead at the equator. (As we'll find out later, this occurs only twice a year, but it is a good starting point for thinking about the impact of Earth's spherical shape on temperatures.) The most direct (and most intense) sunlight strikes at the equator. As you move away from the equator, the sunlight strikes Earth at lower and lower angles, and so the intensity of the light energy decreases (figure 7). In other words, the light energy hitting that surface area is more spread out.

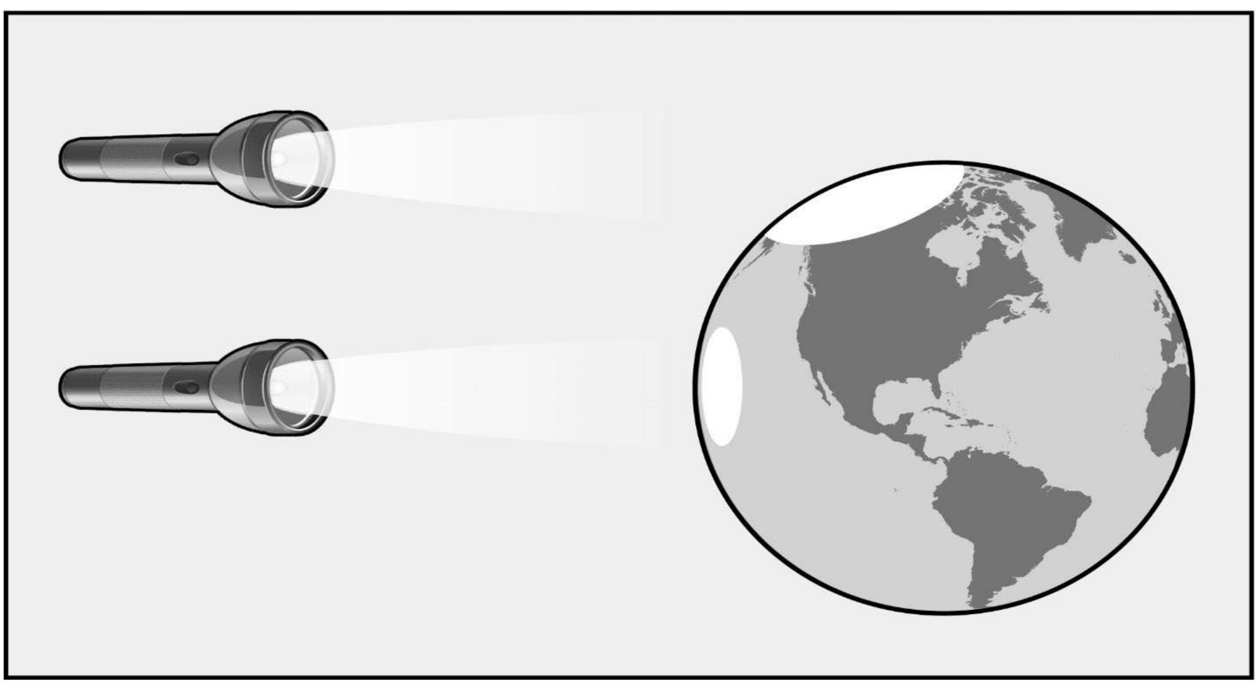


Figure 7: The farther you are away from the equator, sunlight strikes the surface at lower angles, resulting in the Sun's energy being more spread out—less intense—at higher latitudes.

There is another way to figure out the differences in intensity of the Sun's energy hitting different places on Earth. Look at figure 8. The lines of solar radiation represent the parallel rays of the Sun hitting Earth. Count how many lines hit Earth in one of the segments closest to the equator, for example between the equator and 15° N latitude. Now move a little farther from the equator, say, the segment between 30° and 45° N latitude. How many rays of sunlight are "caught" in this band of the Northern Hemisphere? Move all the way up to the polar regions—between 75° and 90° N latitude. How much solar energy is heating this part of the globe?

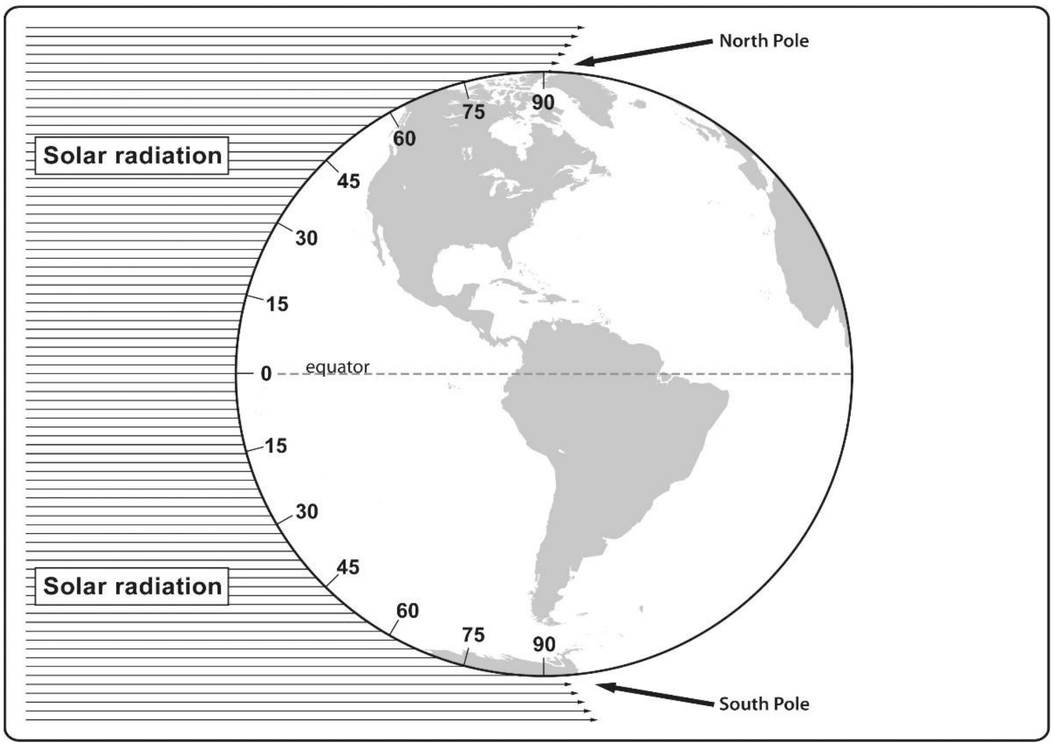


Figure 8: Sun's rays hit Earth.

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?

The angle of sunlight is only part of the story. Remember the factors that contribute to how much an object heats up when hit by electromagnetic waves? The first was the intensity of the sunlight. The second was how long the light shines on the object. Look again at figure 8. From this view, it looks like everywhere on Earth would experience half a day of sunlight and half a day of darkness. Think about your experience throughout the year. Is there ever 12 hours of daylight and 12 hours of nighttime where you are? Unless you are reading this document while at the equator, daytime and nighttime are both 12 hours long only twice a year—once in the spring and once in the fall. We call those particular days of the year the spring equinox and fall equinox. Notice that part of the word *equinox* sounds like "equal," and in fact, on the equinoxes, nighttime and daytime are equal all over the world. If everywhere on the planet got 12 hours of sunlight a day all the time, then the length of time the Sun shines would have no difference from north to south—it would be the same everywhere.

***Misleading distances*:** You might notice that the distance that light travels from the Sun to the equator is slightly less than the distance light must travel 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. This idea might reinforce the misconception that the distance from the Sun causes the temperature variation 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 and sitting 4 feet and 1/4 inch from the campfire. That extra quarter inch makes almost no difference in the intensity of the warmth you feel. The actual difference from the Sun to the equator versus the Sun to the poles is about 6,376 kilometers (3,863 miles), compared to the total distance from Earth to the Sun of about 152 million kilometers (94.5 million miles)!

STOP AND THINK: During what part of the year are your daytimes longer than the nighttimes? What part of the year has 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 the length of the day in the far north—near the Arctic Circle—in the summertime and in the wintertime?

Earth's tilt

In fact, figure 8 represents only part of the story of the Sun's effect on climate and seasons. It explains why colder regions are generally farther from the equator and warmer regions are generally closer to the equator. But we know that there's more to the story. Months with low average temperatures in the Northern Hemisphere are months with high average temperatures in Australia, Africa, and South America. And when we're sunbathing at the beach in August, our counterparts in the Southern Hemisphere are at the peak of ski season! When we consider this additional twist in our climate story, we realize that a location's latitude—its distance from the equator—does not provide a complete explanation for differences in temperature at different times of year.

Figure 8 shows Earth's axis (an imaginary line between the North Pole and the South Pole) as being straight up and down in relation to the Sun. But in reality, the axis tilts at a 23½ degree angle. As Earth orbits the Sun, this tilted axis always points in the same direction—in general, toward the North Star, also known as Polaris. This means that in the middle of the year the

Northern Hemisphere is tilted toward the Sun, and the direct rays of the Sun (which, earlier in the year at the spring equinox, March 21, had been straight over the equator) now strike 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 exactly 23½° N latitude. That latitude might ring a bell. It's the Tropic of Cancer. It marks the northernmost point on the globe where the Sun can be 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 at less of an angle—between March 21 and September 21.

As Earth makes its orbit around the Sun, the tilt continues to point in the same direction. In December, the North Pole will point away from the Sun and the South Pole will point toward the Sun. On the winter solstice (December 21), the direct rays of the Sun will hit 23½° south of the equator at a latitude known as the Tropic of Capricorn. Therefore, between September 21 and March 21, the Southern Hemisphere receives more concentrated solar energy than it did between March 21 and September 21, while the Northern Hemisphere receives light that is more spread out—the result of the lower angle between the Sun and the northern half of the world. The spherical shape of the globe still results in different intensities farther from the place on Earth receiving direct sunlight, but as mentioned earlier, the equator receives direct sunlight only twice a year—at the spring equinox and the autumn equinox. From March to September, direct sunlight strikes between the equator and 23½° N, and from September to March, direct sunlight strikes between the equator and 23½° S.

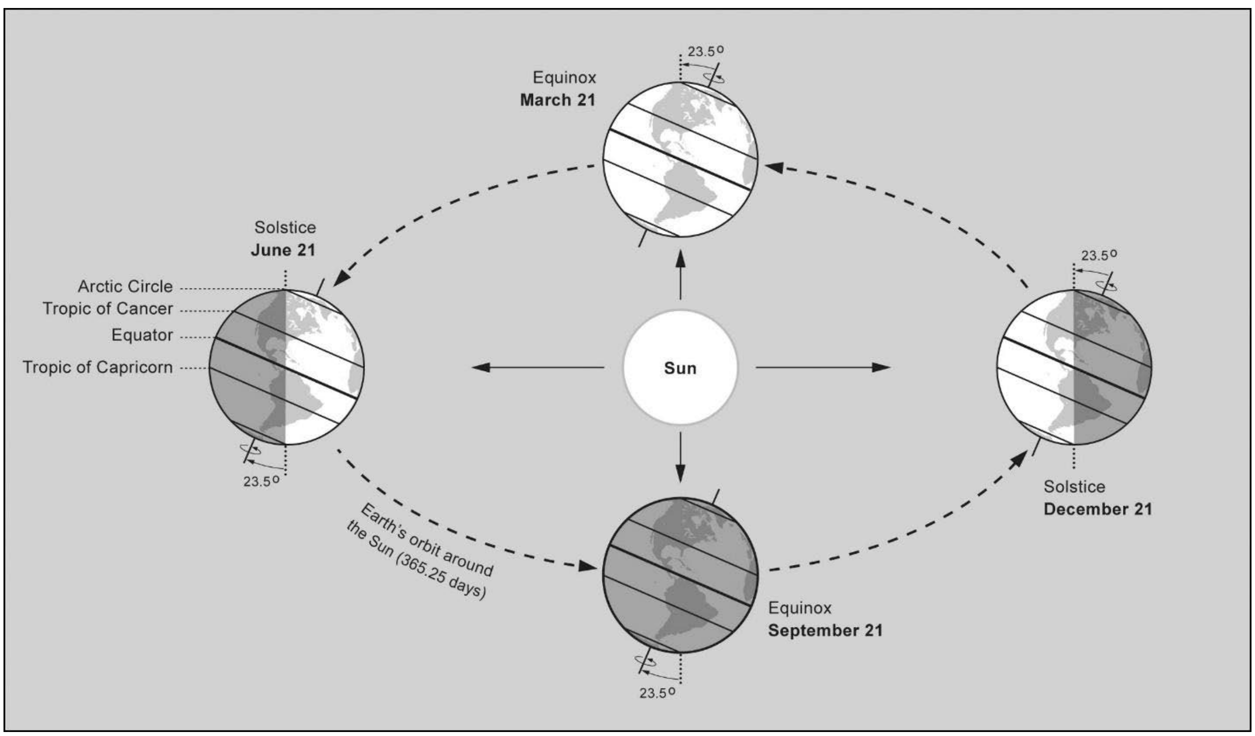


Figure 9: Earth's orbit around the Sun and Earth's tilt combine to cause the angle of the Sun's rays to hit the planet differently at different times of year.

It’s important to note that how you name these solstices depends on your location on the planet. If you live in the Southern Hemisphere, December 21 is the *summer solstice* and June 21 is *winter solstice*. Taking a more global view, many people now call these two dates the *June solstice* and the *December solstice*, eliminating the Northern or Southern Hemisphere bias relating to summer and winter.

In addition to the difference in light intensity in winter and summer, the tilt of Earth on its axis also creates differences in the number of hours of daylight (daytime) and darkness (nighttime). As we noted earlier, in the summer in the Northern Hemisphere, daytime is longer, so there’s not only more-intense sunlight, but the length of time the Sun’s rays hit Earth is of longer duration than in the winter months, providing more time for the Sun’s energy to heat that part of Earth. You may have heard that in the summer, the most northern latitudes are called the “land of the midnight Sun.” Look at figure 10. Can you see why these most northern areas have daylight for a full 24 hours? The Sun never sets in high-northern latitudes for a portion of the summer months.

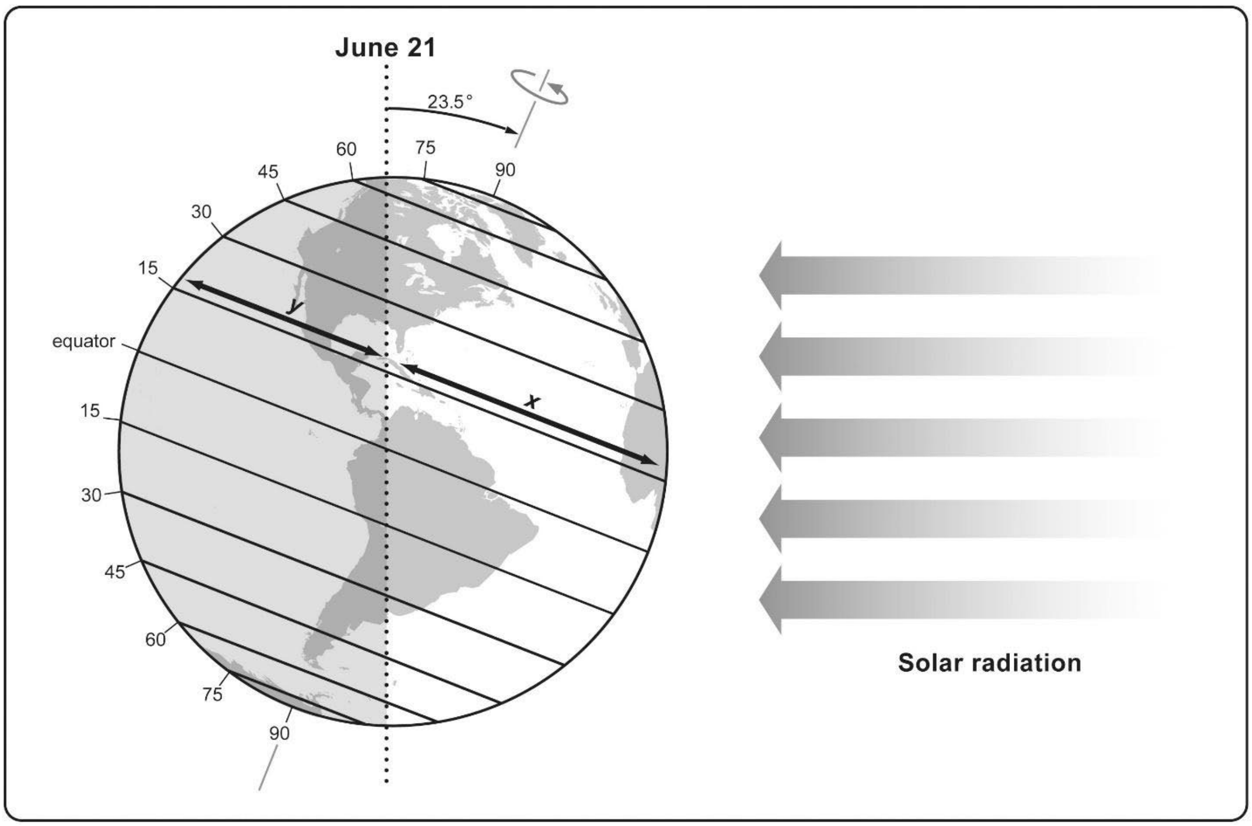


Figure 10: Length of daytime (*x*) and nighttime (*y*) on June 21

STOP AND THINK: How would the image in figure 10 be different on December 21? Would the tilt of Earth change direction? Refer to figure 9 and check your thinking.

Putting it all together: The Sun's effect on climate and seasons

Now you know that the real reason for seasonal temperature differences is not merely because Earth is tilted but because the tilt results in two distinct factors that cause differential (uneven) heating of Earth's surface: (1) the intensity of the sunlight on different parts of Earth changes as Earth orbits the Sun and (2) the length of daytime over the course of the year changes, so the Sun's energy heats portions of Earth for a longer time at certain times of the year.

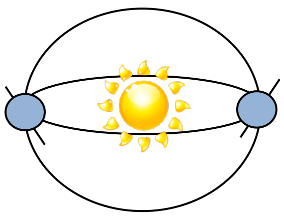
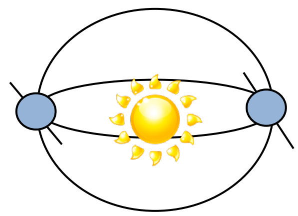
Is one of these two factors more important than the other, or do they play an equal role in seasonal changes? Let's look at a place like Nome, Alaska. Nome is in the part of the world that gets 24 hours of sunlight in the height of summer. Does the length of time that the Sun heats Nome cause it to be warmer than areas that get just 12 hours of sunlight—like at the equator? Of course not. Even though the equatorial regions are getting much less time in the sunlight, they still have higher average temperatures than Nome, Alaska, because the Sun's rays (solar radiation) are more intense at the equator. Receiving twice the number of hours of warming, although helping to make average temperatures higher than they would be with a shorter day length, cannot compensate for the fact that the sunlight is still much more spread out (less intense) at that high latitude than at the equator.

Did you know that equatorial regions have very little seasonal change? If you think about the angle of sunlight between the two tropics—the latitudes of 23½° N (Tropic of Cancer) and 23½° S (Tropic of Capricorn)—it varies only a little. The Sun is *almost* directly overhead all year long. In addition, the number of daytime and nighttime hours is always the same throughout the year; it never varies from twelve hours of daytime and twelve hours of nighttime. As a result, the regions around the equator might have a rainy season and a dry season, but they never have a true summer or a true winter, and temperatures will not vary like they do above the Tropic of Cancer and below the Tropic of Capricorn. Because of the combination of the two factors—intensity and duration of sunlight—the farther you are from the equator, the more pronounced the seasonal temperature differences.

Common Student Ideas about Sun's Effect on Climate and Seasons

Common Student Idea	Scientific Explanation
The Earth gets heat from the Sun.	The Sun is actually too far from the Earth to heat it directly. Instead, the light from the Sun is reflected or absorbed by objects on Earth, including the gases in the atmosphere, clouds, land, and ocean. Absorbed light usually increases the energy in an object, causing the temperature of an object to increase or the object to "heat up".
Light can only be reflected from shiny surfaces (such as a mirror). Students may also believe that an object cannot absorb and reflect light – it must do one or the other.	All objects absorb and reflect light to different degrees. Our ability to see objects depends on their reflection of light and seeing objects as different colors indicates that that object has absorbed certain wavelengths of light and reflected the color that we see.
Cold days are caused by clouds covering the Sun. Snow and ice make it cold.	The temperature of a given day is dependent upon many different things including time of year, location, altitude, prevailing winds, etc. The presence of snow and ice are functions of lower temperatures, not the cause of them.
Some students confuse Earth's daily spin (rotation) with its yearly orbit (revolution) around the Sun. For example, they believe that the side of the Earth not facing the Sun experiences winter.	The Earth's daily spin (rotation) causes our day and night, since any time we are on the side of the Earth not facing the Sun, it's dark outside, and when we face the Sun it's daytime.
Seasons are caused by the Earth getting closer to the Sun in summer and further away from the Sun in winter. (Researchers attribute this misconception to the representations that students often see in their textbooks that show an elongated elliptical orbit, which makes it appear as if the Sun is closer to Earth during certain times of the year.)	Just the opposite! The Earth is closest to the Sun during winter in the northern hemisphere, and farthest from the Sun in the northern hemisphere's summer! Seasons are caused by the tilt of the Earth's axis, and then different amounts of the Sun's energy received during the year by regions north or south of the equator. The Earth's tilt (which oscillates a little) is currently about 23.5 degrees--always pointed toward the North Star. This means that during our summers, the Northern Hemisphere is tilted toward the Sun and receives light at a more direct angle. In contrast, North America is tilted away from the Sun in the winter and the Sun's rays hit at a more indirect angle making them more spread out over a larger space.
The temperature near the equator is warmer because it is closer to the Sun, while the poles are colder because they are further from the Sun.	This is an issue of scale. Consider the distance from Earth to Sun. Comparatively, the difference in the distance from the equator to the Sun or the poles to the Sun is so small that it is inconsequential in creating differences in the temperature at different latitudes. Temperature differences at different latitudes are caused by the curved surface of Earth and the angle that Sunlight hits the Earth, being more direct at the equator, and hitting at more of an angle

	(and therefore more spread out) at the poles. Earth's tilt changes the location that gets the most direct sunlight. Because of the Earth's tilt, the equator receives the most direct Sunlight on the planet only twice a year, the spring equinox (March 20 or 21) and the autumn equinox (September 22 or 23). In June, the most direct sunlight strikes the surface of Earth just above the equator (23.5° N latitude). In December, the most direct sunlight strikes Earth's surface just below the equator (23.5° S latitude). In other words, this direct incoming Sunlight strikes north of the equator between the spring and autumn equinox (creating summer in the northern hemisphere, and south of the equator between the autumn and spring equinox, creating winter in the northern hemisphere and summer in the southern hemisphere.
Earth's tilt causes seasons.	In part, this is correct, but demonstrates a very shallow understanding of the reason for the seasons. The tilt of Earth's axis leads to two effects that cause **differential heating** of the two hemispheres at different times of the year (i.e., seasons). First, tilt directs more radiation to the hemisphere experiencing summer by changing the angle of the Sun's incoming rays (a smaller angle, resulting in more concentrated light energy), and less radiation to the hemisphere experiencing winter (the Sun's incoming rays hit the winter hemisphere at a greater angle, spreading out the light energy). Second, tilt increases the length of day, and thus the amount of heating, for the hemisphere experiencing summer. Keep in mind that differential heating is caused by the curved surface of Earth. Earth's tilt changes the location on the surface of Earth that receives the most direct sunlight.
Climate is simply long-term weather and therefore can't really be predicted with accuracy.	Weather consists of the short-term (minutes to months) changes in the atmosphere. Most people think of weather in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure, as in high and low pressure. Climate, however, is the average of weather over longer time-spans (seasons, years and decades) and space (not my local city, but broad geographic regions). An easy way to remember the difference is that climate is what you ***expect*** based on years of experience or data collection, like a very hot summer, and weather is what you ***get***, like a hot day with pop-up thunderstorms.
Global warming and the greenhouse effect are the same thing.	The greenhouse effect refers to the way that gases in the atmosphere absorb light energy from the Sun and also absorb some of the light and heat energy that is reflected or radiated from Earth back toward space. In other words, gases in the atmosphere trap some of the heat that might otherwise leave Earth. Without the greenhouse effect, Earth would be about 30^{o} C cooler with wild swings in temperature between day and night and the planet would be much less habitable for humans and other living things. Global warming refers to the impact of increasing greenhouse gases in the atmosphere (particularly increased levels of CO_2 produced by

	burning fossil fuels since the beginning of the Industrial Revolution) that trap more and more heat, causing a gradual rise in temperatures. The greenhouse effect (or the atmosphere's ability to absorb light and radiate heat) has been occurring as long as the planet has had an atmosphere, and long before any contribution by mankind. The recent fast pace of global warming that concerns scientists and citizens involves the way that human activity has influenced the composition of the atmosphere increasing the overall temperature on Earth that will have global impacts, such as rising sea levels, shrinking habitats, and changes in ocean currents that influence climate and weather patterns.
Students may have an image that the Earth's has a tilt, but their mental image of that tilt includes it always pointing toward or away from the Sun as in the diagram below, or that it tilts back and forth once a year. 	The Earth's tilt stays pointed in the same direction and angle throughout its orbit around the Sun. We don't know for sure WHY the Earth tilts although the most common theory is that it was caused by a tremendous impact from a Mars-sized object not too long after the solar system formed. 

Sun's Effect on Climate
PRE or Post Test

Name ______________________________ **Date** ________________________

1. **Sun and Earth**

   a. Draw circles to represent a top view of the Earth and the Sun. Label you circles "Earth" and "Sun".

   b. Add to your drawing of Earth and the sun to show how sunlight gets from the sun to Earth.

   c. Explain how your drawing is similar to the real Sun-Earth system and hoe it is different from the real system.

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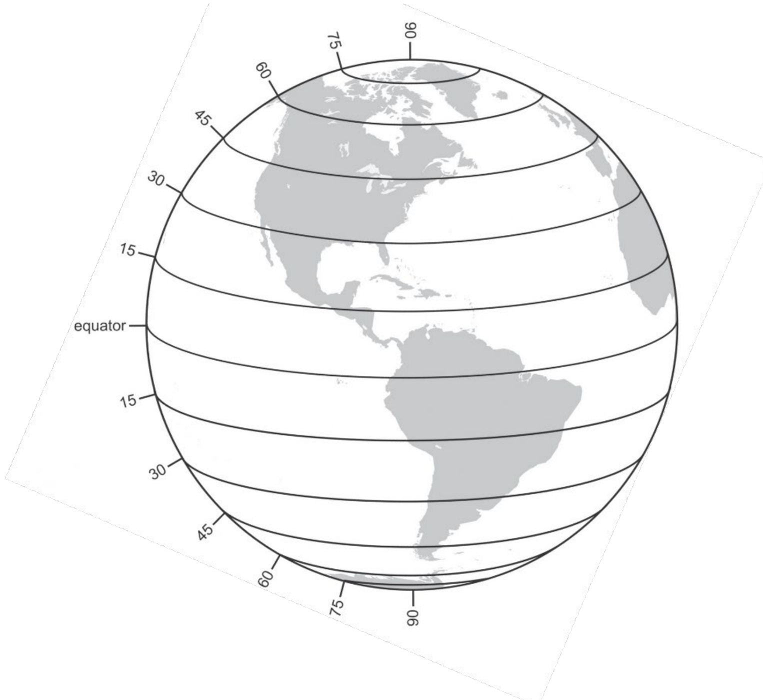

2. **Temperature and Latitudes**

Look at the picture of Earth above that shows different latitudes**.**

Imagine that you are sailing from the equator to latitude **60°N** (**north latitude**). How do you predict the temperature will change as you go on your journey?

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Explain the reason for your prediction.

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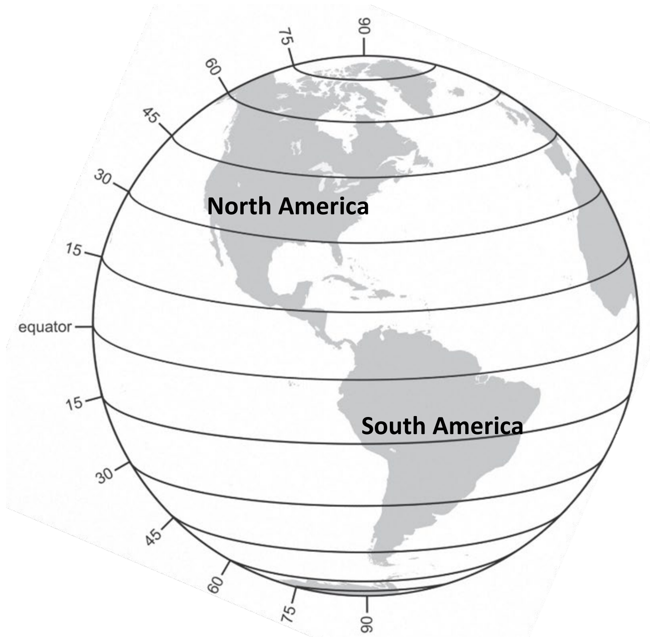
3. The Sun's Energy and Latitudes



Look at the picture of Earth above that shows different latitudes.

a. Which latitudes receive the most energy from the Sun overall?

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b. Which latitudes receive the least energy from the Sun overall?

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c. Explain the reason for your answers above.

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4. Cities in the World

The Table below gives information about four cities, A, B, C, and D.

- Look at the high temperature for each city in January and July.
- Look at the average number of daylight hours for each city in January and July.

	January		July	
City	**Average high temperature**	**Average number of daylight hours**	**Average high temperature**	**Average number of daylight hours**
A	97° F	13.5	66° F	10.5
B	47° F	10.5	93° F	14
C	34° F	8.5	75° F	16
D	89° F	12	90° F	12

Use this information to answer the following questions.

a. Which city or cities are in the northern hemisphere?

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What patterns helped you answer this question?

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b. Which city or cities are in the southern hemisphere?

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What patterns helped you answer this question?

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c. Which city or cities are on the equator?

What patterns helped you answer this question?

d. City C has four more hours of the sunlight in July than city D, 16 hours compared to 12 hours. Even so, city C had a lower temperature than city D, 75° compared to 90°. What is the explanation for this?

5. Summer in South America

Notice where South America is in the picture of Earth in question 3.

a. Draw a picture below that shows why it is hot (like summer) in January in South America. Label your picture.

b. Explain your drawing.