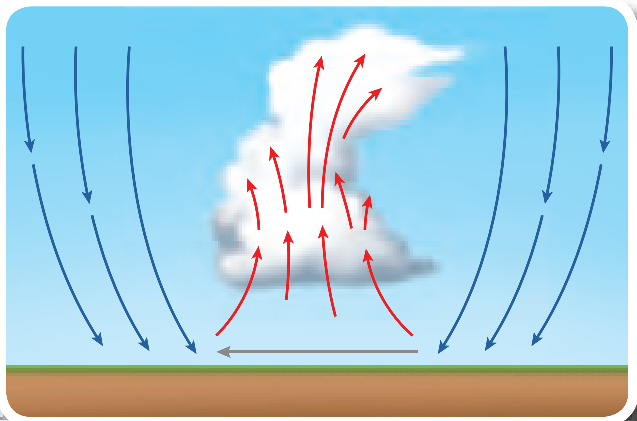
Core Knowledge® SCIENCE

Weather, Climate, and Water Cycling:

Why does a lot of hail, rain, or snow fall at some times and not others?

Science Literacy

Science Literacy Student Reader



Atmospheric circulation

Weather and climate

THIS BOOK IS THE PROPERTY OF:

STATE ____________________

PROVINCE ____________________

COUNTY ____________________

PARISH ____________________

SCHOOL DISTRICT ____________________

OTHER ____________________

Book No. ________

Enter information in spaces to the left as instructed.

ISSUED TO	*Year Used*	*CONDITION*	
		ISSUED	*RETURNED*

PUPILS to whom this textbook is issued must not write on any page or mark any part of it in any way, consumable textbooks excepted.

1. Teachers should see that the pupil's name is clearly written in ink in the spaces above in every book issued.
2. The following terms should be used in recording the condition of the book:
   New; Good; Fair; Poor; Bad.

Weather, Climate, and Water Cycling

Science Literacy Student Reader

Core Knowledge®

ISBN: 978-1-68380-787-2

Weather, Climate, and Water Cycling

Table of Contents

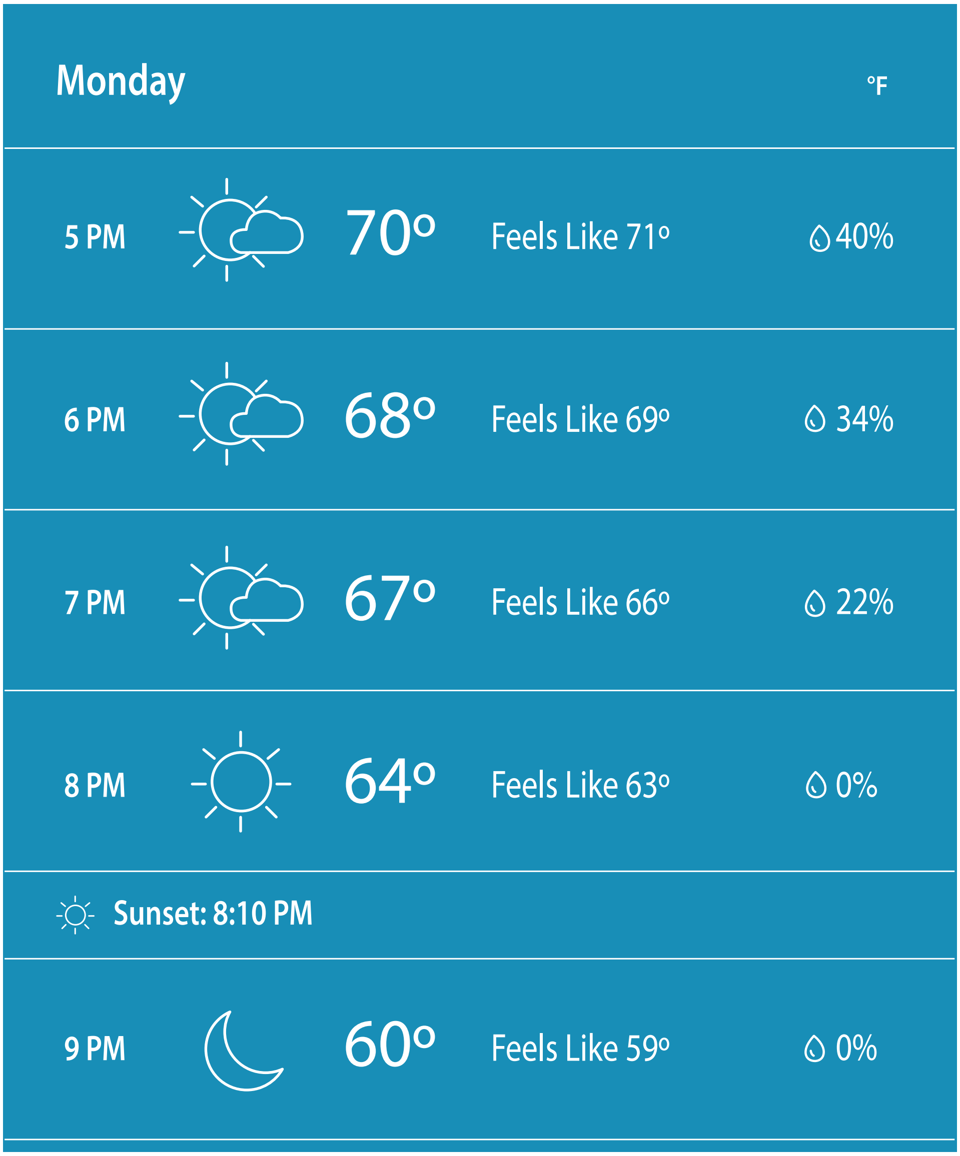
Put Yourself in This Scene

It's 3:00 on a summer afternoon. You and your friend Thea have been planning to head to the local basketball court to get a game going in the early evening. The sky looks clear, and the temperature is not too hot. Seems like a perfect time to play. You send Thea and some other friends a group text message:

"Hey. Play hoops at 5:30 at Emerson? Perfect temp."

Thea responds in a few minutes: "Um, IDK. Looks OK outside right now but my weather app says rain starting at 5."

That's odd. Your phone's weather app didn't make it look like rain was coming, at least



not a few hours before when you last looked. You check again.

The row for 5 p.m. shows partly sunny skies, 70ºF, a "Feels Like" of 71ºF, and a 40% chance of precipitation. Later, the temperature is slightly cooler, and the chance of precipitation declines. You're puzzled that Thea is put off by a chance of rain that is not even 50%.

"I'm looking at the same app as you," you write. "The forecast is for partly clear skies and just a slight chance of rain."

"40% is more than slight." Thea replies. This text is liked by five of your mutual friends.

"But that's just the chance of ANY precipitation at all. It could literally be two seconds of rain. That would barely make the court damp!" This message gets hit with a question mark by several friends.

"I'm not sure. 40% is almost 50%. I'd rather not risk it."

Argh, you think. *What use is this weather app if Thea and other people don't know how to read it?!*

You decide to bike to the park and practice your shot. One friend shows up. You play some one-on-one. There is a brief passing shower, but that's it. As you predicted, it barely dampens the basketball court. If anything, it feels kind of nice after working up a sweat. You think about what it means for something to have a probability, or a chance, of occurring, as well as the accuracy of weather service predictions.

That's what this book is about—scientific literacy, which means knowing how to think about science topics that you read or hear about. Our world has 24–7 news, social media, and too many websites to count. The amount of information we must sort through is overwhelming, and all the information is not reliable. In the internet age, sources of information are often obscure or not trustworthy. It is good to process information with a healthy degree of skepticism.

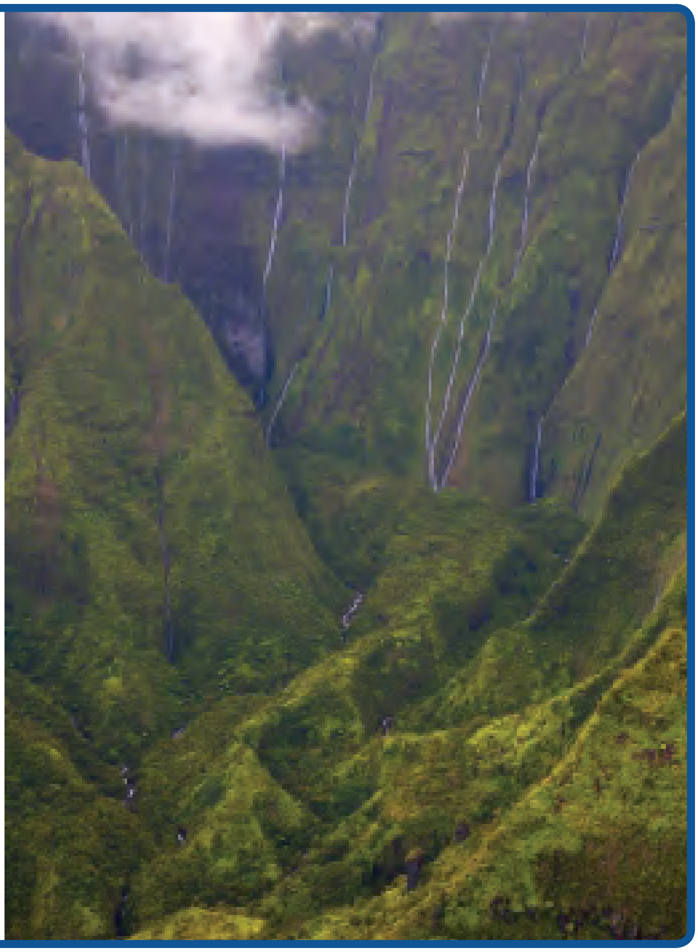
We will make our way back to the topic of correctly interpreting weather forecasts by the end of the book. Along the way, the series of reading selections and the writing exercises that go with them will help you flex your mental muscles and sharpen your science literacy skills. The ability to read about science, understand the information, and tell truth from fallacy or misrepresentation is important. Science literacy helps you as an individual and as a consumer, and it shapes the ways you affect the community in which you live.

Rain, Snow, and Hail Capitals

Look outside a window. What is the weather like today? Is it cloudy, sunny, wet, or windy? Weather happens every day, everywhere. But it differs from one place to the next. Some places have more **precipitation** than others. Rain, snow, and hail are forms of precipitation. Rain is liquid water that falls to Earth's surface from the sky. Snow consists of frozen crystals of ice that are loosely stuck together. Hail is more like a solid ball of ice. All three types of precipitation can occur almost anywhere in the United States, but each type has its own capital, where more falls than anywhere else in the country.

Rainfall Capital of the U.S.: Mt. Waialeale, Kauai, Hawaii

If you're ever planning to visit the island of Kauai, you might want to pack an umbrella. Kauai is one of the main islands of the Hawaiian island chain. You may notice from the picture that it is lush and green. That's because it receives a lot of rainfall. Mt. Wai'ale'ale takes the title of rainiest place in the United States thanks to an average annual tally of 460 inches, or 11.64 meters, of rainfall. (By contrast, Chicago gets about 37 inches of rain per year.) This side of Kauai receives moisture-rich wind from the North Pacific. The steep cliffs and overall shape of the landscape funnel moist air and direct it upward, concentrating moisture in a relatively small area.

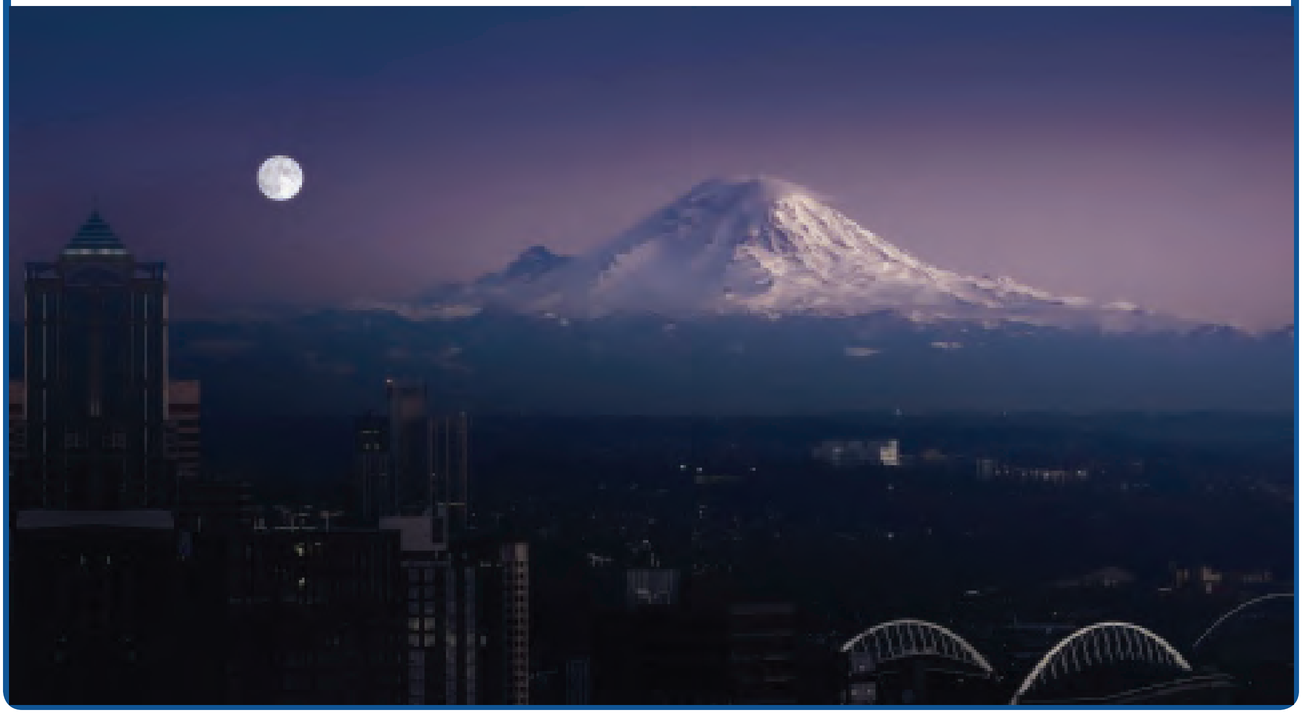


Vocabulary

precipitation, n. rain, snow, sleet, or hail that falls to the ground

Snow Capital of the U.S.: Mount Rainier, Washington

The name might suggest that Mount Rainier is a very rainy place, but it is actually the snowiest place in the United States. On average, the Paradise area of the mountain, at an elevation of 5,400 feet, receives about 640 inches (16 meters) of snow each year. The mountain gets its name from a British naval admiral who surveyed the Pacific coast in 1792. If only someone named Snow or Snowier had spotted it instead!



Hail Capital of the U.S.: "Hail Alley"

The area where Wyoming, Colorado, and Nebraska share borders is known as "hail alley" because it receives considerably more hail than other regions of the United States. Cheyenne, the capital of Wyoming, probably gets more hail than any other U.S. city, with nine days per year on average. Hail develops when small ice crystals circulate in certain storms and grow larger and larger until they fall to the ground.

A History of Mapping Weather

Weather maps have been around for a while, but they have gotten more complex over the years. A weather map shows a variety of weather data on a two-dimensional visual of an area on Earth's surface. Making an accurate weather map first requires an accurate map of the area for which weather is being analyzed.

The earliest maps were hand drawn, based on estimates or measurements of distances between places. Cartographers—people who draw maps—had to study latitude and longitude. Latitude could be determined once people knew how to measure the position of the sun in the sky at noon. If the sun is directly overhead, for example, you must be near the equator. Determining longitude required knowing what time it was in Greenwich, England, and what time it was locally. This required an accurate clock to show the time in Greenwich and precise instruments to measure the sun's position at noon. An accurate clock that could be taken on ships was not available until 1735, so people, especially sailors, had a very hard time navigating the world, not to mention making accurate maps.

Fast forward a few hundred years, and we now have extremely precise maps of Earth's surface, and the average mobile phone can tell you your latitude and longitude with the touch of a button.

Words to Know

Latitude refers to how near or far a point is, north or south, from Earth's equator or poles. *Longitude* is how far east or west a point is from the prime meridian, the arbitrary starting point that runs through Greenwich, England.

Dig into Data

The lines of longitude run from 0 degrees to 180 degrees. The prime meridian in Greenwich, England (shown in the picture), has a longitude of 0 degrees.

The line of longitude that lies directly 180 degrees east and west of the prime meridian is known as the antimeridian. If you travel from Rome (with a longitude of 12 degrees E) to Istanbul (with a longitude of 28 degrees E), are you moving toward the prime meridian or the antimeridian?

First Map

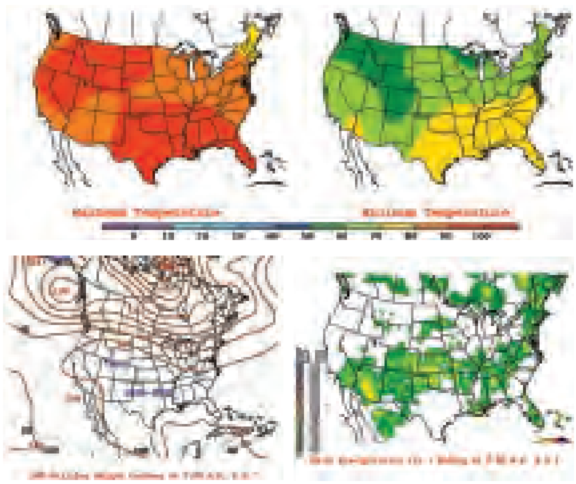
The history of weather maps in the United States begins in 1871, when the U.S. Signal Office began publishing weather maps as *War Department Weather Maps*. At the time, the Civil War was barely in the past. The United States consisted of states as well as territories that were relatively young. You can see this reflected in this weather map from July of that year. The map has atmospheric pressure readings stamped on it, along with symbols that describe local weather conditions, but mainly in states east of the Mississippi River.

More Detailed Maps

By 1938, U.S. weather maps were produced by the Department of Agriculture. Weather maps were far more detailed at this point. This map shows and describes a hurricane hundreds of miles off the east coast of Florida. This hurricane would eventually turn north and strike Long Island and the coasts of Connecticut, Rhode Island, and Massachusetts with devastating consequences two days later.

Today's Maps

Today, one can view a wide variety of accurate weather data, often in real time—meaning data that are being recorded just moments before they show up on a screen. These four maps show maximum and minimum temperatures, atmospheric pressure readings, and precipitation for a single day in July of 2021.



Modern Weather Data Visualizations

What do the camera on a phone and this weather satellite have in common? They are both used for taking pictures. But while the camera on a phone takes pictures of things that are close by, this weather satellite can take pictures of weather patterns forming on Earth from thousands of miles away!

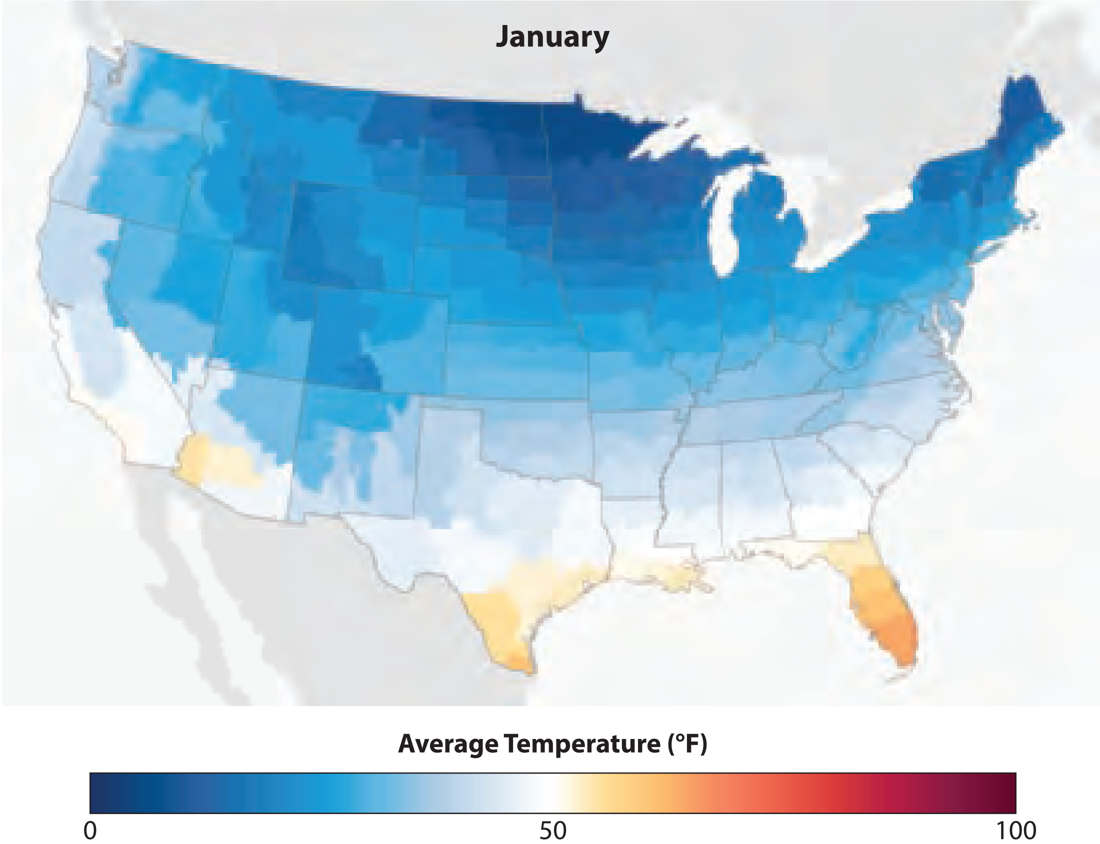
Sophisticated satellites, like the one shown here, allow scientists to capture information about the weather and use it to study trends and make predictions about weather in the future. The pictures and data collected from these satellites—as well as other types of weather technology—are presented in map form. Some are true weather maps that describe the observed weather for a specific snapshot in time. Others summarize trends or reveal averages for temperature, precipitation, and more.

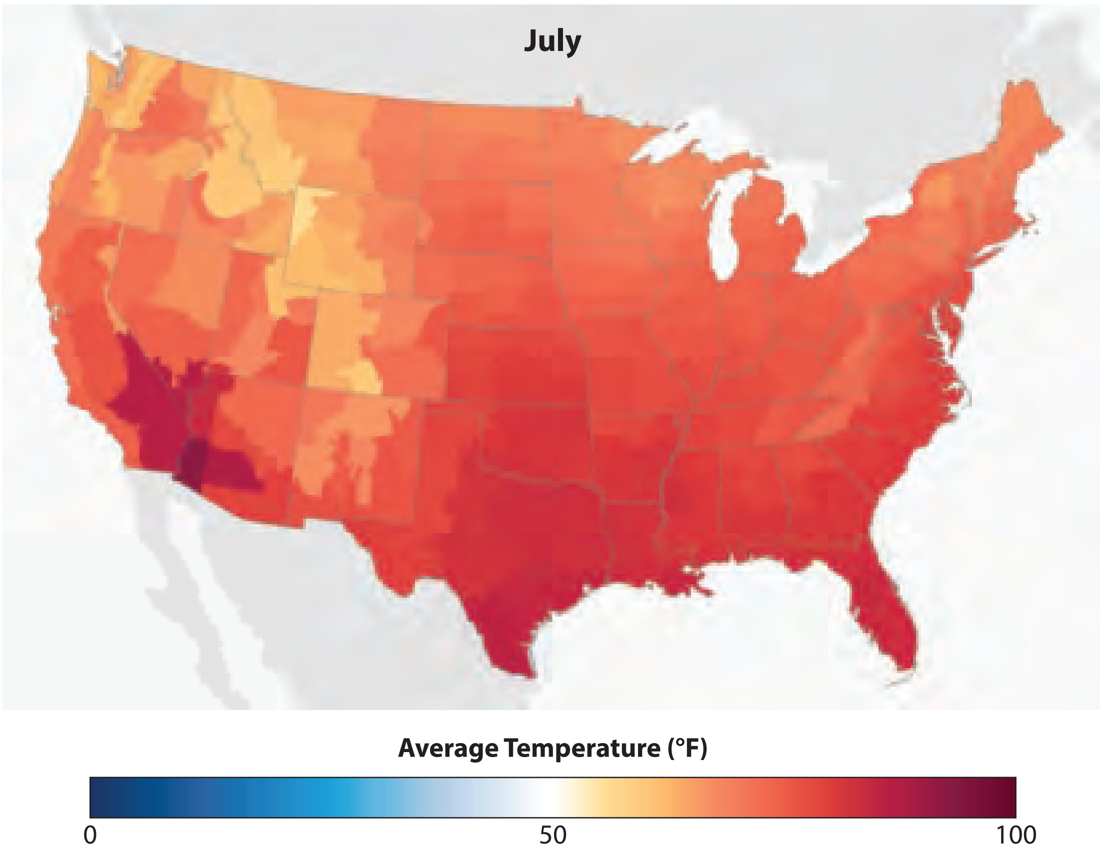
The maps to the right show the average temperatures for two months, January and July, in the contiguous United States from a 30-year period. The average, or mean, temperature is based on thousands of measurements of temperature from all 31 days in January, taken from the past 30 consecutive years. Weather stations reporting similar temperatures are grouped together as regions within the 48 states on the map. For example, there are five distinct temperature regions distinguishable in Florida in winter.

You can infer a few things about temperatures in the United States from these 30-year-mean maps. One inference is that the United States is much colder in January than in July. Another is that northern areas are cooler than southern areas.

Words to Know

A *mean* is an average. It's the value calculated by summing a set of values and dividing that sum by the number of values.


January
Average Temperature (°F)
0
50
100

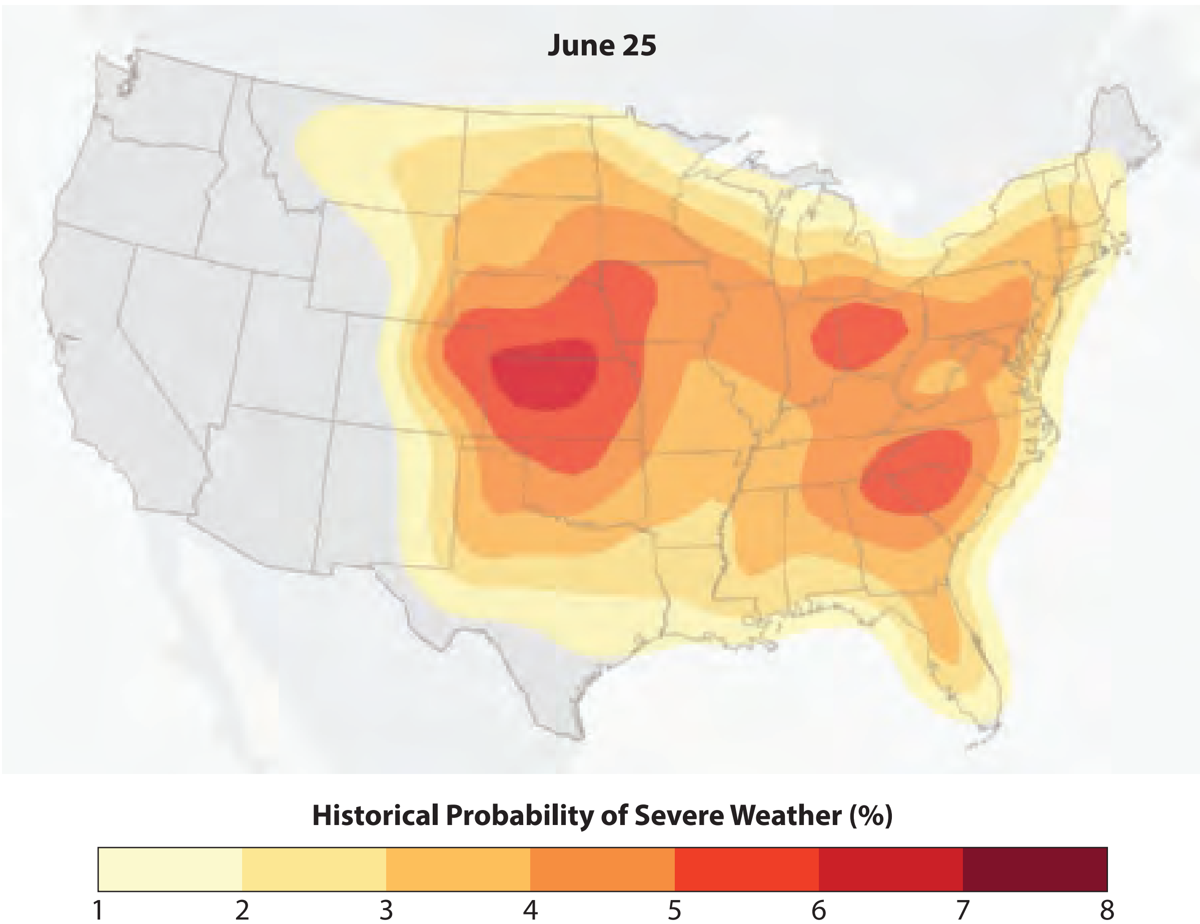

July
Average Temperature (°F)
0
50
100

Some visualizations summarize averages over relatively long periods of time. If the July map showed the high temperatures across the United States in a single day or week in July, then it would be a weather map, because the conditions of a relatively short period of time would be shown.

Having accurate records of weather helps paint the picture of climate. Such records can also be used to make rough predictions of specific weather events, like storms. Forecasts based on current observations of weather can also be compared to historical data to give people some idea of how the weather might be different next week from how it was during the same week in years past.

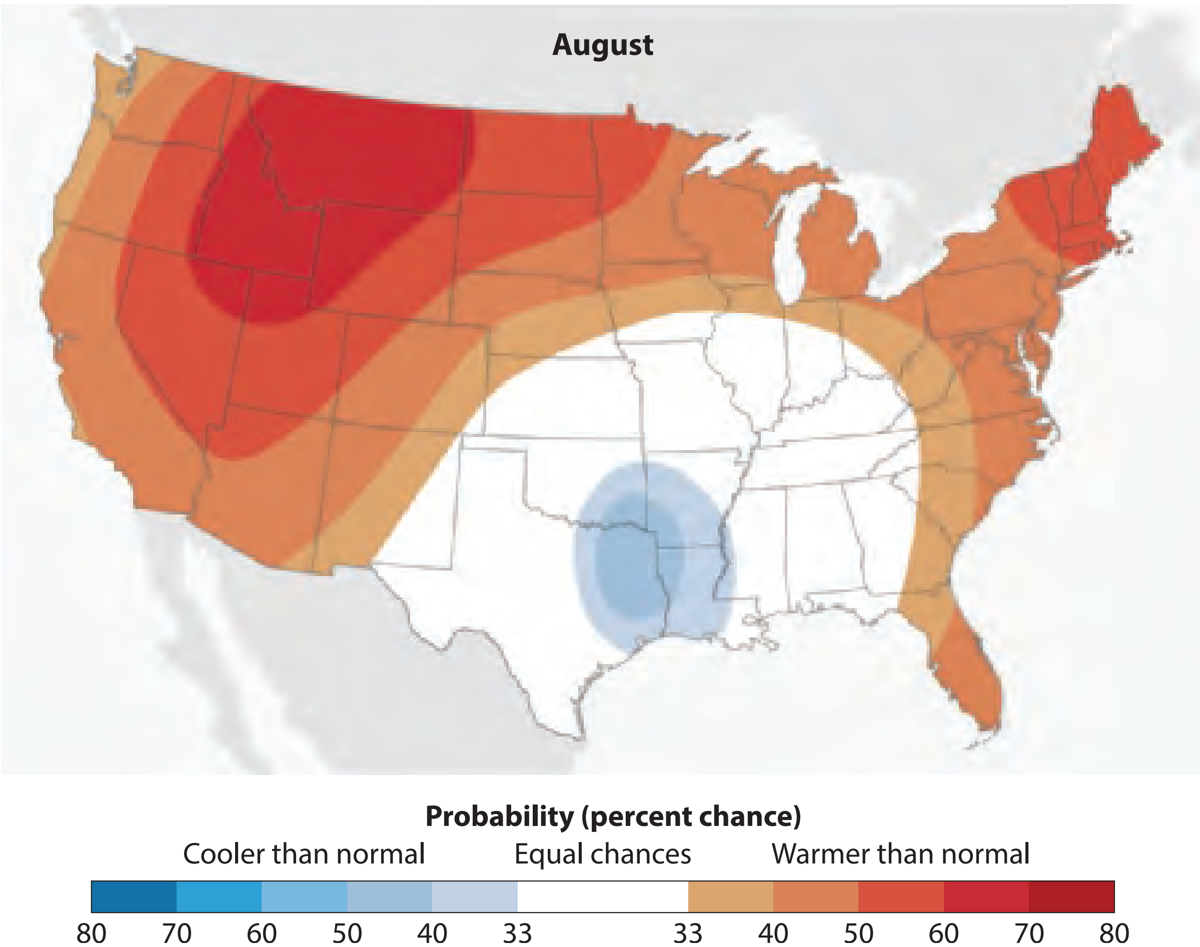
The map below shows the relative **probability**, or chance, of severe weather occurring in different regions of the United States on a specific date: June 25. This is not a weather forecast based on data from the atmosphere on June 24. Rather, it is based on severe weather from 30 previous June 25s. The reader can see that there is a 6–7%

> **Vocabulary**
>
> **probability, n.** the chance or likelihood that something will occur



chance of severe weather occurring around the border shared by Nebraska and Kansas but just a 1–2% chance of such weather in southern Maine. Severe weather is defined as tornadoes, thunderstorm winds over 58 miles per hour, or hail larger than three-quarters of an inch in diameter. Someone who is thinking about vacationing in Maine in late June might look at this map with relief. Someone who is thinking about camping in Kansas might have second thoughts or at least come up with a backup plan.

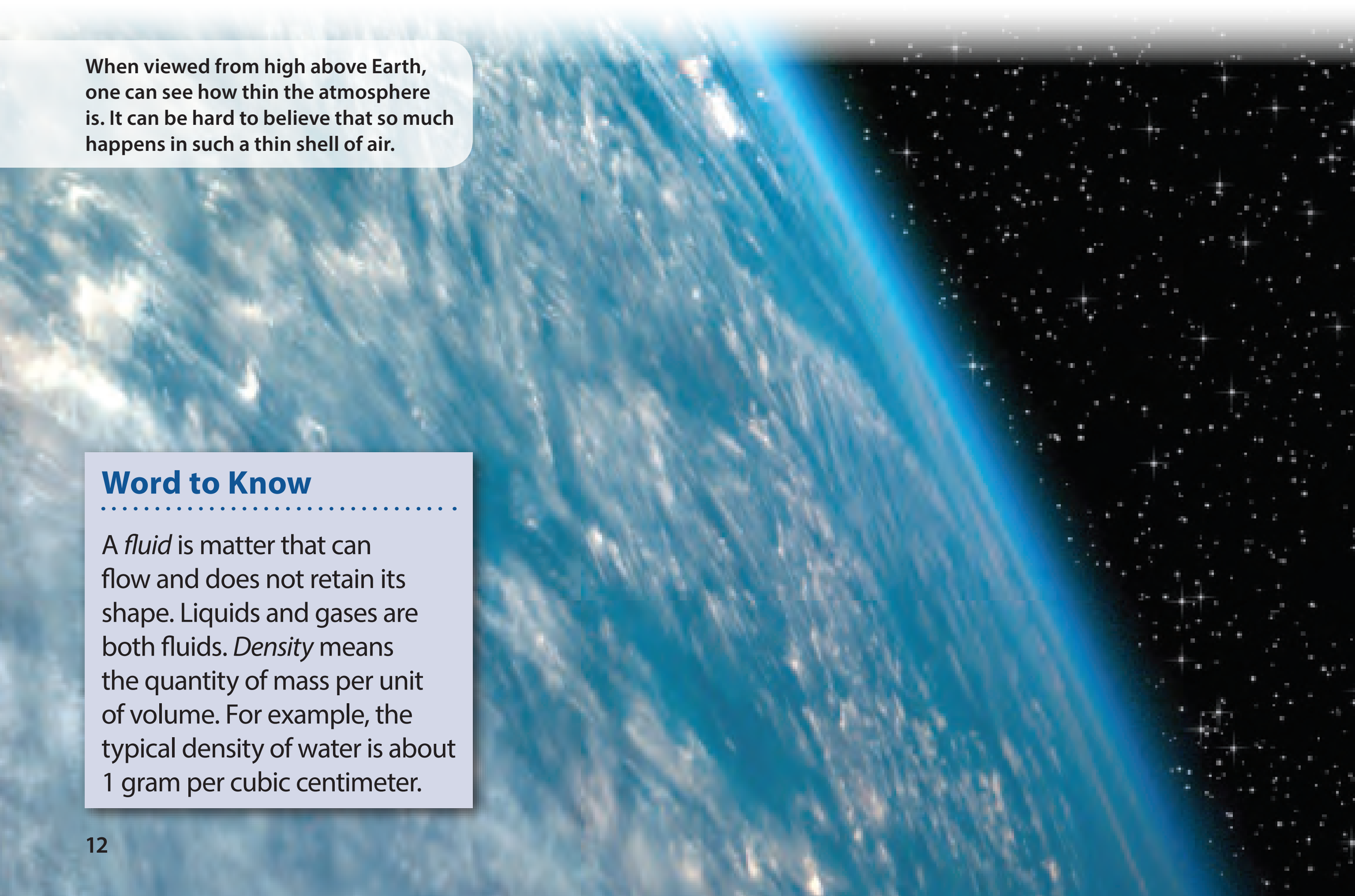
The map below is called an outlook. It combines a one-month temperature forecast for the month of August with historical data from previous Augusts to give the reader an idea of where the United States will likely be cooler or warmer than in Augusts past. This outlook for August 2021 shows a high probability of warmer temperatures in the northwest and northeast, with a somewhat high probability of unusually cool temperatures in eastern Texas. Note that in this map the deep red does not mean very hot. It means there is an 80% chance that the air will be warmer than normal, with "normal" being defined by Augusts of recent decades.



The Atmosphere as a Fluid

Earth is basically an 8,000-mile-wide sphere with a very thin envelope of air around it. If you could hold Earth in your hands like a basketball, the atmosphere would be like a layer of plastic wrap—the kind you might wrap around a sandwich. But unlike a sheet of plastic, the atmosphere is not a solid consisting of particles that are fixed in place. The atmosphere is a fluid, meaning its particles can flow like those in a liquid. Gravity keeps the atmosphere held to Earth's surface, but there is a lot of movement within the atmosphere. In that sense, a better model for the thin layer of air around a basketball might be a layer of honey.

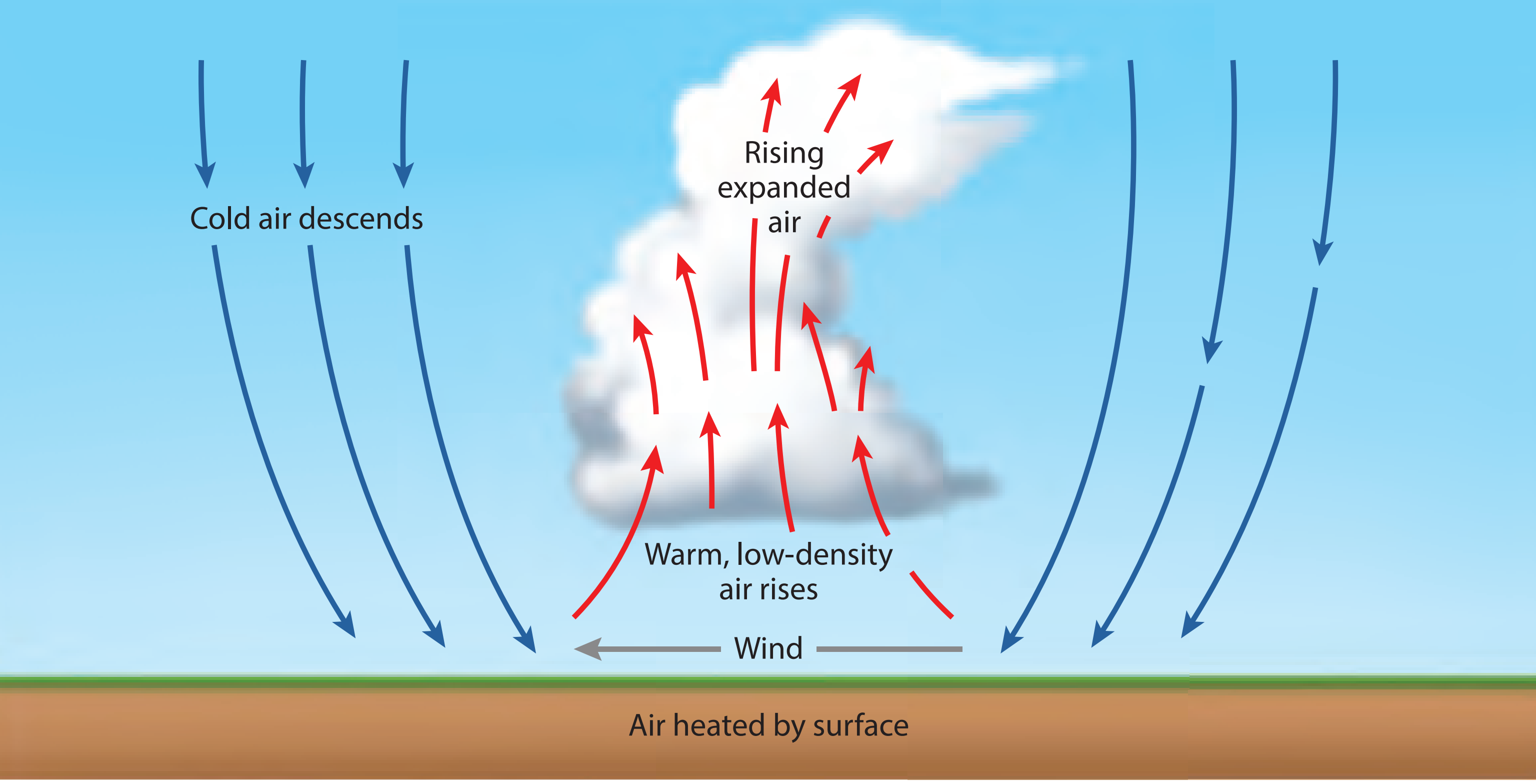
In general terms, the air and moisture in the atmosphere can be tracked as they move up or down, as well as across Earth's surface—north, south, east, west. What causes movement in the atmosphere is heat, both from direct sunlight and from Earth's surfaces warmed by sunlight. Where the surface of Earth is hot, the air gets heated, expands, and becomes less dense. Because the atmosphere is a fluid, the expanded air can rise through and above a denser mass of air. This can shove aside some of the denser, colder air above that spot on Earth's surface. Meanwhile, because the heated air has moved up, a void is left over the hot surface.



When viewed from high above Earth, one can see how thin the atmosphere is. It can be hard to believe that so much happens in such a thin shell of air.

Word to Know

A *fluid* is matter that can flow and does not retain its shape. Liquids and gases are both fluids. *Density* means the quantity of mass per unit of volume. For example, the typical density of water is about 1 gram per cubic centimeter.



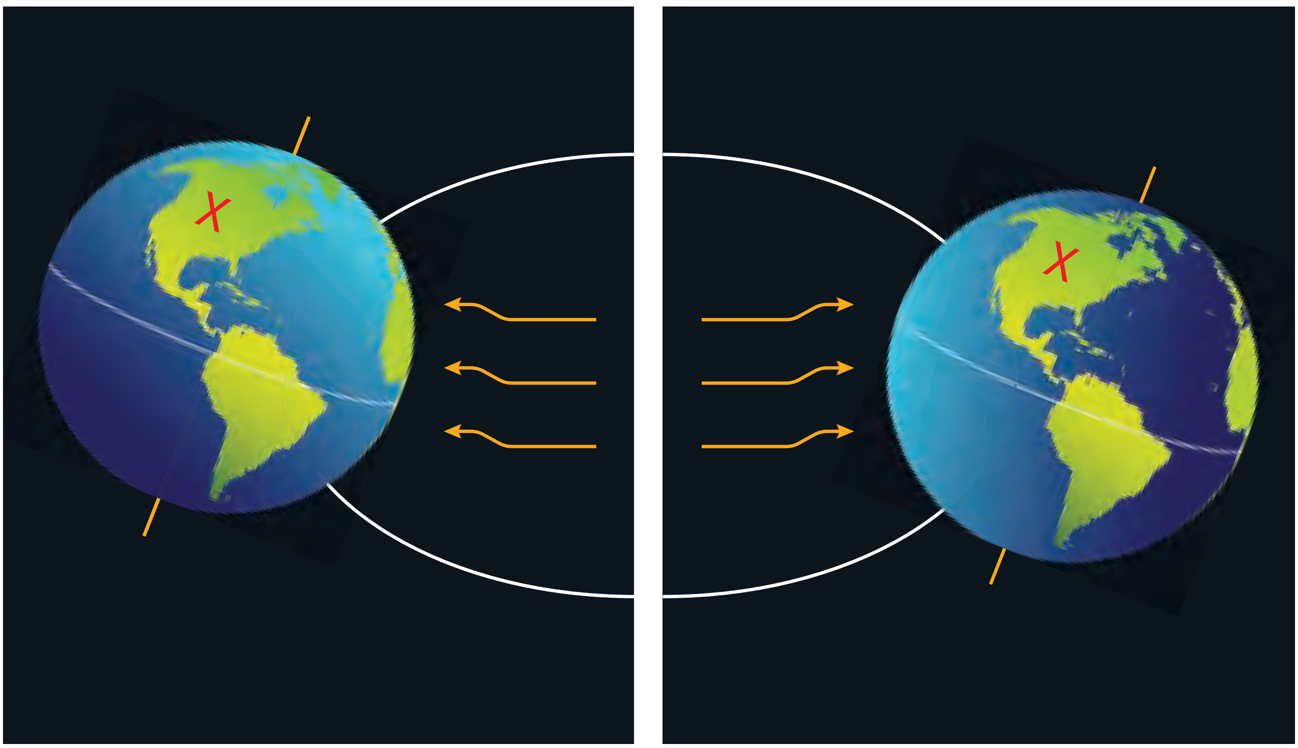
Air from another area above Earth's surface will flow in to fill the void. The horizontal movement of air is wind.

If you've flown on an airplane, you might know it's helpful to chew gum when the plane takes off and lands to minimize pain in your ears. Ear discomfort can come from the pressure that changes when you go up and down in the air. Chewing gum helps "pop" your ears to release some of that pressure. Similar pressure changes occur on Earth. Over any given spot on Earth's surface, there is a column of air. The weight of all that air is experienced as atmospheric pressure. At sea level, about 14.5 pounds of pressure push on every square inch of objects that happen to be at the bottom of that column of air. At higher altitudes, the column of air is shorter, and therefore there is less weight and less pressure pushing down on things. The air is said to be "thinner" at high altitude because there is less matter per volume of air. Our bodies can perceive this when we are trying to breathe at high altitudes. There is less of what we need—oxygen—in thin, high-altitude air. You can also feel atmospheric pressure drop when your ears pop.

Hot-air balloons rise by heating trapped air. The relatively low density of the trapped air allows the balloon to rise through and above the cooler, denser air around it. Masses of air warmed by Earth's surface behave similarly.

Uneven Heating of Earth

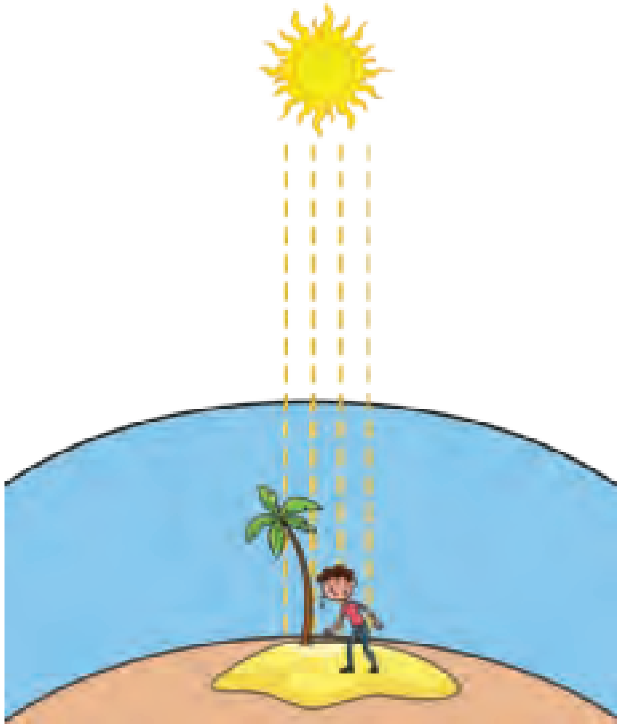
The sun-warmed ground heats the air. But why does it warm the air differently in different places? Earth's atmosphere filters sunlight. The more atmosphere sunlight passes through, the less energy reaches Earth's surface.



Earth is tilted on its axis, and because it revolves around the sun, one hemisphere is facing the sun more directly in summer…

…and less directly in winter. This is why Earth has seasonal climates, especially farther from the equator.

Close to the equator, the midday sun's light strikes Earth at almost a 90-degree angle.



Midday sunlight at the equator passes through less atmosphere than farther north or south, so more of it reaches Earth's surface.

Farther from the equator, sunlight strikes Earth's surface at an indirect angle.

So, sunlight must pass through even more atmosphere before reaching Earth's surface.

Solar Irradiance

Each year, thrill-seeking people enter an event called the polar bear plunge, where they take a quick swim in freezing-cold water in the middle of winter. The winter months in the Northern Hemisphere, where the United States is, are cold because of something called *irradiance*.

Solar irradiance is how much and how directly solar energy strikes a square meter of a flat surface. The surface can be on or parallel to the ground. During winter in the Northern Hemisphere, the north half of Earth is tilted away from the sun. So, much less solar energy strikes directly on any square meter. In contrast, during summer, when Earth's axis is tilted toward the sun, far more solar energy directly strikes any square meter of a flat surface. This makes the summer months hotter (and more enjoyable for swimming).

Dig into Data

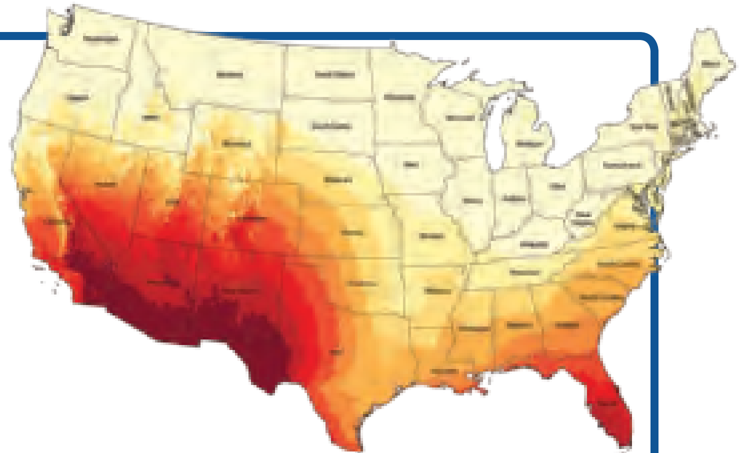
Global horizontal irradiance is a measure of how much solar energy strikes a given area, in this case a square meter, of flat ground or another object that is parallel to the ground. These data can help guide the installation of solar panels. In areas where the sun never gets high in the sky, panels can be set at an angle to receive sunlight more directly. However, much of the radiation is absorbed by the atmosphere when the sun is relatively low in the sky.

Solar Irradiance in December, U.S.

In the Northern Hemisphere, less direct solar energy from the sun heats Earth during winter months. This map from the National Renewable Energy Laboratory, which is a branch of the U.S. Department of Energy, shows very little horizontal irradiance in the United States in December. The sun is relatively low in the sky, so sunlight strikes the surface of North America at a less direct angle, while passing through more atmosphere on its way. This is why much of the United States is cold in December.

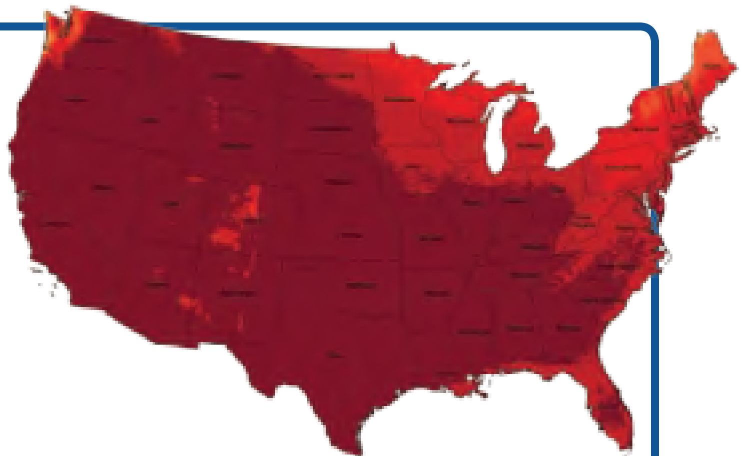
Solar Irradiance in March, U.S.

In March, Earth's hemispheres are equally tilted toward and away from the sun. It is springtime in the Northern Hemisphere and fall in the Southern Hemisphere. In the United States, the southern states get more solar radiation, especially in the southwest where skies are relatively clear. An irradiance map from October would look similar.



Solar Irradiance in August, U.S.

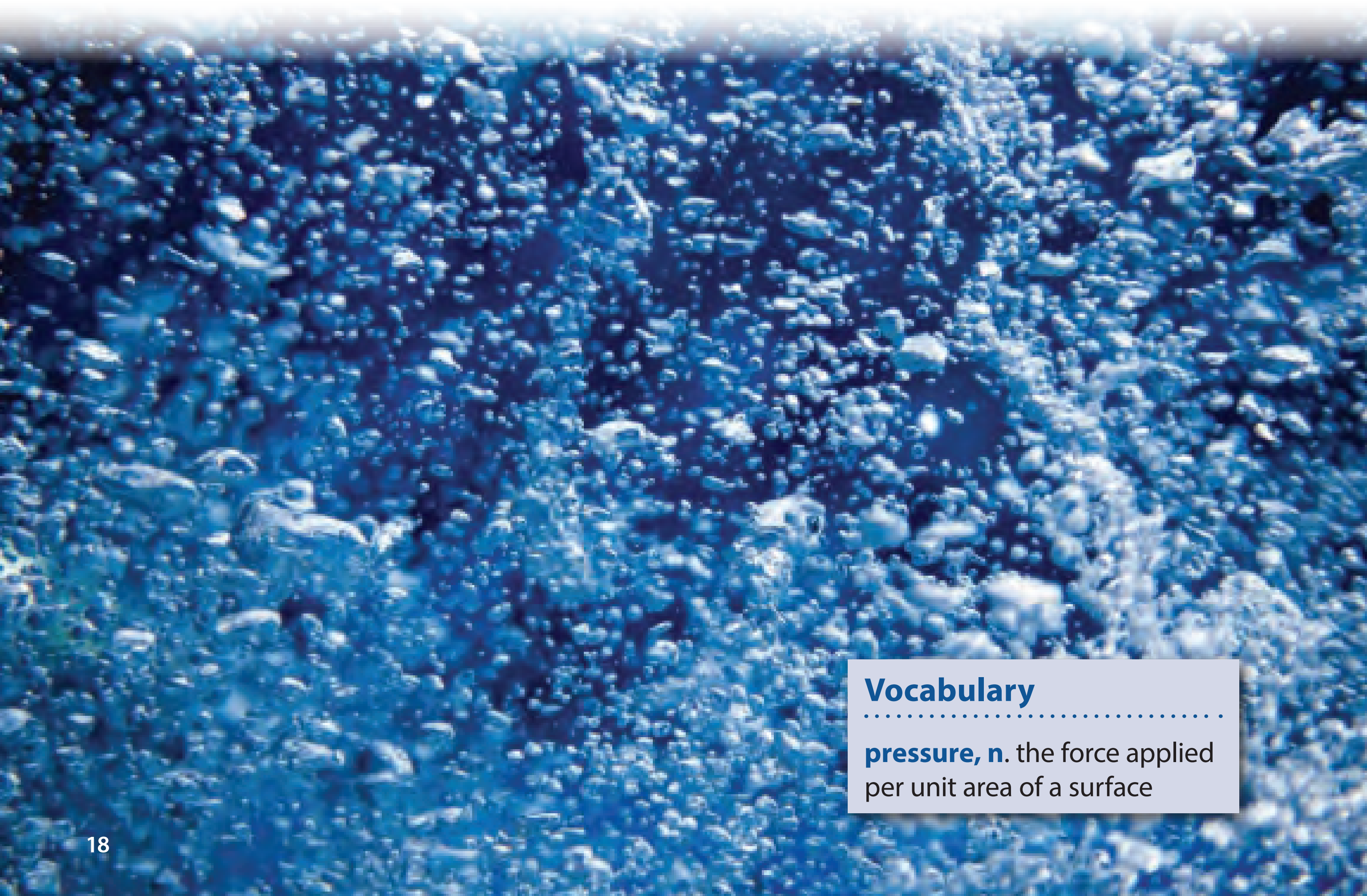
In August, the Northern Hemisphere is tilted toward the sun. Days are long, and the sun is higher in the sky above the United States than it is in spring, winter, and fall. This results in much more irradiance. Alaska still does not have much irradiance despite having between 18 and 24 hours of daylight per day. The sun is above the horizon almost all the time, especially in northernmost Alaska, but it is not very high in the sky.



But what about Alaska? Alaska has low irradiance all year round. Because of its location on Earth, this state doesn't get as much irradiance as the others, even in the summer. This image shows the path of the sun through the northern Alaskan summer sky as the sun "sets" and then rises. The sun remains low in the sky but never drops below the horizon at this time of year in this location.

The Atmosphere and Pressure

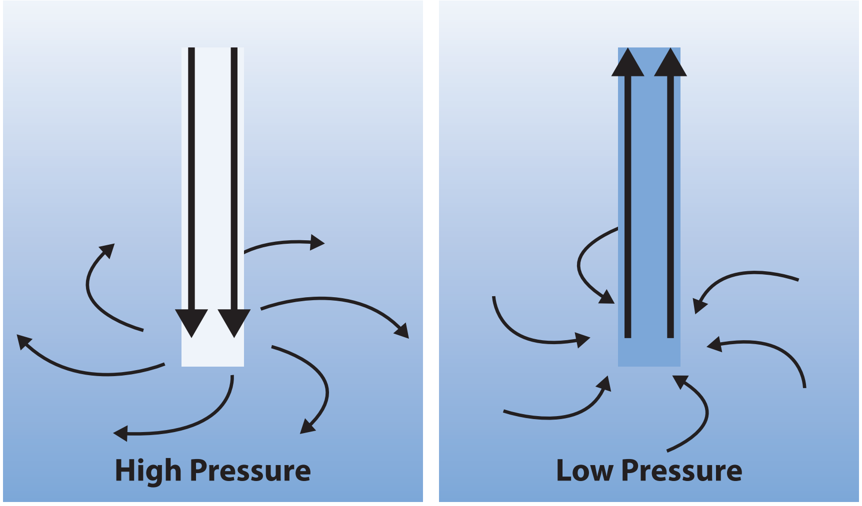
The atmosphere is a fluid. So is an ocean. In both, the fluids move if they experience an increase in pressure. Fluids will move from areas of high pressure to areas of low pressure. You have a glass jar filled with air. Now close it tight with a lid. If you were to hold this jar under water and remove the lid, water would flow into the jar, and the air would be forced out of the way, producing large bubbles of air that would rise through the water and escape into the atmosphere. The relatively high pressure of the water would displace the lower-pressure air. If you were to repeat this demonstration with a jar of some other fluid with a density similar to water, the water would not rush in and displace the other fluid. The similar densities of the two substances would mean they wouldn't move much at all, because the pressure within each and acting on each would be so similar.



Vocabulary

pressure, n. the force applied per unit area of a surface

In the atmosphere, some portions, or masses, of air have lower or higher pressure than others. A mass that has higher pressure will try to spread out. Wind is basically air moving from a higher-pressure area to one of lower pressure. A high-pressure mass will spread out from its center, causing winds to flow outward. A low-pressure mass will experience winds flowing toward its center and air rising higher into the atmosphere. A low-pressure mass of air is like the air that is displaced from the jar under water.



If you headed to the beach with your friends and saw these clouds in the sky, you might decide to turn around and go home. This type of cloud can often mean that rain is on the way. Here's why. The ocean and atmosphere work together to produce weather. Where the ocean absorbs a lot of sunlight and becomes warm, the low-density warm water tends to sit above the high-density cold water. This allows the warm water to continue to get even warmer as it receives solar radiation. Some of the heat from the water radiates into the atmosphere above it. Water also evaporates from the warm water. The warmed air becomes less dense. This causes the warm, moist air to rise in the atmosphere. As it rises, the warm, moist air gets colder. It gets denser, too, and molecules of water get stuck together as droplets. Zoom out from this, and all those droplets form a very large, fast-growing cloud: a type of cloud that can easily turn into the ultimate party-crasher. If the cloud gets cool and dense enough for the droplets to stick together, a heavy rainstorm will interrupt your beachy, outdoor plans.

Earth's Diverse Surfaces

Earth's surface is flattest on its oceans and lakes. Some landscapes are relatively flat, but many are not. And many are covered with trees and other objects that make the surface bumpy. Meanwhile, Earth's surfaces and the things on them are made of a wide variety of substances, some of which reflect sunlight well and therefore absorb very little energy. Meanwhile, others absorb a great deal of energy. Read on to explore the diverse nature of Earth's surface.

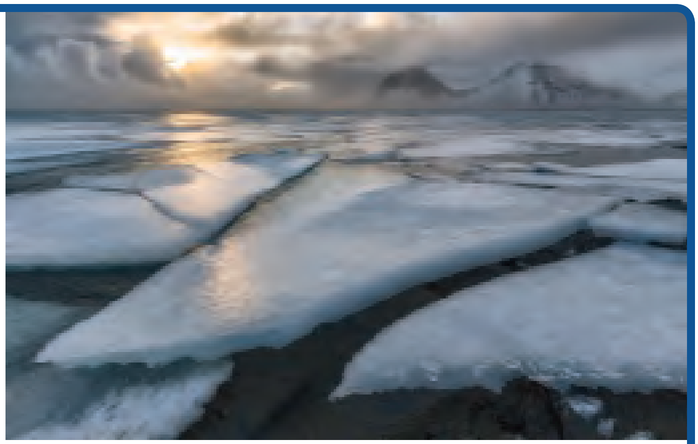
Sand

Sand is made of different substances. On a tropical island, the sand might consist of tiny fragments of coral and seashells. This sand does not absorb much energy from sunlight, so it does not conduct much heat into the air—or into someone's bare feet. But you would want to wear your shoes to a sandy beach on a large continent, where the sand might consist of tiny fragments of weathered rock. This type of sand might get much warmer in less direct sunlight than the tropical beach because the material the sand is made from does a better job of absorbing solar energy. Volcanic sand consists of fragments of volcanic rock and basalt and can get hot because the color black absorbs sunlight so well.

The Samoan island of Savai'i has white sand made of coral as well as black sand made of weathered volcanic rock.

Water

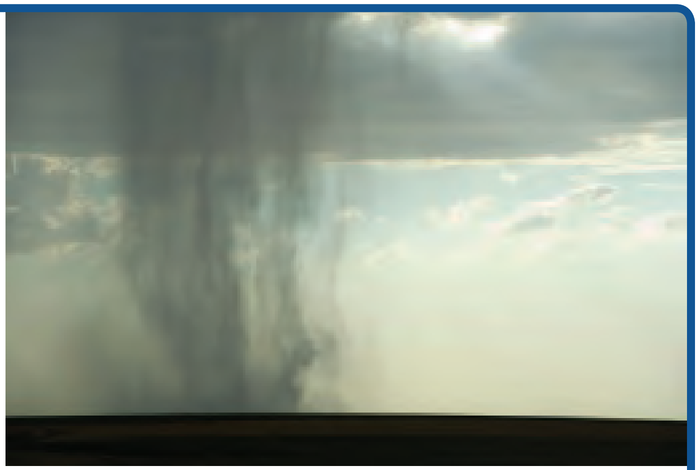
Most of Earth's surface is covered by water. It takes a lot of heat to warm water, and warm water is slow to lose its heat. This property of water tends to make the climate milder than it would be if the water were not there. For example, Southern California's coastal cities would be much hotter if the Pacific Ocean were not nearby. Large bodies of water are also significant drivers of weather, including rainstorms and hurricanes. When water is frozen, it reflects sunlight, which helps keep the icy regions and the planet as a whole cooler.



Water can absorb, store, move, and release heat. This is a major driver of weather. When frozen, a body of water can chill a region. Ice also reflects sunlight very well, making it that much harder for the liquid water under the ice to warm up.

Soil

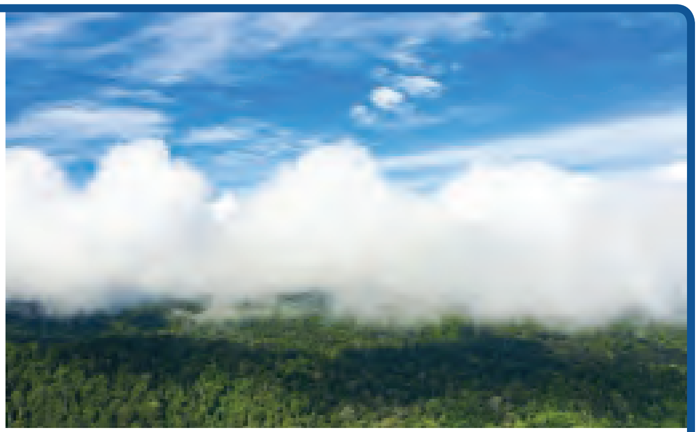
About 25% of the incoming solar energy that reaches Earth's surface ends up in the atmosphere thanks to evaporation. Here's how it works. Sunlight heats liquid water, causing a change of phase from liquid to gas, and the gaseous water molecules enter the atmosphere. Much of this evaporation occurs in warm bodies of water, but it also occurs in moist soil. Weather, including rainstorms, can form because of the heat and moisture contained in a large volume of soil. About 20% of global rainfall ends up evaporating from soil.



Soil absorbs rainwater, then cycles some of the water back to the atmosphere when sunlight warms the moist soil. Moisture in the air can end up falling back to Earth as rain.

Plants

Plants are organisms that take up water from soil, along with carbon dioxide from the atmosphere, to produce sugars for themselves. The sugars are a source of energy and building blocks for plant growth. Plants release water into the atmosphere through a process called transpiration. The amount of water vapor that plants introduce into the atmosphere is greater than the amount that evaporates from soil.



Water released by plants cycles back to the atmosphere, where it can condense into clouds that produce rain.

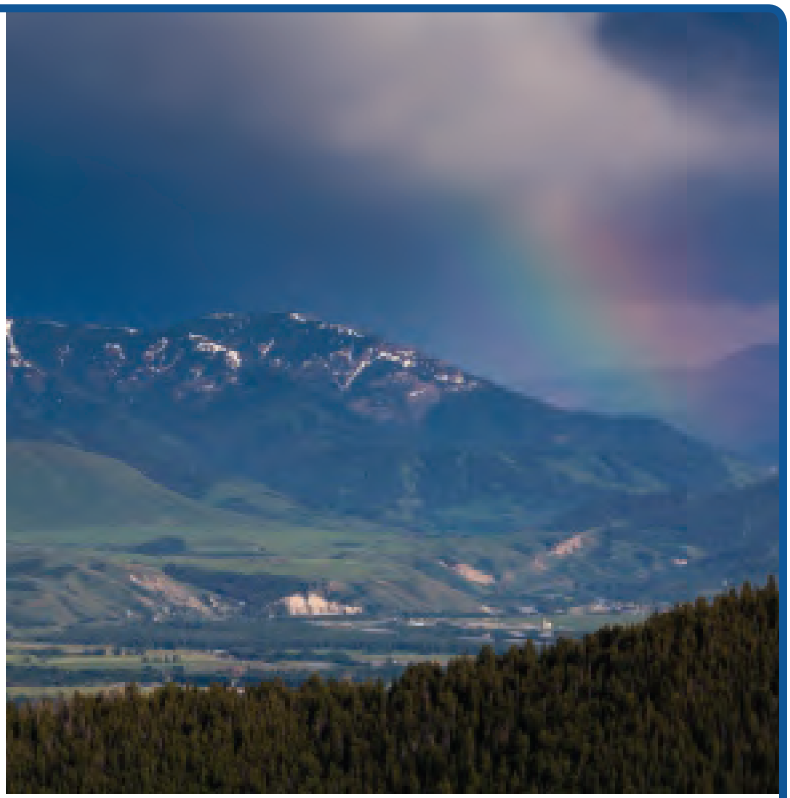
Heat Islands

Structures made by humans tend to be made of materials that absorb sunlight and conduct heat into the atmosphere. Concrete and asphalt pavement are two examples. Concrete is made of fragments of rock and cement. Asphalt pavement is a mix of rock fragments and petroleum. Asphalt's dark color makes it absorb sunlight. In cities, there are so many structures made of concrete and asphalt that the cities become "heat islands" that conduct heat to the atmosphere and surrounding areas. Cities can have their own microclimates thanks to the heat island effect.

The amount of concrete and other materials that absorb and conduct heat can affect the formation of weather and give a city its own climate.

Mountains

Mountains, like other land surfaces, can be covered with snow, ice, plants, and other materials that can affect the atmosphere in their own ways. But the most direct effect of mountains is to force air to move in specific directions. If wind blows against a mountain, the slope forces the air to flow upward, carrying with it whatever water is in the air. When the air rises, it cools, causing water to condense. This often causes rain or snow to fall on the windward side of the mountain. By the time the air crosses the summit and moves to the less-windy, leeward side of the mountain, much of the water that was in the air is already gone. The effect is a drier climate on the leeward side of mountains.



Air must move over or around mountains. This results in different types of weather.

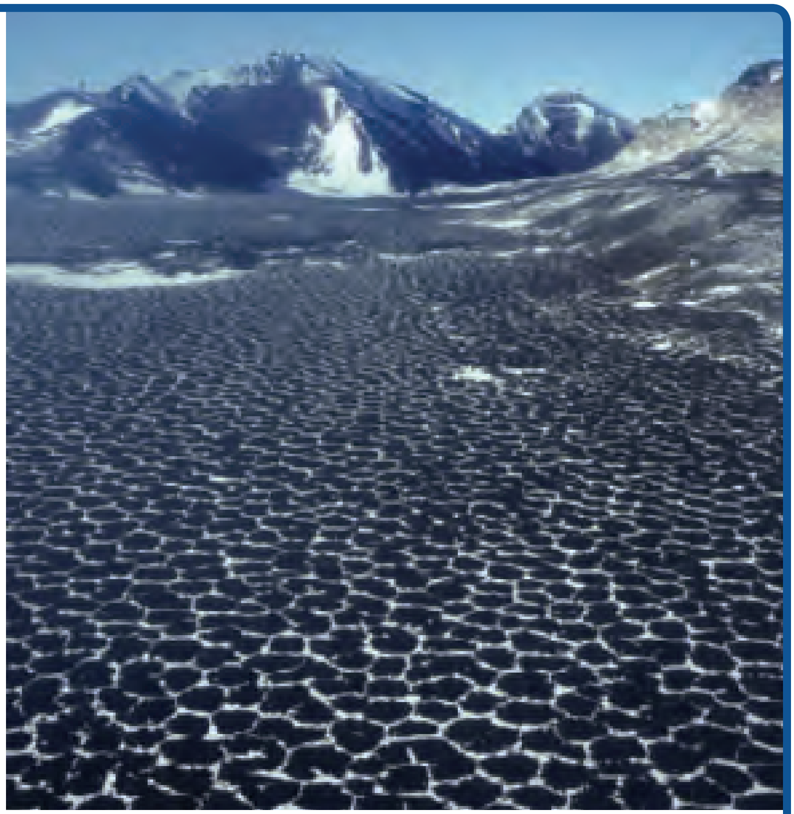
Ice Sheets and Glaciers

Over hundreds or thousands of years, so much snow can build up on a polar landmass or a mountain range that an ice sheet or glacier forms. These are long-lasting, large masses of ice. Their slow melt provides liquid water to power the water cycle. They also reflect sunlight, absorb heat, and act as coolers for the local climate. Global temperatures determine the rates at which large, long-lasting ice masses melt.

A glacier moves over time, carving out rock from a valley as it slowly drifts down.

Deserts

We tend to think of deserts as barren, sandy places, but the scientific definition of a desert is a land that loses more water to evaporation than it gains from rainfall. Over one-third of Earth's land qualifies as a desert. Antarctica, for example, is considered a desert because what little snow it receives does not easily melt into liquid water that might support life. Because the atmosphere over a desert is dry, deserts also tend to have temperature extremes. These extreme temperature changes can result in high winds, and the winds can pick up dust and sand to form sandstorms. Dust from these storms can blow across an ocean and affect weather on other continents.

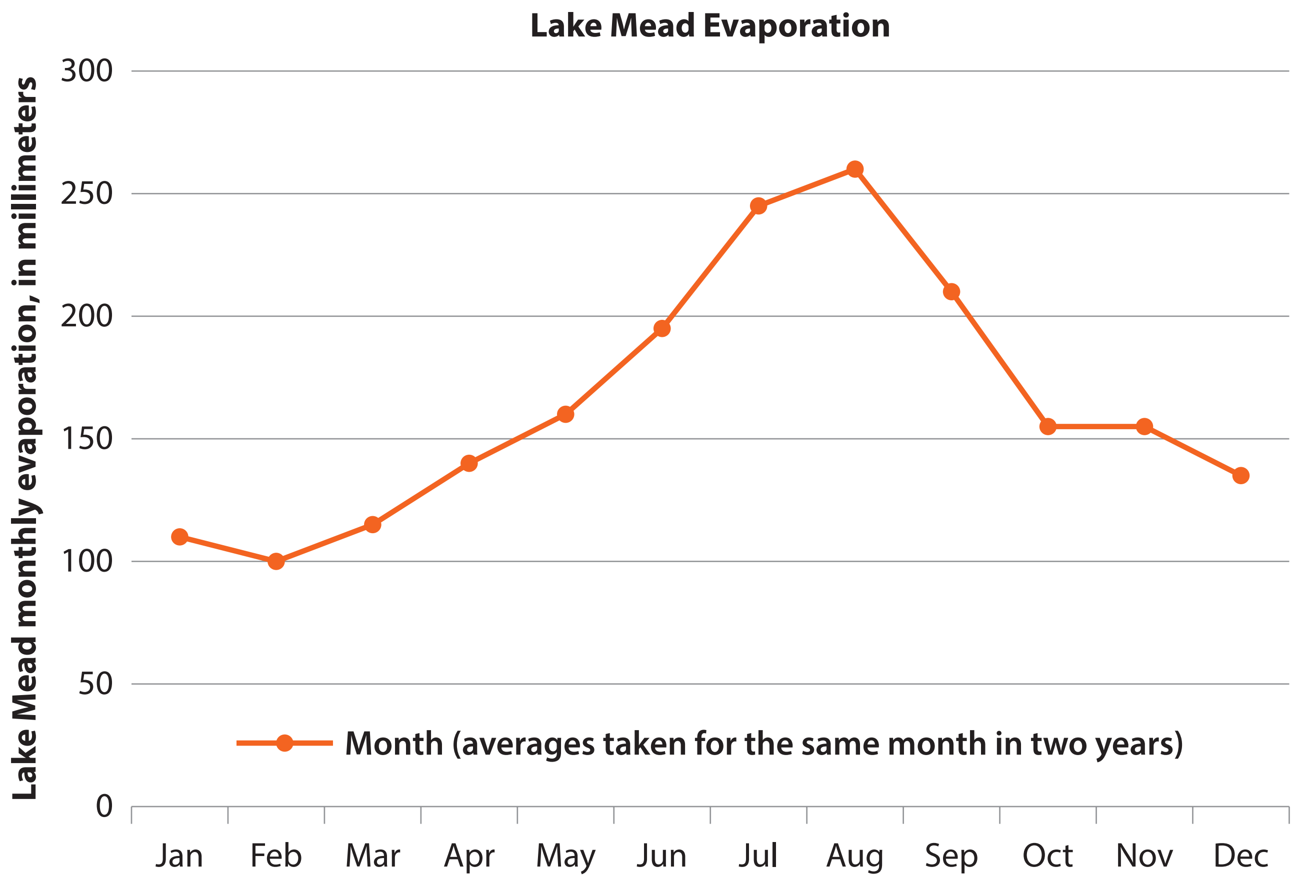


While Antarctica is not cold or sandy, it is considered a desert because of how little liquid water there is. Almost all the life in Antarctica is found in the ocean around it. Some organisms, such as penguins and leopard seals, come onto the island to reproduce or rest, but they rely on the ocean for food.

Lake Mead

Lake Mead in Nevada is a reservoir of water along the Colorado River. Since 2000, it has lost nearly 200 feet of depth due to drought conditions, heavy use of water by people, and evaporation. Evaporation can have significant impacts on bodies of water that humans rely on for drinking water, irrigation of farms, recreation, and more. Lake Mead is an example of a body of water that has very high rates of evaporation, especially in the hot, dry summer months. In a typical August, the lake can lose 250 millimeters, or one quarter of a meter, of depth, just to evaporation alone. Over the course of a year, about two meters of water is lost. Given the area of the lake, this adds up to 300 billion gallons. Since 2000, the lake has lost 5.5 trillion gallons of water in total.

The climate in the Nevada desert makes Lake Mead vulnerable to evaporation. There is intense sunlight that warms the lake, especially its surface water. The air is dry and warm, making it easier for water to evaporate. Winds supply the lake atmosphere with new masses of warm, dry air. A heat wave can cause an extra 10 billion gallons of water to evaporate from the lake in a single week.



Evaporation Rate Factors

Have you ever tried to air-dry a damp towel? If you left it out in direct sunlight on a warm, dry day, it probably did not take long to dry. If you tried it on a cloudy, cool, or damp day, the damp towel likely did not get dry at all. The ability of liquid water to evaporate depends on temperature as well as how humid the air is. **Humidity** is a measure of how much water vapor is in the atmosphere in a location. If there is already a lot of water in the atmosphere, it is more difficult for evaporation to occur. Low humidity, like what you would encounter in a desert, acts like a vacuum to suck up molecules of water from a damp towel or a small pond. Wind can also aid evaporation, as it carries freshly escaped water molecules away from the body of water and can replace the humidified air with drier air.

Word to Know

Evaporation is the process in which liquid turns into gas.

Vocabulary

humidity, n. the amount of water vapor in a region of the atmosphere

Sticky Water

You might not think of water as being "sticky," but in fact, water molecules readily stick together. This is a property called cohesion. You see cohesion when dew forms on blades of grass in the morning. The leaf is almost parallel to the ground. With gravity pulling each water molecule toward Earth's center, you might expect the water to be a flat, thin film instead of gathering in bead-like droplets. These mound-shaped droplets form and maintain their shape because water is cohesive. The force drawing the water molecules together competes with the force of gravity that would flatten the droplet. Up to a certain size, cohesion wins. But droplets can only be so large before gravity breaks them into smaller droplets.

Cohesion also gives water a surface tension that makes it more difficult for things to break through the surface, including water molecules that might otherwise break free

Words to Know

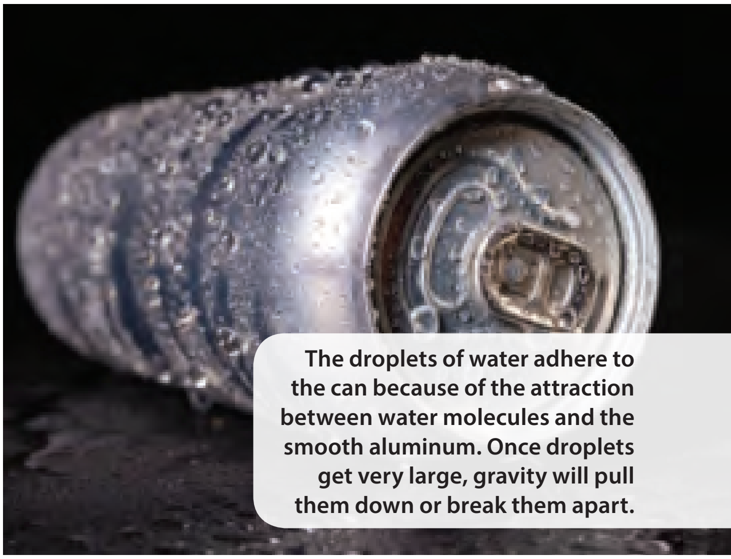
Water's *cohesion* explains why water sticks to itself and forms droplets. Water's *adhesion* explains why it also tends to stick or cling to some other substances.

Cohesion causes small volumes of water to stick together in almost round shapes.

This water strider will sink if it manages to break the surface tension that is keeping it on the surface of the water.

and enter the atmosphere. Surface tension can be strong enough to support water insects or relatively light objects that would sink if they broke the surface tension.

Water will cling to other substances, too. This is called adhesion. Cohesion keeps water droplets together, but adhesion keeps the droplets clinging to the surface of an aluminum can.



The droplets of water adhere to the can because of the attraction between water molecules and the smooth aluminum. Once droplets get very large, gravity will pull them down or break them apart.

The stickiness of water helps clouds form. If water did not have such an attraction to itself, clouds would be less likely to form, less precipitation would fall, and the water cycle might not work at all. At the same time, cohesion among water molecules is weak enough to allow water molecules to break free via evaporation. Too much cohesion would make evaporation difficult, which would also threaten the water cycle.

Connection

How water cycles through the atmosphere, the hydrosphere, and even the biosphere depends, in part, on its stickiness. Water that is at the surface of a body of water wants to stick with the rest of the water. But certain factors, like heat and wind, actually “peel” layers of the water away through evaporation, thus moving water around in the water cycle. These happenings are what make weather.

Science Fiction, Science Fact

In Frank Herbert's sci-fi classic *Dune*, the Fremen are the native people of the desert planet Arrakis. The rugged survivors have mastered coexistence with monstrous sand worms that inhabit the dunes of their planet. But the shortage of water is as big a threat as the giant worms of Arrakis. The Fremen are masters of collecting the water that's so desperately scarce on their planet's surface. Every Fremen wears a stillsuit that recaptures their bodily moisture, including from their exhaled breath. The Fremen also have engineered secret windtraps that harvest moisture from the air.

Like all great science fiction stories, Frank Herbert's 1965 masterpiece builds on plenty of science facts. The specific workings of Freman windtrap technology may be far-fetched, but dew collectors that harvest moisture from the air really do exist on Earth.

Dew forms when lowered temperature causes water vapor in the air to condense into liquid on a surface that's cooler than the air. The cooler surface can be as tiny as a thread of spider silk.

Cool desert nights make the mesh on this dew collecting structure cool, too. Water vapor from the night air condenses into droplets on the mesh. When the droplets become too big to adhere to the mesh, they roll down the material and trickle into a catch container.

These mini moisture catchers collect condensation from the air. Condensed water droplets roll down the mesh and drip in concentrated places in the dry soil. The simple, little structures provide regular moisture to plants that have been reintroduced to this arid location.

A Minute to a Million Years

Precipitation can evaporate minutes after falling, or it can be locked up in a polar ice cap for a million years. Scientists have analyzed the different paths that water takes through the different parts of the water cycle and generated estimates of residence times—how long water stays in a place, on average.

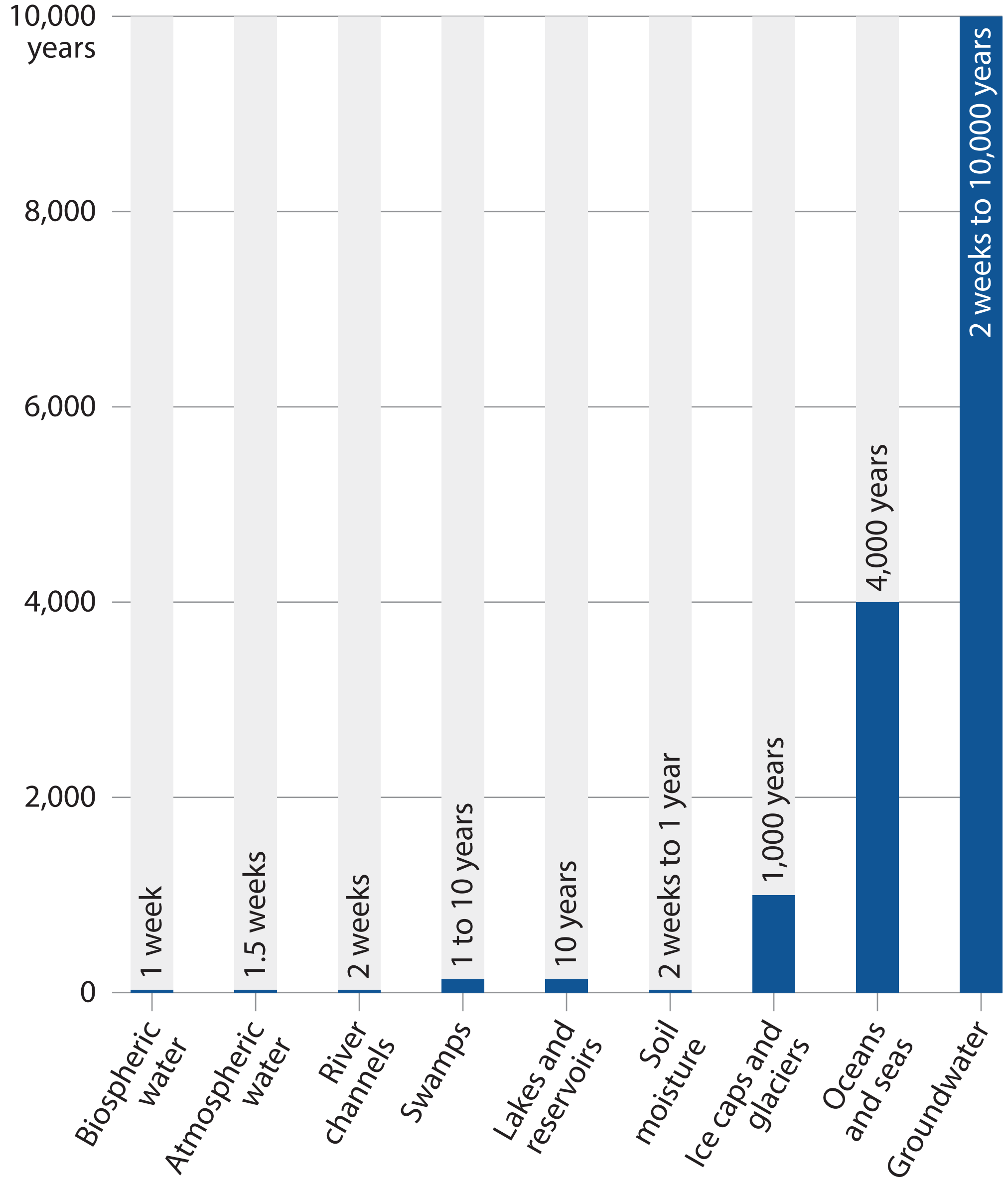
The water cycle carries water molecules through different physical states, locations, and systems. The sun provides most of the energy for this process by heating liquid water and causing evaporation, which moves water into the atmosphere. From this position, gravity can bring water back to Earth's surface as precipitation, and it can carry it deep below the surface to become groundwater or downhill to lakes or oceans. Without the sun, the water cycle would be almost completely shut down.

Fossils of marine organisms, such as this whale skeleton, can tell scientists that the ocean used to be deeper. What is now dry desert in Egypt was once the ocean floor.

Where there is more solar energy and higher temperatures, more evaporation occurs. This makes it more likely that a water molecule that is in, say, the Gulf of Mexico will not reside in that body of liquid water as long as a water molecule would in the Bering Sea or the Arctic Ocean, where there is less solar energy to evaporate liquid water. The graphic below summarizes these estimates.

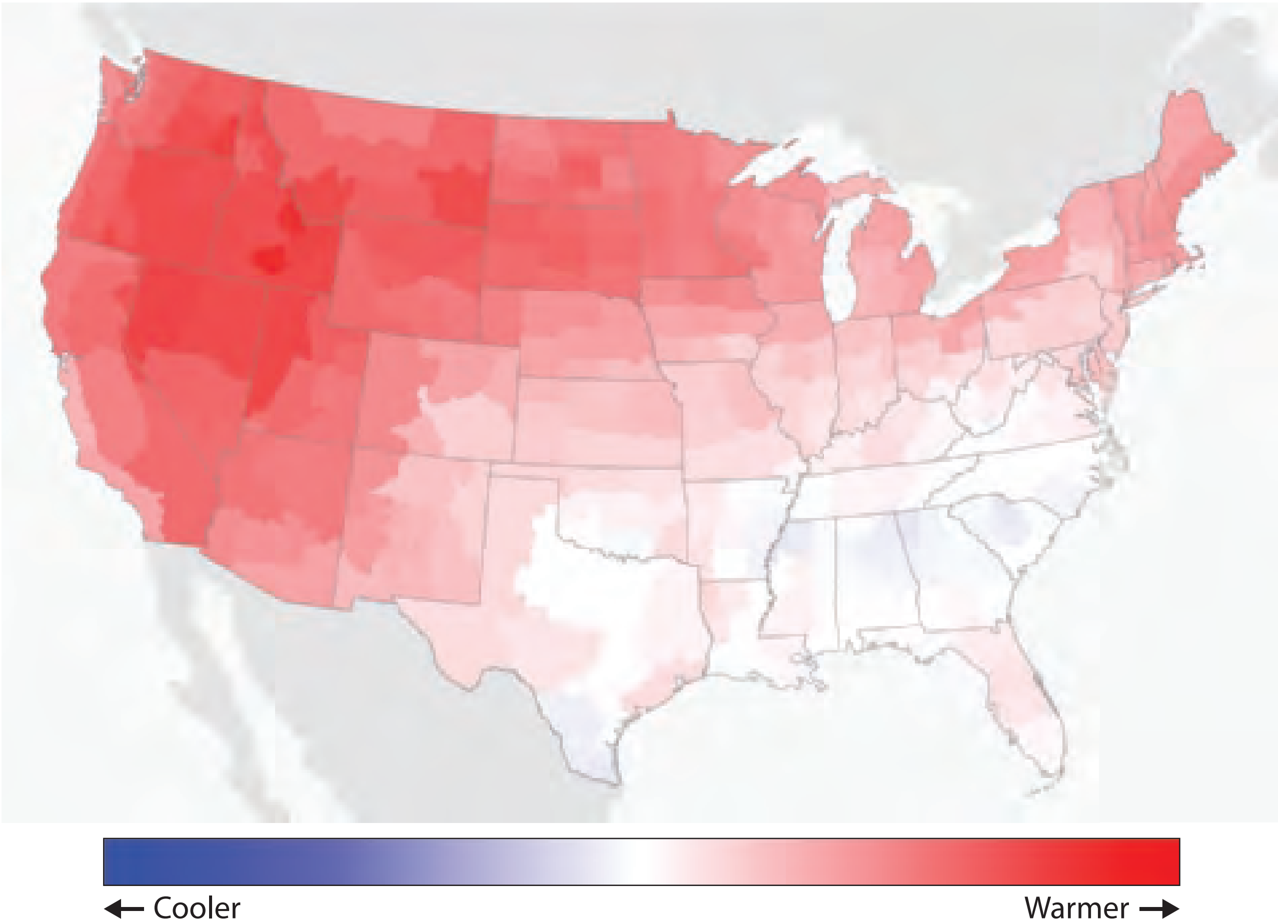
Three million years ago, Earth's climate was warmer, and that meant there was less ice. More of Earth's water was in the ocean, so the ocean was deeper. Areas that are now many meters above sea level were underwater. More recently, during the last ice age, Earth was colder, glaciers covered a third of its landmasses, and the ocean was about 120 meters below its current level.

Estimated Residence Times of the World's Water Resources



Heat and Drought

Average June Temperature Differences from Previous 30 Years

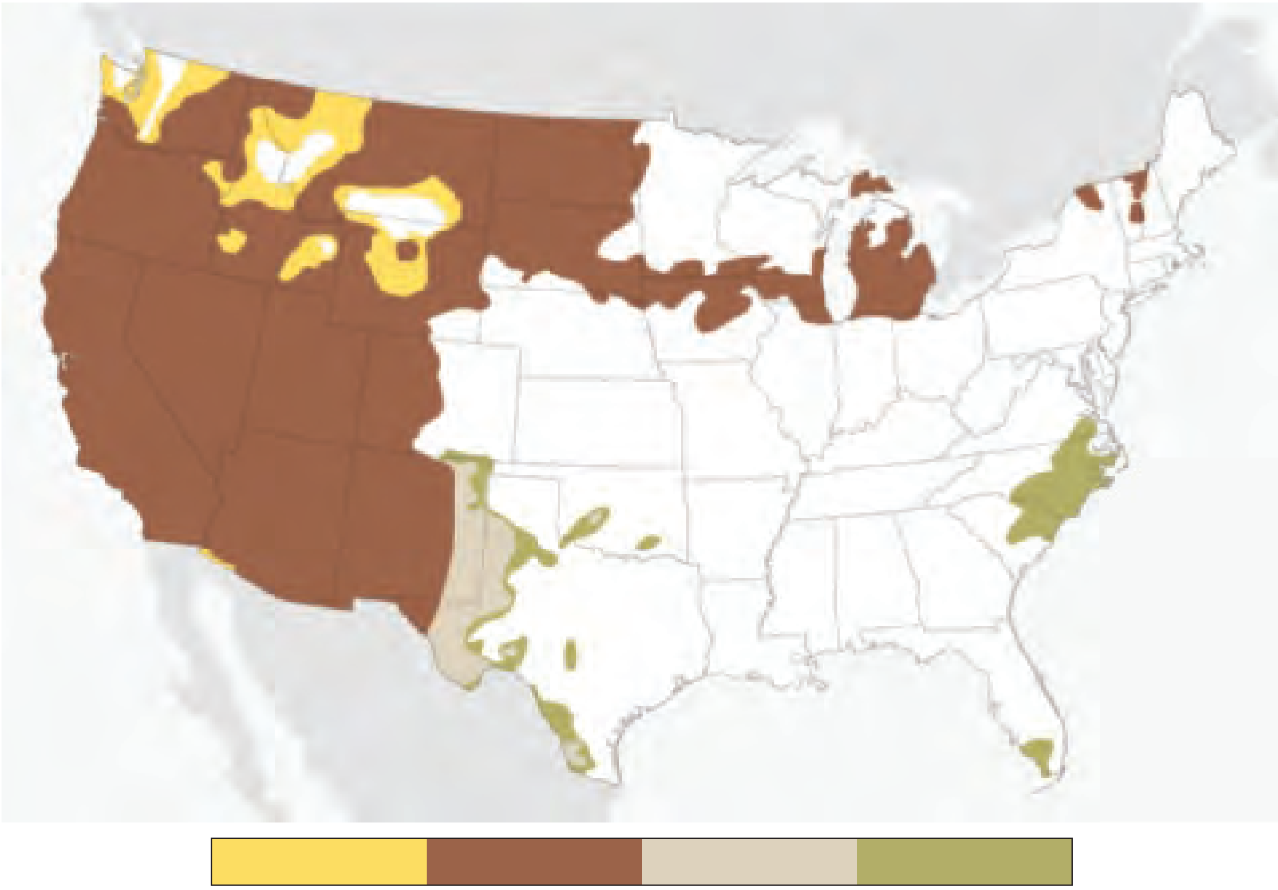


This map shows how much the June 2021 average temperatures differed from the June averages from the 30-year period, 1981–2010, in the contiguous United States. The color-coded temperature range represents 11 degrees cooler (blue) through 11 degrees warmer (red) on the Fahrenheit scale. It is clear that much of the West was significantly warmer in June of 2021 than it was during the period from 1981 through 2010.

Heat and water scarcity often go hand in hand. More warmth often means more evaporation, which can deplete sources of liquid water that are at, or below, Earth's surface. Without moisture in soil or irrigation that taps groundwater or a nearby reservoir, plants dry out. When plants dry out, they cannot release water through transpiration, which means the air gets even drier.

The **drought** becomes part of a positive feedback loop that can cause the drought to expand in time and space. Droughts have become common and long lasting in the western half of the United States.

Drought Tendency for June 2021



This map is an outlook for drought in the United States for June 2021. By comparing the two maps, you can see how much overlap there was between unusually high heat and drought conditions in the West in mid 2021.

Drought can affect natural habitats that depend on water, such as rivers and forests, but it also affects farmland. California's Central Valley is a major producer of vegetables and fruit for the United States. Extended droughts in the valley have forced farmers to siphon water from rivers. Snowpack has dwindled on California's mountains.

Vocabulary

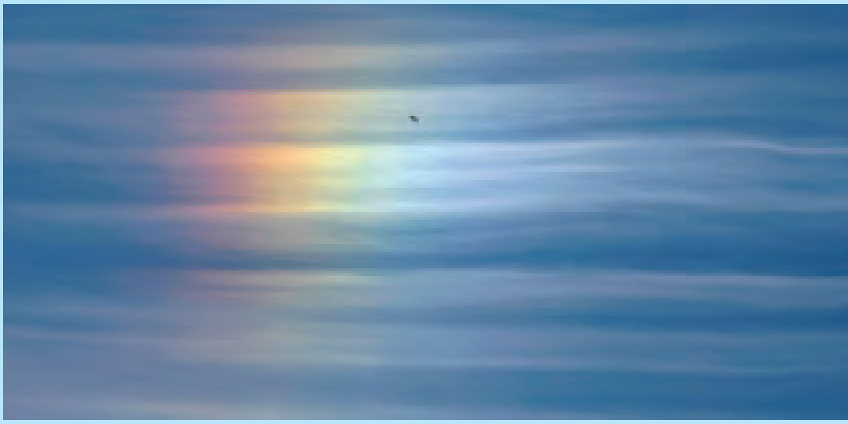
drought, n. a prolonged period of unusually low precipitation, leading to a shortage of water

Cloud Types

High Clouds (16,500–45,000 feet)

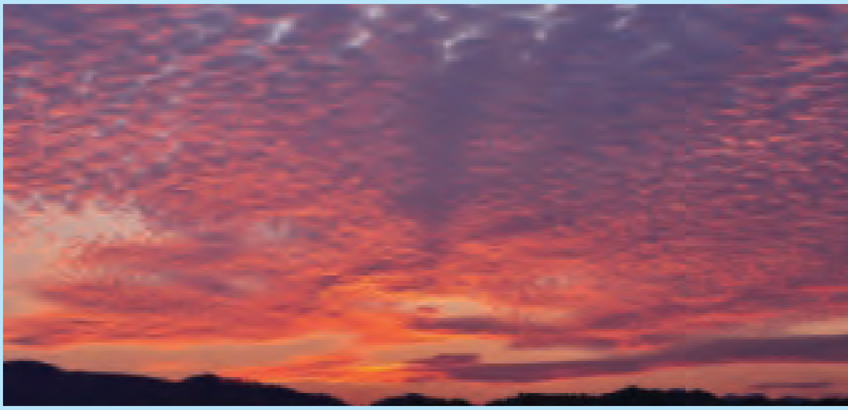
Cirrostratus

Thin white clouds that act as a veil across the sky. Can produce a halo effect around the sun. Reflected sunlight off these clouds can produce brilliant visuals. Associated with future precipitation.



Cirrocumulus

Thin and patchy, often with a rippled appearance. Associated with cool weather approaching. In tropical areas, can be associated with a coming cyclone.



Cirrus

Wispy, thin clouds twisted by strong high-altitude winds. Heavy cirrus coverage indicates that the weather is about to change. This is because winds in the upper atmosphere are the result of shifting air masses.

Mid-Level Clouds (6,500–23,000 feet)

Altocumulus

Similar to cirrus in appearance but lower and consisting of liquid water rather than ice crystals. Associated with fair weather.

Altostratus

Mixture of ice crystals and water droplets. Often cover the entire sky. Associated with lengthy rain or snowfall.

Nimbostratus

Very thick gray clouds that can produce heavy rain or snowfall.

Low Clouds (<6,500 feet)

Fog

Type of cloud that touches Earth's surface. Forms where air is humid and cool enough for moisture to condense into water droplets or ice crystals.

Stratocumulus

Patchy gray or white. A large group can have a honeycomb-like appearance, with dark, heavy parts surrounded by thinner, well-lit areas or gaps between.

Cumulus

Resemble cotton balls of varying shapes and sizes. Usually associated with fair weather. Cumulus clouds can develop into other forms that extend into higher reaches of the atmosphere, as shown on the next pages.

Clouds with Vertical Development

Some cloud types form in the upper, middle, or lower levels of the atmosphere, but others can begin in the lower level and then grow vertically into other levels.

Cumulonimbus

A cumulus cloud that is low in the atmosphere can grow horizontally or vertically. This often occurs where warm, moist air from Earth's surface rises up. The added moisture gives the cloud more volume. The lower temperature of the upper atmosphere causes condensation, giving the cloud more height. These towering cumulonimbus clouds are responsible for sudden downpours, especially in summer or in tropical areas over large bodies of water.

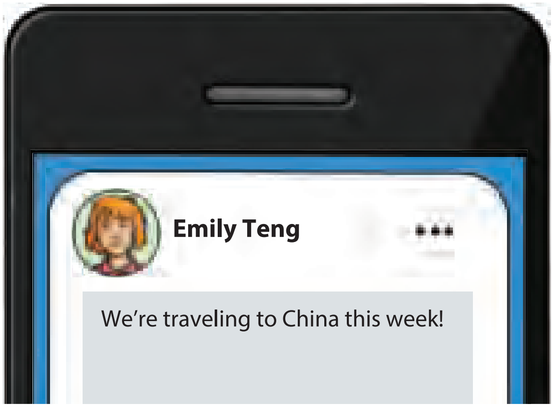
Cumulonimbus Incus

When a towering cumulonimbus cloud reaches the boundary between the stratosphere and the troposphere, the top of the cloud flattens and is blocked from rising any higher. The cloud can take the shape of an anvil, hence the name *incus,* which is Latin for "anvil."

Lenticular Clouds

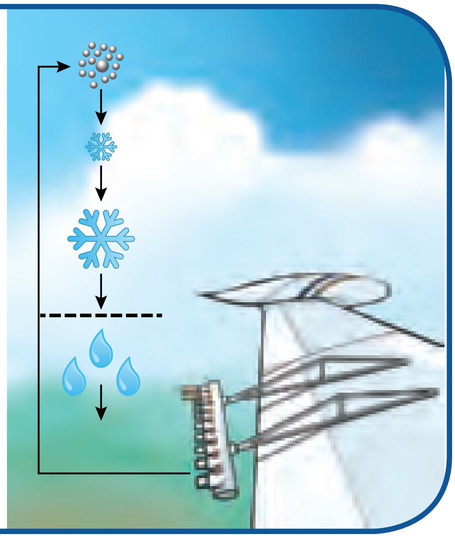
Where air rises from a relatively low altitude to a higher one around a mountain peak, a pillow-like cloud can form. The clouds can rise and form stacks like pancakes.

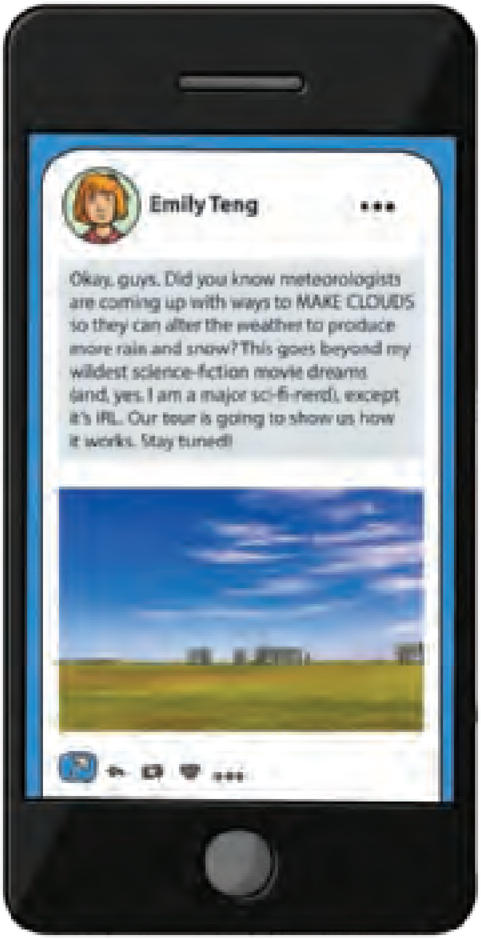
Cloud Seeding



SCIENCE IN HERE

To get precipitation, you need clouds. To get clouds, you need molecules of water to cluster together into droplets. Then, those droplets need to stick together to make larger droplets that either fall to Earth as rain or crystallize into ice. Often there is a single particle of dust or salt that acts as the starting point, or nucleus, for condensation. Humans have attempted to use other substances as nuclei to "seed" clouds, especially in areas that are experiencing drought. Silver iodide is a popular cloud-seeding substance, as it occurs naturally, has no harmful effects on the environment, and can be dispersed into the atmosphere from airplanes with special silver iodide dispensing tubes.



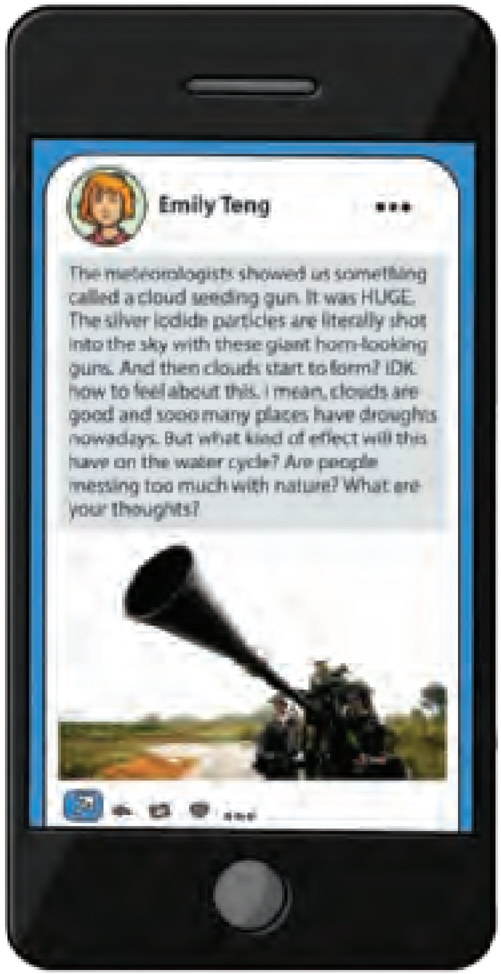


SCIENCE IN HERE

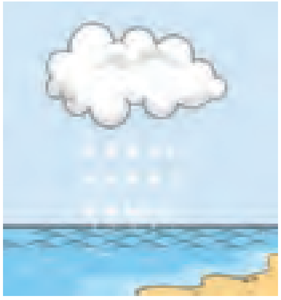
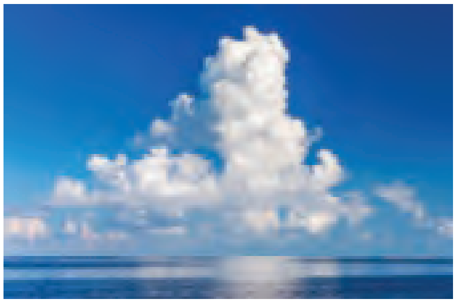
Cloud seeding usually works by producing what's known as cold rain. This is rain that begins as snowflakes but melts as it falls through lower, warmer altitudes. There are different ways for clouds to be seeded. They can be seeded from the ground or in the sky. From the ground, a propane burner is used to produce a plume of warm air that carries silver iodide particles into the sky. Alternatively, silver iodide artillery shells are shot into clouds by large guns from the ground, or rockets packed with silver iodide are fired in a similar manner. In recent years, China has spent hundreds of millions of dollars to seed clouds in this way.

SCIENCE IN HERE

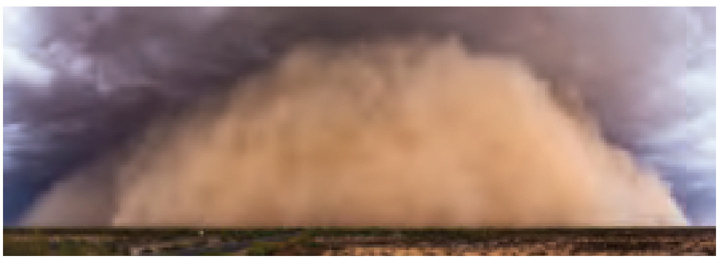
Cloud seeding can be used to produce rain, but it can also be used to produce snow! Producing snow can be more desirable if a region's mountains have lost glaciers or snowpack. These are larger stores of water that tend to melt at predictable rates, feeding streams and rivers, which in turn are tapped for use in farming and other industries. As Earth warms and glaciers and snowpack decline, replenishing those frozen sources of water is important. Studies of cloud seeding operations in western states and several foreign countries have suggested that they can increase snowfall by 10 to 15 percent.

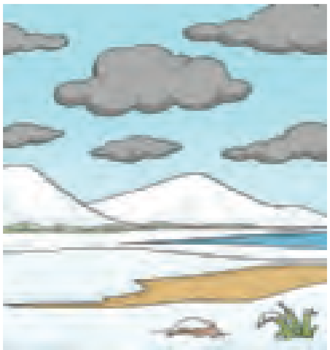
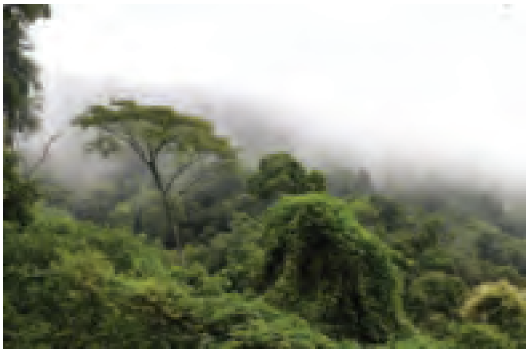


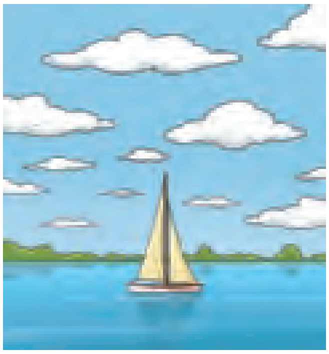
Cloudy Understanding

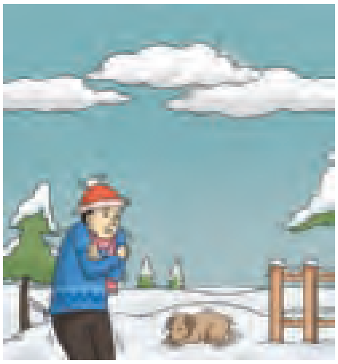
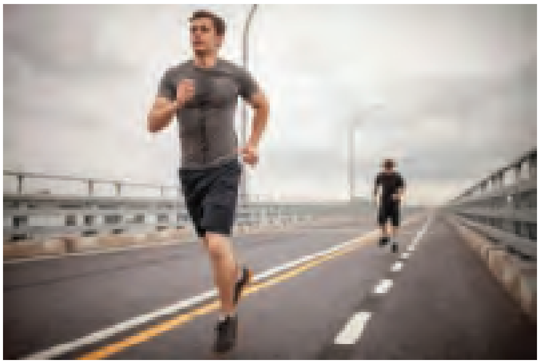
Misconception	Reality
	
Sunlight causes water to boil. The boiling water becomes steam that forms clouds.	Sunlight is not intense enough to boil water. It can provide enough energy to cause liquid water to become water vapor. Water vapor can condense into clouds.

Misconception	Reality
	
Rain clouds come from smokestacks and forest fires.	Some “smokestacks” release more water vapor than smoke into the air, and this vapor might help a rain cloud form. Actual smoke, which is mostly carbon, does not form clouds of water vapor.

Misconception	Reality
	
Clouds are made of dust. The dust soaks up water vapor, then releases it as rain or snow.	Dust particles can help seed rain clouds, but a thick cloud of dust doesn’t turn into a rain cloud. This dust storm results from wind picking up dust from the ground.

Misconception	Reality
	
Colder places are cloudier and snowier because cold air holds more water.	Warm air can hold more water vapor than cold air. Warmer places tend to be cloudier because more evaporation is occurring, providing more material for cloud formation.

Misconception	Reality
	
A lot of clouds in the sky means it won't be very windy.	Wind is produced by the uneven heating of Earth's surface and air masses moving as a result. Clouds do not block wind, and a cloudless sky does not mean it's windy.

Misconception	Reality
	
Clouds block sunlight from reaching Earth's surface, resulting in cold weather.	Clouds can block sunlight and result in cooling, but some sunlight does get through clouds. Water vapor is also a greenhouse gas, so clouds and humid air can trap heat near the surface and make an area warmer than it would be otherwise.

Clouds and Cities

Some cities are naturally cloudy, by way of their locations. London and San Francisco are famously foggy, thanks to their proximities to cool ocean waters that produce fog. Seattle, Portland (Oregon), and Buffalo all experience over 200 days a year of heavy clouds. Again, proximity to large bodies of vapor-emitting water is a major factor in their cloudiness.

Other places are cloudy because they are at high elevations. The ancient city of Machu Picchu is 7,000 feet above sea level, tucked among peaks of the Andes Mountains of South America. At this elevation, the city can be bathed in clouds.

The sunniest, least-cloudy cities in the United States are almost entirely found in the West, in arid areas. This makes sense, as less moisture on Earth's surface means less water vapor is available to form clouds above it. One exception on the list is Key West, Florida, which is surrounded by warm ocean water. Despite all of that water and evaporation, Key West has about 260 sunny days per year, and during daylight hours it is sunny 76% of the time. Why? In the Keys

Machu Picchu

Sunniest Cities in the U.S.

City	% Sunshine
Yuma, Arizona	90
Redding, California	88
Phoenix, Arizona	85
Tucson, Arizona	85
Las Vegas, Nevada	85
El Paso, Texas	84
Fresno, California	79
Reno, Nevada	79
Flagstaff, Arizona	78
Sacramento, California	78
Pueblo, Colorado	76
Key West, Florida	76
Albuquerque, New Mexico	76

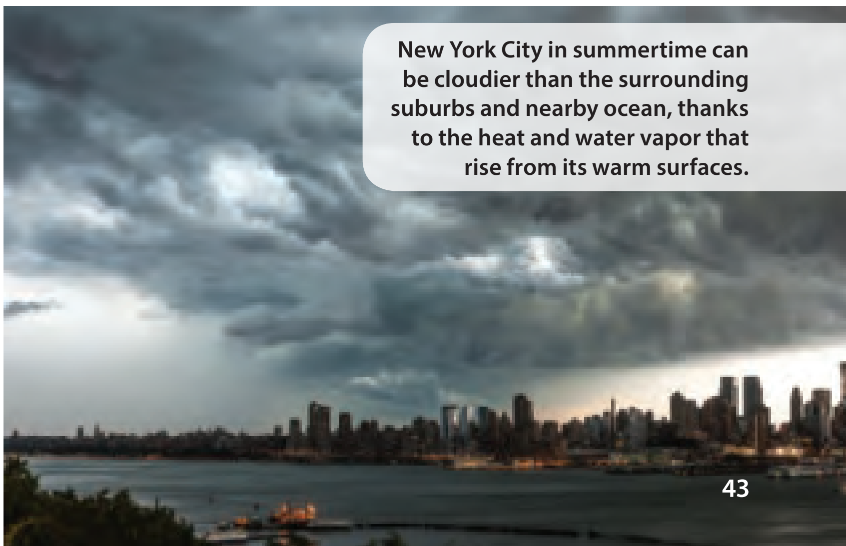
Isolated rain shower off Key West, Florida

and many other parts of coastal Florida, there tend to be heavy but relatively brief storms. In summer, high heat and high rates of evaporation from the Gulf of Mexico cause large cumulonimbus clouds to form, typically in the early afternoon or midafternoon. These clouds dump heavy rain but not for very long. The day still counts as a "sunny day" despite the regular, heavy rainfall.

Cities can also influence their own weather. A sunlit city rich with concrete, asphalt, and heat-absorbing rooftops can become a heat island, significantly warmer than areas immediately surrounding the city. Water that is evaporating from the city's surfaces can rise with the warm air and add to the volume of cumulus clouds in the lower atmosphere. Recent research suggests that afternoon cloud cover in cities during spring and summer is about 10–15% higher than in less-developed areas around them.

Dig into Data

The table of sunniest cities in the United States is based on how clear the sky is between dawn and sunset. It does not mean that there are no clouds in the sky. Rather, the cloud cover is sparse enough to allow direct sunlight at least 75% of the time during those hours.



New York City in summertime can be cloudier than the surrounding suburbs and nearby ocean, thanks to the heat and water vapor that rise from its warm surfaces.

Hailstorms

The largest hailstone measured in the United States was an eight-inch stone recovered after a storm in South Dakota. It weighed just under two pounds! Imagine that falling down from the sky! Hailstone size is often compared to familiar objects. This gives weather reporters a way of conveying hailstone size using objects that people can relate to.

Hailstone diameter (inches)	Comparable object
0.25	pea
0.75	penny
1.0	quarter
1.5	table-tennis ball
1.75	golf ball
2.75	baseball
4.5	grapefruit

Hail forms during thunderstorms. As water vapor in the cloud cools and condenses into raindrops, gravity *should* pull them to Earth's surface. Instead, an updraft lifts them higher where the air is colder. Here the raindrops freeze into solid balls of ice. The hail can fall down through the cloud, colliding with liquid water droplets that freeze on the hail, adding new layers of ice. At this point the hail might fall to Earth, or another updraft might carry it back to a

Word to Know

An *updraft* is an upward flow of air, as in a thunderstorm.

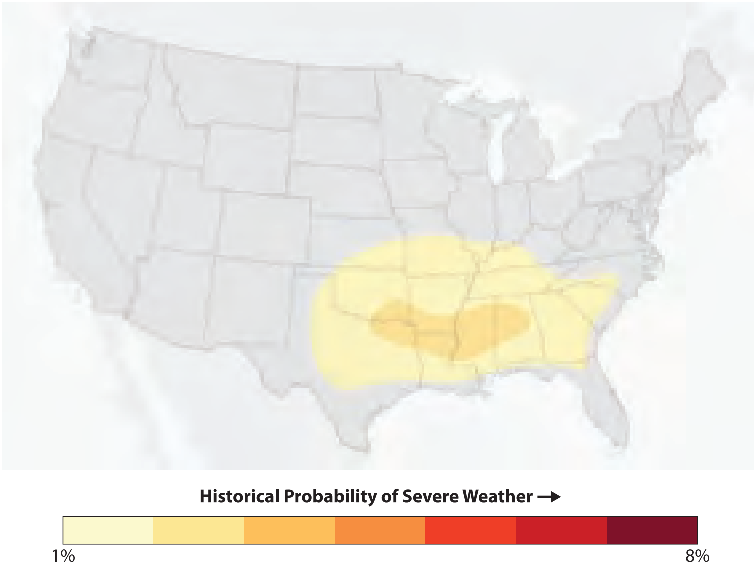
This cloud has the volume and height to provide the moisture and temperature extremes to make hail.

higher, colder elevation. It freezes solid, then has a chance to go through another round of accumulating more mass. This can occur over and over, producing larger and larger hail. If the hail gets so large that it cannot be kept aloft by updrafts, it will fall to Earth.

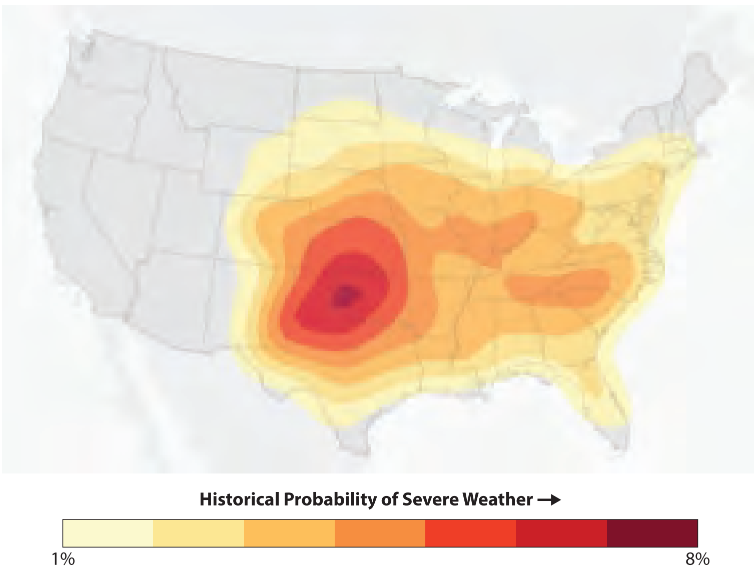
The car windshield pictured above was no match for a hailstorm. Hailstones that fall to Earth or get carried by winds can be strong enough to crash through windows of cars or homes and even damage the siding of a house. The relatively round shape of hail and the slick surfaces of hailstones that have begun to melt can allow hail to flow into gutters, sewers, and other things that are meant to drain liquid water. Because the hail is thicker and less able to flow, these structures can become clogged.

Severe Weather Hot Spots

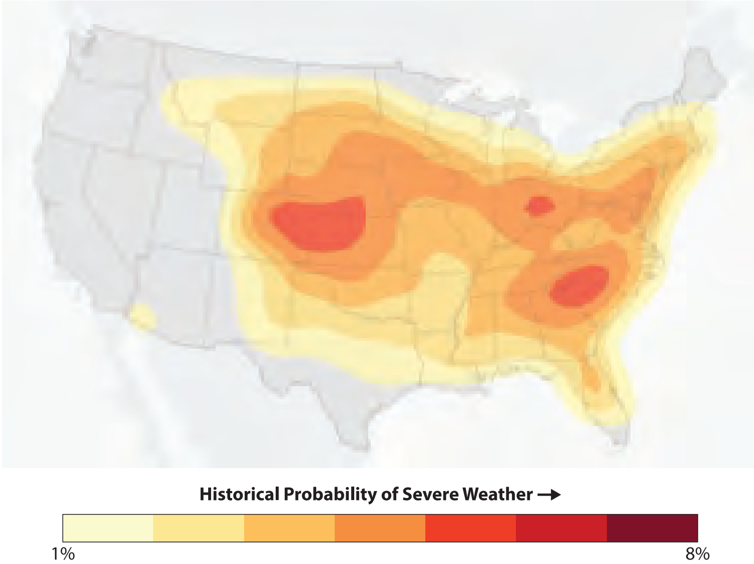
These maps indicate the probability of severe weather in the contiguous United States, or "lower 48," based on data from a 30-year period. In this context, "severe weather" means tornadoes, thunderstorm winds over 58 miles per hour, or hail larger than three-quarters of an inch in diameter.



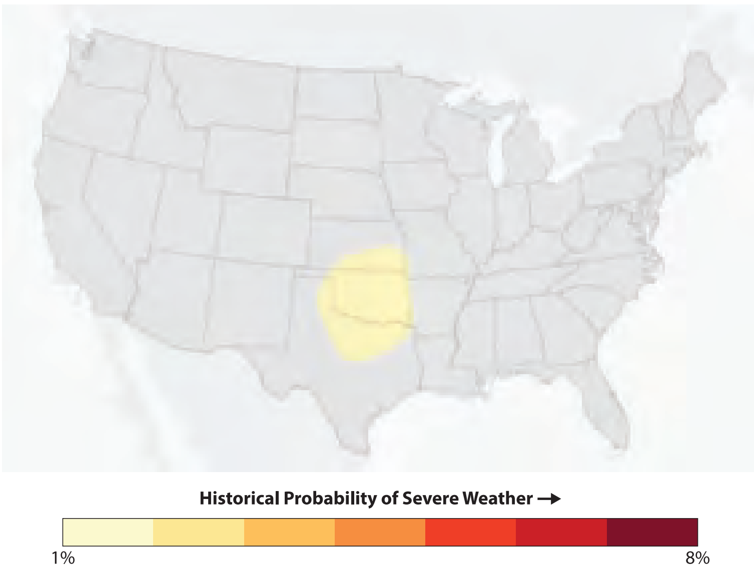
In early March, much of the South has low to moderate risk of severe weather, particularly thunderstorms and tornadoes.



In late spring, severe weather is more likely across a much broader swath of the United States, especially the Plains states.



By early July, the hot spots of severe weather are less hot, but there are more of them. The moist, hot area between the Carolinas sees many thunderstorms. Kansas, Nebraska, and Colorado experience hail, damaging winds, and the occasional tornado. The Ohio Valley sees thunderstorms that begin as systems to the west, travel quietly overnight through the Midwest, and then flare up upon reaching the valley.



By the fall, the risk of severe weather has all but vanished.

Dig into Data

If you stick to the definition of severe weather as defined by NOAA and its visualizations on these pages, you might think the fall is a very safe time in terms of weather. But in this context, severe weather does not encompass storms such as hurricanes or blizzards. A map of historical probability of hurricanes in October would look very different than the one on this page, especially along the Gulf Coast and Eastern Seaboard.

Perspectives on Climate Change

An Actuary's Thoughts on the IPCC Report

The latest report by the Intergovernmental Panel on Climate Change provides yet another compelling look at the data that show climate change is occurring, as well as some specific forecasts for how it will affect the world. As someone whose livelihood depends on providing my clients with accurate assessments of risk, I have been paying very close attention to this issue for years, and I suspect I will continue to do so until the day I retire. (And as someone who would like to retire to a pretty, pleasant, peaceful place that is not awash in climate-related natural disasters, I will most likely pay close attention to the science of climate change after I retire, too!) In today's post I would like to focus on some of the severe weather phenomena that occur in my current home state of Colorado.

The good news—or the slightly less-bad news—is that the 2021 IPCC report has low confidence that hailstorms will be more common or more intense in the warmer future. This means that if you asked climate experts if hailstorms would be more or less common in the future, they would lean toward "more" but without the confidence that they have in predicting that, say, sea levels will rise and air temperatures will be warmer. Hail Alley is not going to get much more "hailacious." However, the western United States is getting hotter and drier, and Colorado is no exception. One trend of particular concern is the decline in the snowpack, or average amount of snow atop mountains, in this region. The IPCC report cites a study that shows a 10–20 percent loss of snowpack between 1980 and 2000. The report also predicts a loss of 60 percent of what's left of the region's snowpack by 2050. Less snowpack means less water flowing into streams and rivers. More intense heat waves will also lead to faster melting, which means more flooding. We are also at significant risk of seeing wildfires, which in turn will spell poorer air quality.

All in all, more severe weather means it could get more expensive to buy insurance for your home or automobile. Or it could mean that insurers will be less likely to offer insurance for specific, high-risk, high-probability events such as floods. This is something that homeowners will need to think about as the world faces climate change.

Until next time,
Reese M. Oden

Rob Lyons Fort Collins, CO

The new climate change report says we're in for a lot more extreme weather in the years to come. As you all know, I'm in construction, so my livelihood depends on being able to build and remodel homes in northern Colorado. I don't have any intention of leaving this area, but I do intend to listen to the science and be smart about heading into this warmer, drier, more-extreme future. I am interested in starting a group of like-minded construction professionals to discuss ways in which we can build better/smarter for the future. I think that means working more hand-in-hand with landscape architects and foresters so we can better protect homes from the threat of wildfires. I think it also means preparing homes to deal with flooding. Anyhow, look for more posts on this topic, as I think we all need to get smarter about this.

Reid Woodland Boulder, CO

Dude, I hear you. Definitely hit me up to join your group. I'm in the auto-glass repair business, and I'm trying to figure out how many more windshields and other pieces of auto glass I'm going to be hired to replace as weather gets wilder and more objects are flying through the air or falling on cars during storms. Especially hailstorms! On the one hand, the science suggests all kinds of storms will be more common or more severe. But if the climate around here is going to be warmer and drier in general, I wonder if we might actually see less hail—because if there's less moisture in the air, and the air is warmer, I'd think hail wouldn't form as easily.

Rob Lyons Fort Collins, CO

Geez, I hadn't thought of that. In some ways climate change could be great for your business if there's more stuff breaking people's windshields! LOL!

Consider the Sources

An actuary is someone who analyzes statistics to determine risk. Many actuaries work for insurance companies. Insurance companies make bets on how likely it is that a given event that results in expenses will occur. The better the company is at making these bets, the more profit it can make, because it will not have to pay very much to its clients. If the company makes bad bets, it will make less profit and could go out of business. The builder and auto-glass repairer do not have to determine risk in the same formal way that the actuary does, but they do need to have some idea about how their work is going to be affected by things like weather and climate. If they use the wrong insulation or roofing materials for the weather and climate, the home they build could need costly repairs, and the builder's reputation could be ruined.

Jet Streams and Weather

As if climbing Mt. Everest weren't hard and dangerous enough, the top peak of Mt. Everest lies in the middle of a 100-mile-per-hour jet stream. Climbers who reach the jet stream have to wait for these freezing, forceful winds to slow down before they can even leave their tents, or they risk fatal conditions. A jet stream is a fast current of air that circles the globe at altitudes between 30,000 and 45,000 feet. But jet streams aren't all bad. An airline pilot flying from Seattle to New York might ride the jet stream, reducing the fuel consumption of the plane as well as the flying time.

The polar jet stream moves around the Northern Hemisphere, from west to east. The altitude, size, and speed of the jet stream are affected by how polar air and temperate air come together. In summer, heating of the temperate zone tends to nudge the polar jet stream farther north. In winter, the lack of heat in the temperate zone allows the polar jet stream to drift farther south.

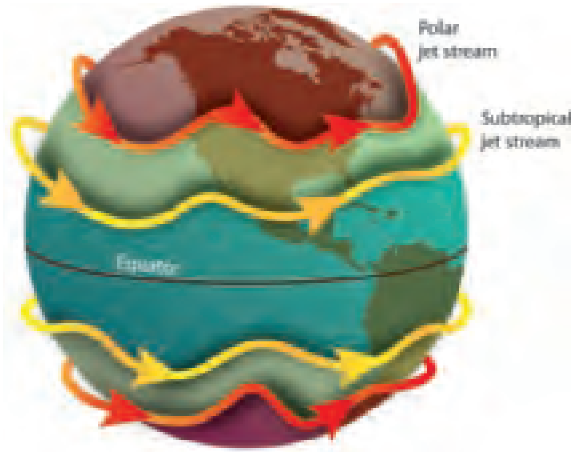
Word to Know

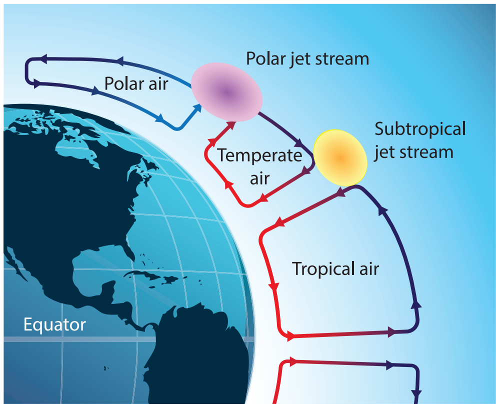
Weather media often refers to *the jet stream* as if it is only one thing. Currents in the atmosphere regularly change, though. There are two variables related to a jet stream that can shape the weather tens of thousands of feet below it:

- its location
- its shape

Some parts of Oklahoma can have days of 0°F temperatures in the winter and days of 100°F in the summer. Why? The relatively flat terrain of the Plains states and the meandering of the polar jet stream can spell extremes of seasonal temperatures. If the polar jet stream dips far to the south in the winter, much of the United States can experience freezing temperatures, with the Plains and Midwest plunged into arctic conditions. In summer, if the jet stream is far to the north, the Plains can be stuck in extreme heat zones.

But that's not all. In the Plains, there are few obstacles to get in the way of moving air masses near Earth's surface. If the polar jet stream is directly over the Plains, it draws air up from Earth's surface. This lowers pressure, letting air move in from Canada and the Gulf of Mexico. The low-pressure system and the flat terrain allow these different air masses—one cold, one warm and moist—to collide at high speed. The result is severe weather: powerful, large thunderstorms, high winds, tornadoes, and hailstorms.





The globe shows how jet streams flow around Earth from west to east. The lower diagram shows how two jet streams interact with cold and warm air currents. All of this movement of air produces weather.

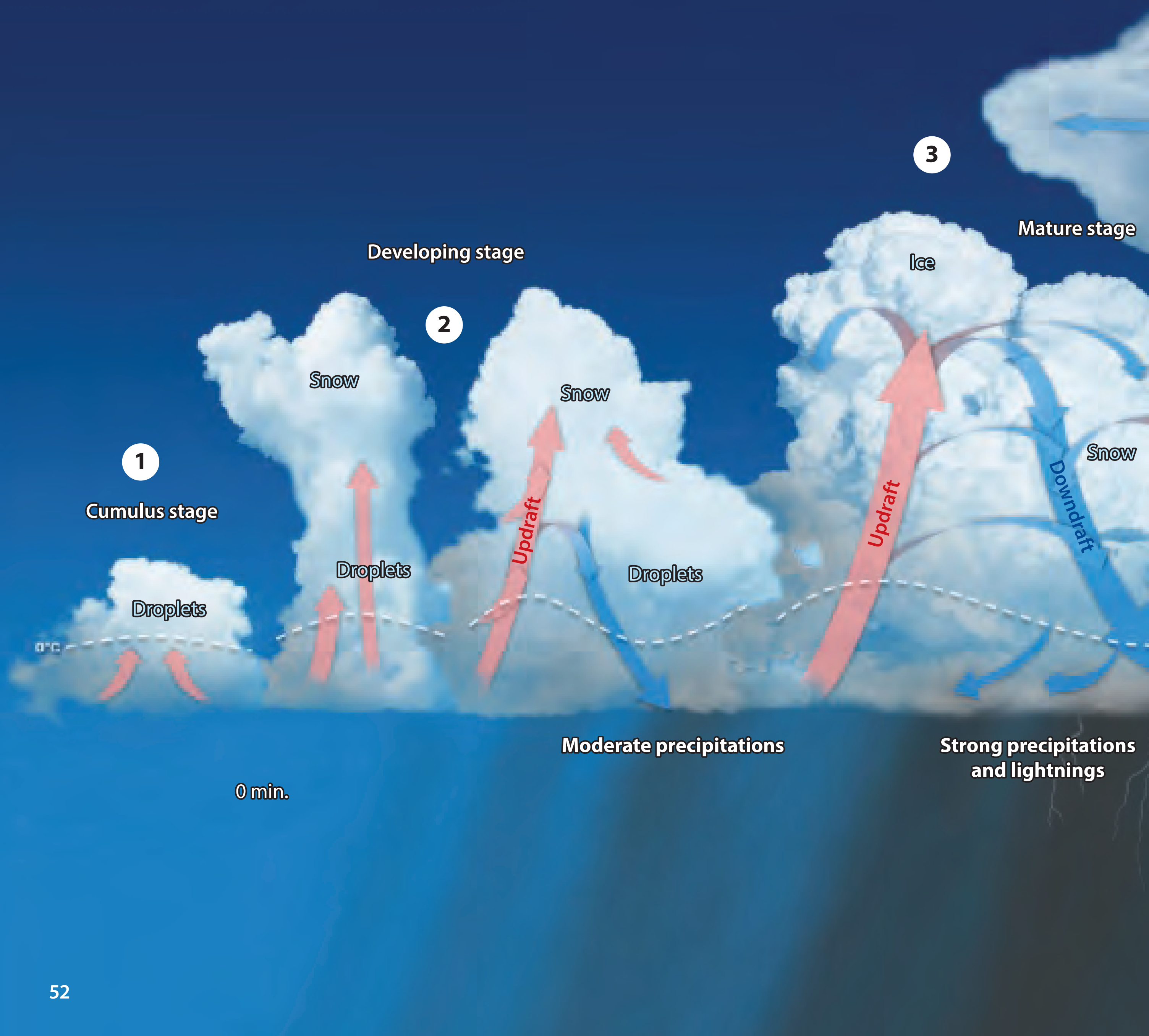
Parts of Germany were devastated by flooding in July 2021 when a low-pressure weather system became stuck for several days because of currents of air.

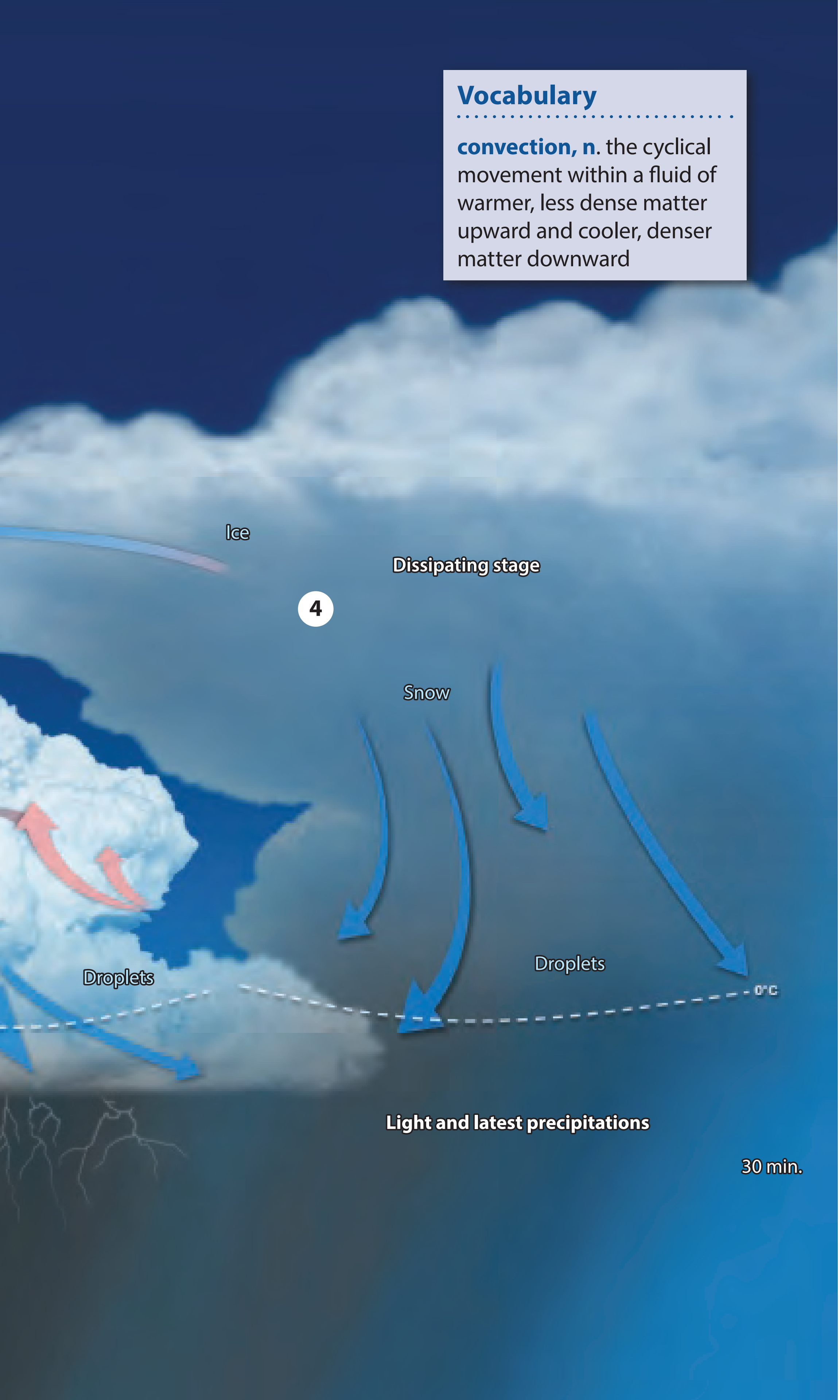
Connection

Climate scientists are concerned that a warming world weakens jet streams. When there is colder air to the north and warmer air to the south of a jet stream, the stream is more likely to stay in place and have a stronger current. If the air in the Arctic gets warmer, the polar jet stream loses its strength, slows down, and tends to meander more. The weaker, slower jet stream allows the weather system to just sit in one place for many days at a time.

Convection and Storms

Another term for a thunderstorm is a convective storm. It gets its name from convection, which is the cyclical movement of a fluid driven by differences in density. When a convective storm consists of a single body, or cell, it can be called a single-cell thunderstorm. The more heat and moisture there is near the ground and the colder the air higher up is, the more likely it is that the storm will be powerful and severe. An especially large storm of this type is a supercell.





Vocabulary

convection, n. the cyclical movement within a fluid of warmer, less dense matter upward and cooler, denser matter downward

1. Convection begins with warm, moist air rising from Earth's surface due to its low density. As the air rises, its temperature declines, and moisture begins to condense into droplets. The updraft has started, and the cumulus cloud has formed.

2. As moisture condenses, the air gains some heat from the process of condensation. This allows the air to stay warm and to keep rising. The cumulus builds in height, and droplets of water accumulate into snowflakes or raindrops. The falling of the rain or snow drags cooled air down toward Earth's surface. This is the downdraft, or "down," part of the convection cycle.

3. As convection kicks into high gear, bringing warm air up and cool air down, precipitation gets heavier. Now lightning develops, and hail can form if melted snow or raindrops are caught by an updraft. If a large, steady updraft occurs, it can produce a tornado. Eventually, the downdrafts begin to outpace the updrafts, and convection weakens.

4. Precipitation and evaporation cool Earth's surface. This shuts down the updrafts, because the air along Earth's surface is no longer warmer and less dense than the air above it. The storm dissipates. Precipitation continues but is weaker. The moisture in the remaining cloud turns into ice crystals, and the top part of the "anvil" spreads out and breaks up.

Destination: Florida

A trip to one of Florida's sandy beaches is the vacation you've always been dreaming about. With miles of sand and warm ocean waters, there are plenty of activities for the whole family to enjoy. Whether you want to bask in the sun, go parasailing, taste the local cuisine, or check out boat tours or underwater excursions, Florida has something for everyone.

If you come to Florida during its summer season—which lasts from April through October—you are bound to enjoy temperatures that stay above 70ºF, according to the National Weather Service. For those of you who are tired of endless winters and cold, rainy climates, this just might feel like paradise.

Fan-Florida Travel is the company that can help you book your dream vacation. Offering premiere concierge services, Fan-Florida Travel can assist you with every step in your trip, from booking beach-front hotel accommodations to reserving spots for scuba diving lessons. Still not convinced? Call us today for a free quote, and receive 20% off when you book your next trip. Trust us: you don't want to miss out on this once-in-a-lifetime opportunity! Come visit the magical sands that travel experts around the world call the "best beaches in America."

Appeal to Emotion

Ads are designed to connect with their audience and often elicit an emotional response from the reader. This is an advertising strategy that can make readers feel more strongly toward using the proposed product or service. Think about how this ad appeals to the reader's emotion.

Appeal to Logic

Although ads are written to persuade you to try a product or service, they often still provide truths and facts to help strengthen their argument. The logic here is the National Weather Service reference related to the temperature in Florida. Think about how this ad appeals to logic by providing these data.

Appeal to Authority

Appeal to authority has to do with insisting that a claim is true only because someone (who is an authority on the subject) says it's true. Here, a claim is made that travel experts say that the beaches in Florida are the best beaches in the country. The ad wants you to think this is true, but there is no way to validate this claim.

Consider the Source

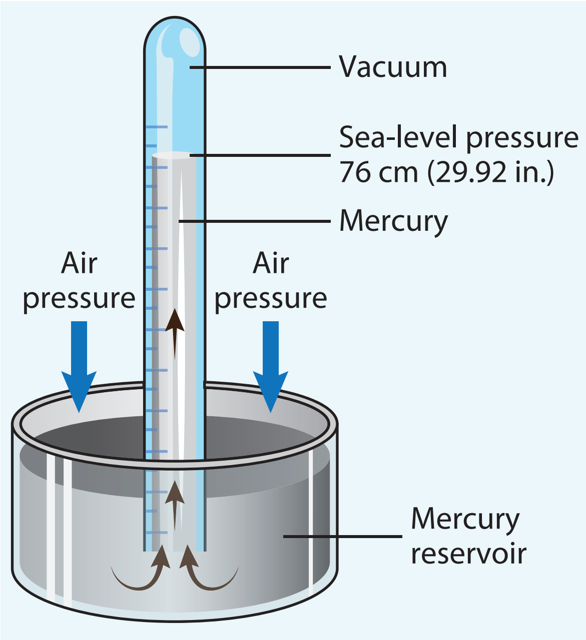
The writer of this ad is a travel writer who has a vested interest in people taking vacations to Florida. The point of the ad is to entice people to travel to Florida. The writer has a motive to get the facts right and has cited information from the National Weather Service, a reputable source. On the other hand, this is not a scientific paper or an example of science journalism.

Barometers: Then and Now

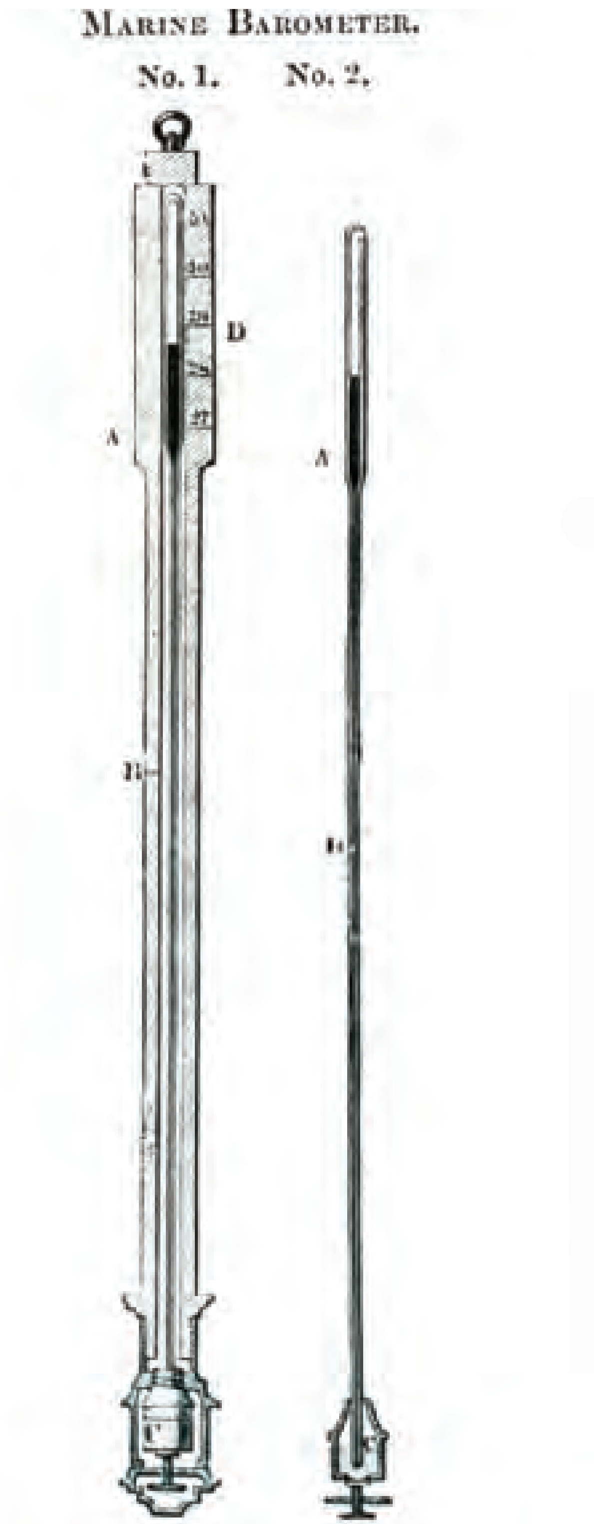
Before barometers were invented, sailors had little way of knowing how weather might change in the coming hours. A sudden decline in weather could spell disaster for a ship at sea. Sailors could use weather vanes to find out which direction the wind was coming from. And they could use thermometers to measure the temperature. The invention of the barometer made it possible to forecast upcoming weather a bit more effectively. A barometer measures atmospheric pressure.

Different styles of barometers were designed throughout the years. These barometers could provide an atmospheric reading as well as a weather forecast because of the cause-and-effect relationship between atmospheric pressure and weather.

In general, very low pressure signals stormy weather, and very high pressure signals clear, dry weather.



The first barometers consisted of a tube of mercury along a labeled scale. The atmosphere pressing down on the mercury in an open reservoir caused the column of mercury inside the tube to move up or down. More pressure meant the mercury would rise. Less pressure would cause it to fall. These basic barometers spilled mercury and could be difficult to read on a rocking ship.



Edward Nairne—a British scientist—developed a barometer that had bent glass tubes, which allowed the reservoir to seal so the mercury would not spill. Nairne's design also featured gimbals, which are pivot points that allow something to remain level. The gimbals helped the barometer respond only to changes in pressure, not the rocking and rolling of a ship.

Some barometers were designed to resemble clocks. These barometers were labeled to provide a weather forecast along with the atmospheric pressure reading.

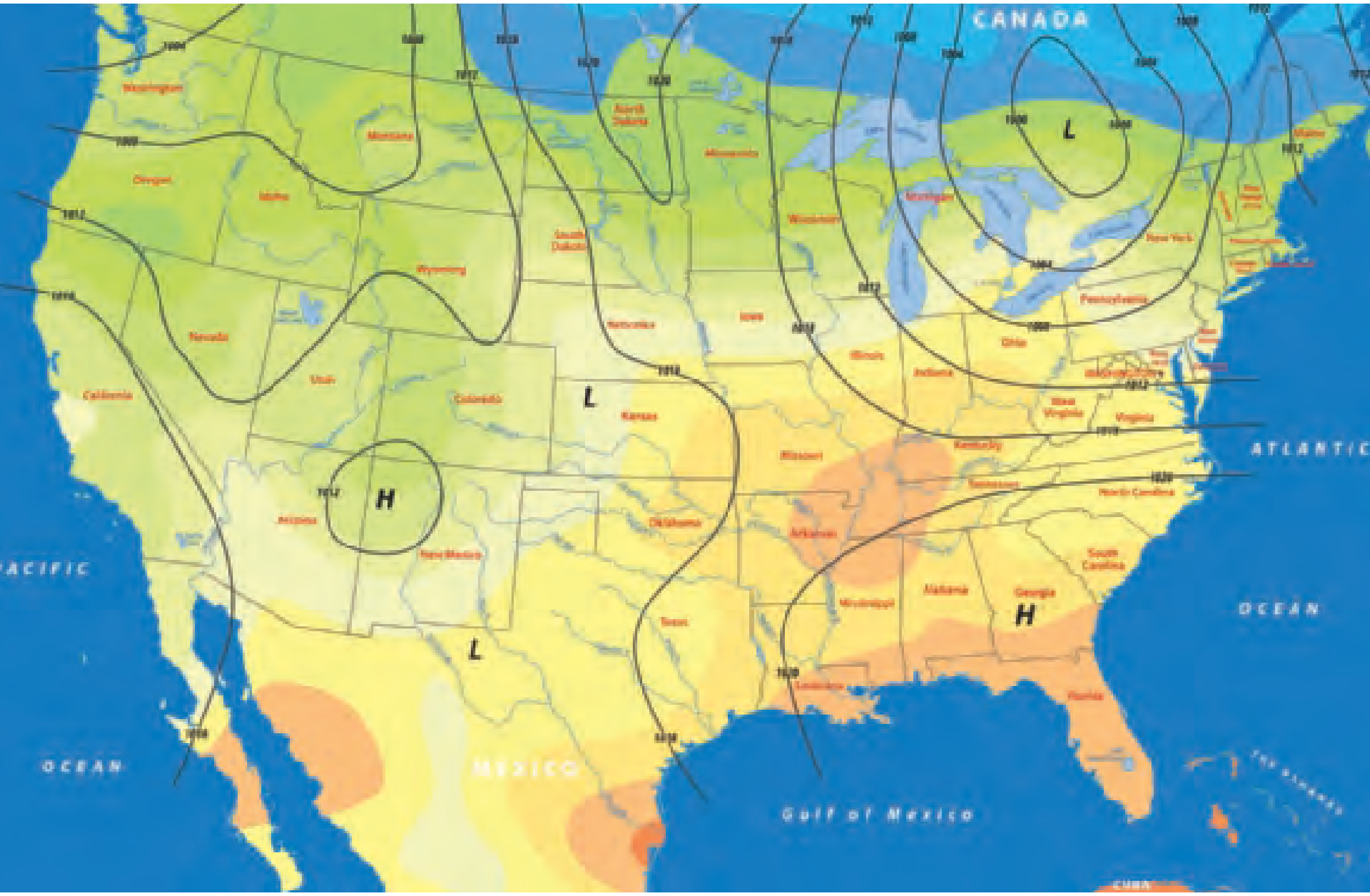
Dig into Data

Atmospheric pressure is usually measured in millibars (mb), a unit developed for use in the metric system. Standard pressure in millibars is 1013 mb. A high-pressure system might register 1050 mb on a barometer. A low-pressure system can dip into the low 900s or beyond. The table shows record highs and lows for the United States and the world.

	Record Low Pressure (mb)	Record High Pressure (mb)
United States	**925** Dutch Harbor, Alaska, 1977	**1079** Northway, Alaska, 1989
Global	**870** Typhoon Tip, Guam, 1979	**1094** Tsetsen-Uul, Mongolia, 2020

We live in a modern world. Today, people use digital barometers to gauge atmospheric pressure. Digital barometers do not use mercury (which is a good thing, since mercury is poisonous). Instead, they rely on special computer chips to read the air properties. The chips are sensitive to changes in air pressure and can give an up-to-date measurement that is easy for the user to read on an LCD.

In fact, it's possible that your smartphone has a barometer chip built into it. Such chips have very tiny parts that can sense changes in the air pressure around you. A small digital home weather station can also send measurements to your mobile phone or tablet.



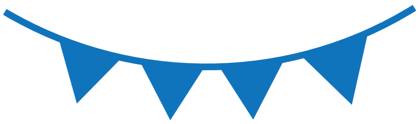
Air pressure readings from barometers all over the continent can supply data for mapping air pressure. In a way, this looks similar to a map that shows fronts of air masses that are differentiated by temperature.

Connection

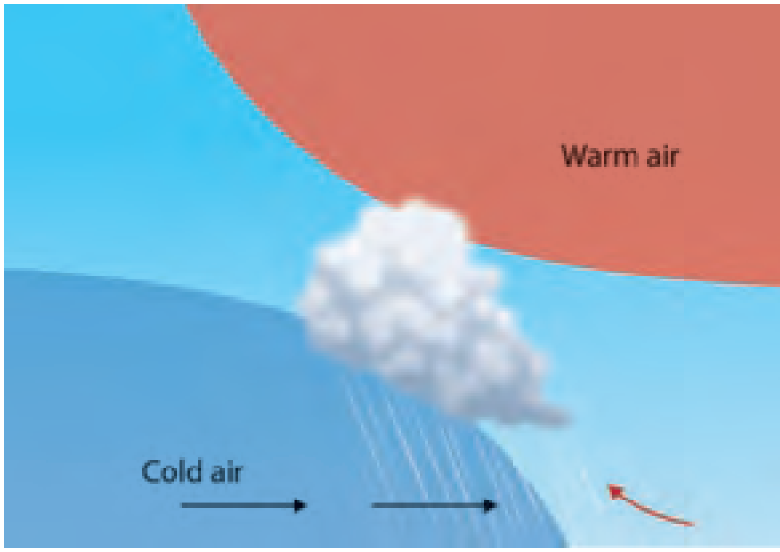
Atmospheric pressure is not just for sailors out at sea. We encounter air pressure in our daily lives when we fill up our bicycle or car tires with air, play musical wind instruments, use straws to sip soft drinks, water plants with a hose, and blow up balloons.

How Air Masses Behave

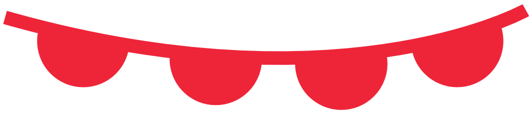
Cold Front



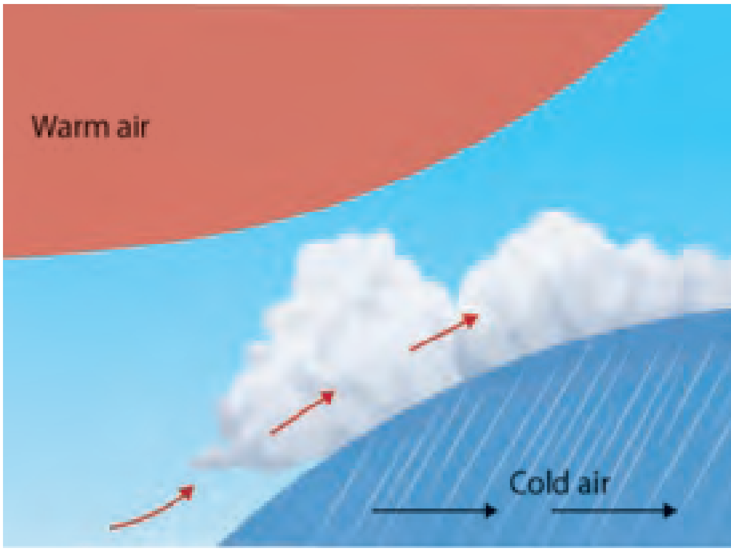
Have you ever looked at a weather forecast and seen a map with a solid blue line with a series of triangles on it? If so, you were looking at the symbol for a cold front. Air masses have boundaries called **fronts**. The ways air masses behave at their boundaries can provide clues about the type of weather ahead. In a cold front, a mass of cold air meets a mass of warm air. The warm air is forced up and over the colder air. The triangles that you see here point in the direction the cold air mass is moving. This indicates how the front is moving relative to Earth's surface. Large clouds and stormy weather can accompany a cold front. A cold front also marks the edge of a low-pressure system.



Warm Front



If there's such a thing as a cold front, then there must be such a thing as a warm front. With warm fronts, masses of warm air replace colder air masses that are moving in the same general direction. The warmer air flows up and over the cold air. On a weather map, a warm front is symbolized by a solid red line with semicircles pointed in the direction of the front's movement. Gentle precipitation often occurs because of this interaction at the front.

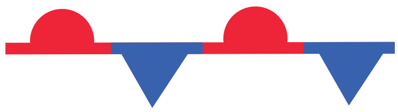


Cirrus clouds can mark the arrival of a warm front. Below the cirrus clouds, small rain clouds can form. The change in weather at a warm front tends to be less severe than at a cold front, as both air masses are moving in the same general direction. After some gentle rain, a warm front usually spells clear skies, high pressure, and, of course, warmer temperatures.

Vocabulary

front, n. the borderline where two different air masses meet

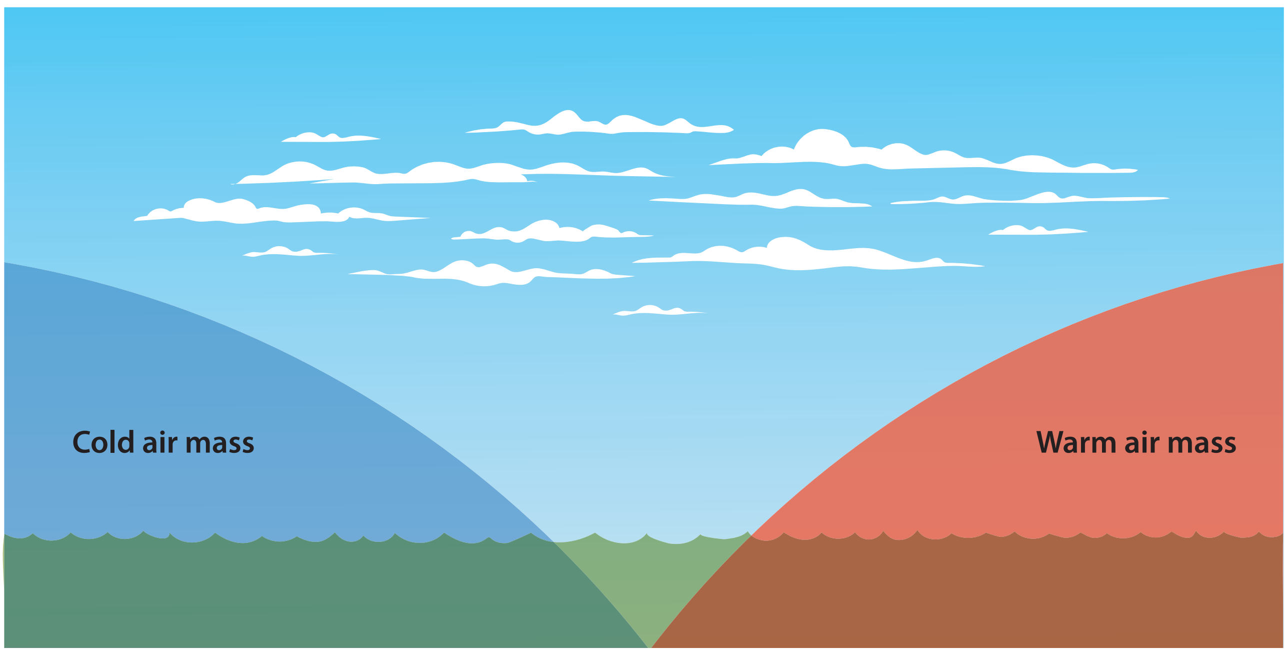
Stationary Front



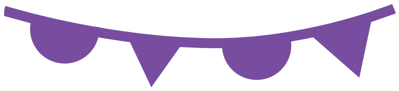
When two air masses are basically stuck in place, with neither one sliding under or over the other, the boundary between them is called a stationary front. The symbol for a stationary front is a combination of the warm and cold front symbols: an alternating red-and-blue line with blue triangles and red semicircles.

At a stationary front, winds at the edge of the two air masses often travel in opposite directions parallel to each other. If one of the air masses gains energy and its wind shifts into the other, the stationary front can become a cold or warm front, depending on which gets moving. During the standoff between the two air masses of a stationary front, rainy or snowy weather can develop and sit in place for days. A stationary front is often a cold front that stalls.

A stationary front can result in consistent rain over days, causing a lot of flooding.

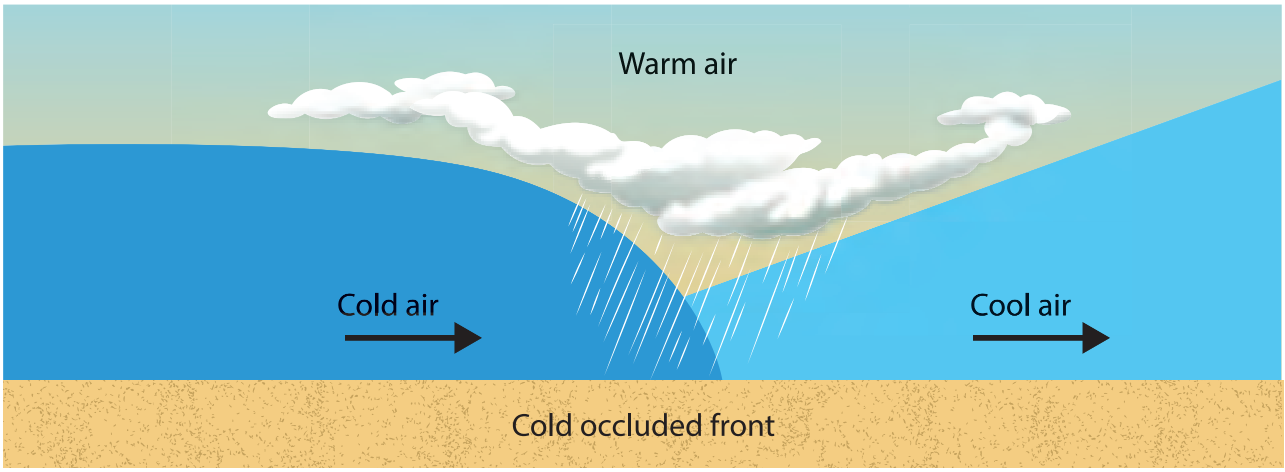


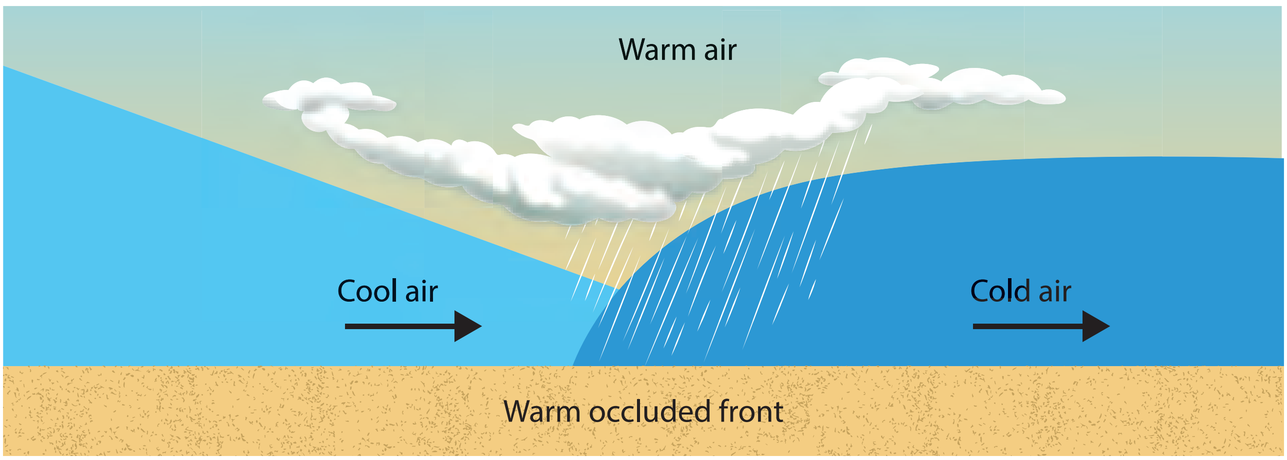
Occluded Front



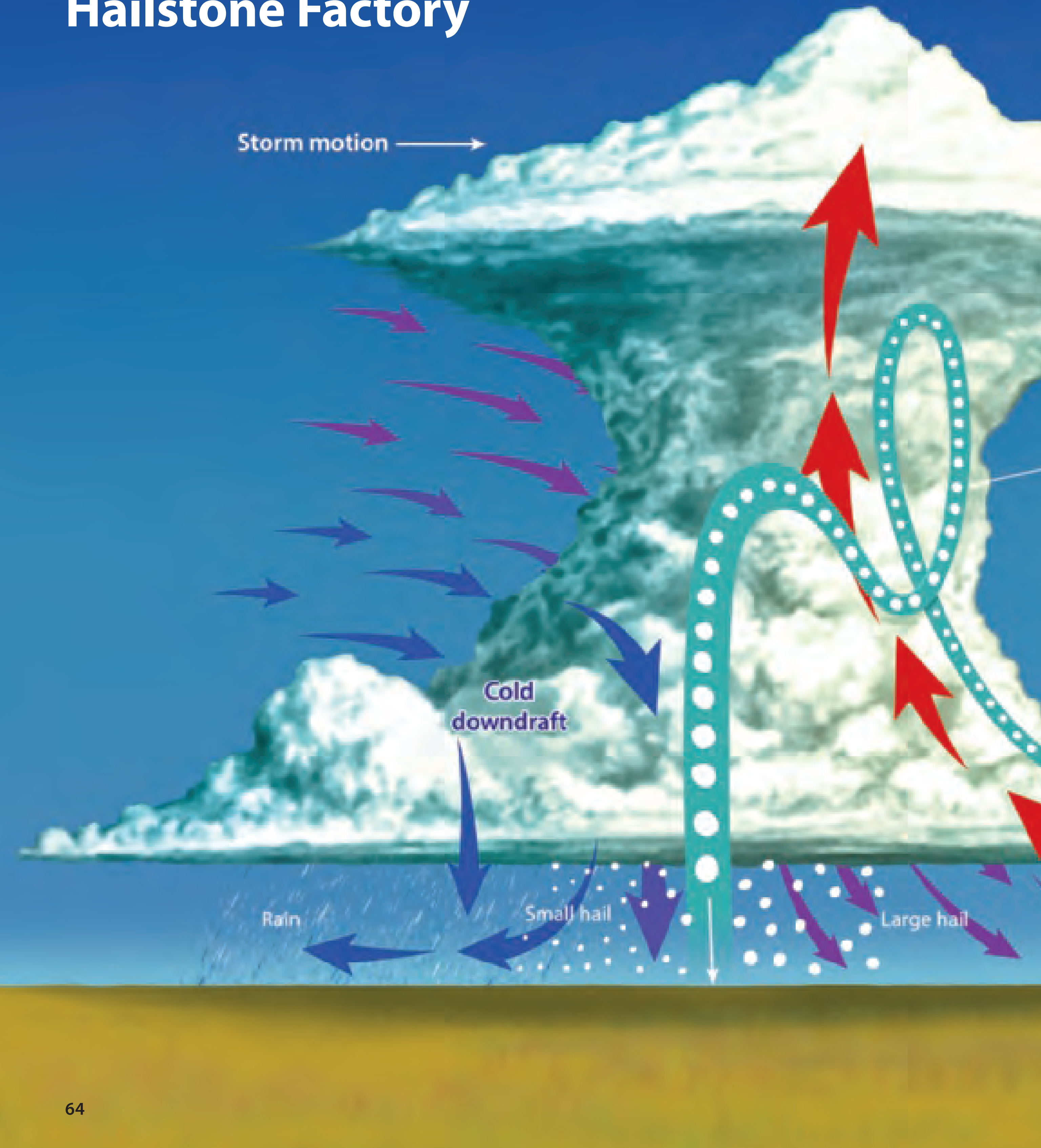
If you see this solid purple line with triangles and semicircles of the same color on a weather map for your town's forecast, beware! An occluded front can help a cyclone form. Cold air masses tend to move more quickly than warm air masses. Sometimes a fast-moving cold air mass can overtake a warm air mass that's moving slowly. This forces the warm air mass up, which in turn creates space for a cool air mass to be drawn in, even though it is moving in the same direction as the cold air mass.

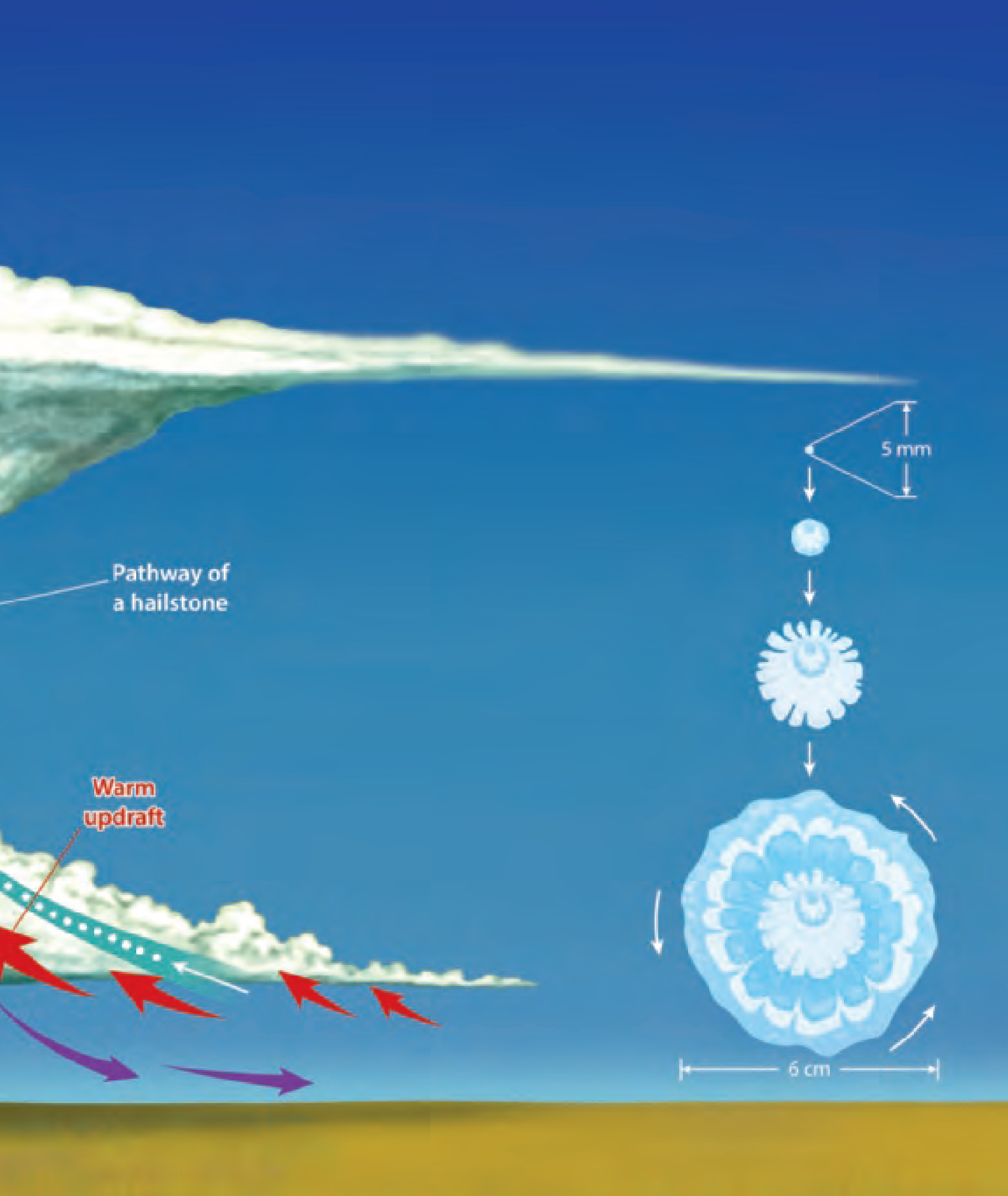
The low density of a warm air mass causes it to be forced up by the cold and cool air masses. If the cold air mass is to the rear of the cool air mass, this is called a cold occluded front. If the cool air mass is behind the cold air mass, it's called a warm occluded front. At an occluded front, precipitation can be intense as moist, warm air is cooled between the two wedges of colder air.





Hailstone Factory





5 mm
Pathway of a hailstone
Warm updraft
6 cm

Inventions in Weather

The next time you check the weather, take a moment to appreciate the years of work scientists have put into studying the atmosphere. It is because of specialized knowledge and tools for measuring and tracking weather that we know when to plant and harvest crops or when to evacuate because of a coming storm.

1

340 BCE
Aristotle wrote *Meteorologica*, a go-to reference for meteorology that conveyed his views on how air and water moved in the atmosphere. This reference endured until the end of the 17th century.

2

17th and 18th centuries
Thermometers, barometers, and hygrometers (instruments for measuring humidity) were invented in Europe.

3

Mid-19th century
The invention of the telegraph allowed weather data to be transmitted to other locations. This allowed a "big picture" view of the weather conditions in a region to be developed.

4

1920s
Weather balloons, also known as radiosondes, were developed. A hydrogen-or helium-filled balloon carried weather instruments high into the atmosphere, and readings were transmitted to Earth's surface by radio. Radiosondes are still used today.

5

1950s
Advances in computing ushered in a new age of meteorology based on math and modeling. What would have taken a roomful of people and thousands of calculators could now be handled simply by a large computer.

6

Early 1960s
Satellites and radar became important tools in meteorology. Some satellites act as cameras, sending photographic visuals of Earth from orbit. Others have sensors that can measure temperature or calculate cloud densities. Radar is basically radio waves sent out through the atmosphere. It can help provide a picture of what's out there, including incoming thunderstorms.

7

2000s
Powerful computers, sophisticated models, and satellites can provide us with very accurate data about weather, which allows observations and forecasts to be remarkably accurate. Here, a MODIS satellite shows the image of two different tropical cyclones in the Pacific Ocean heading toward Asia.

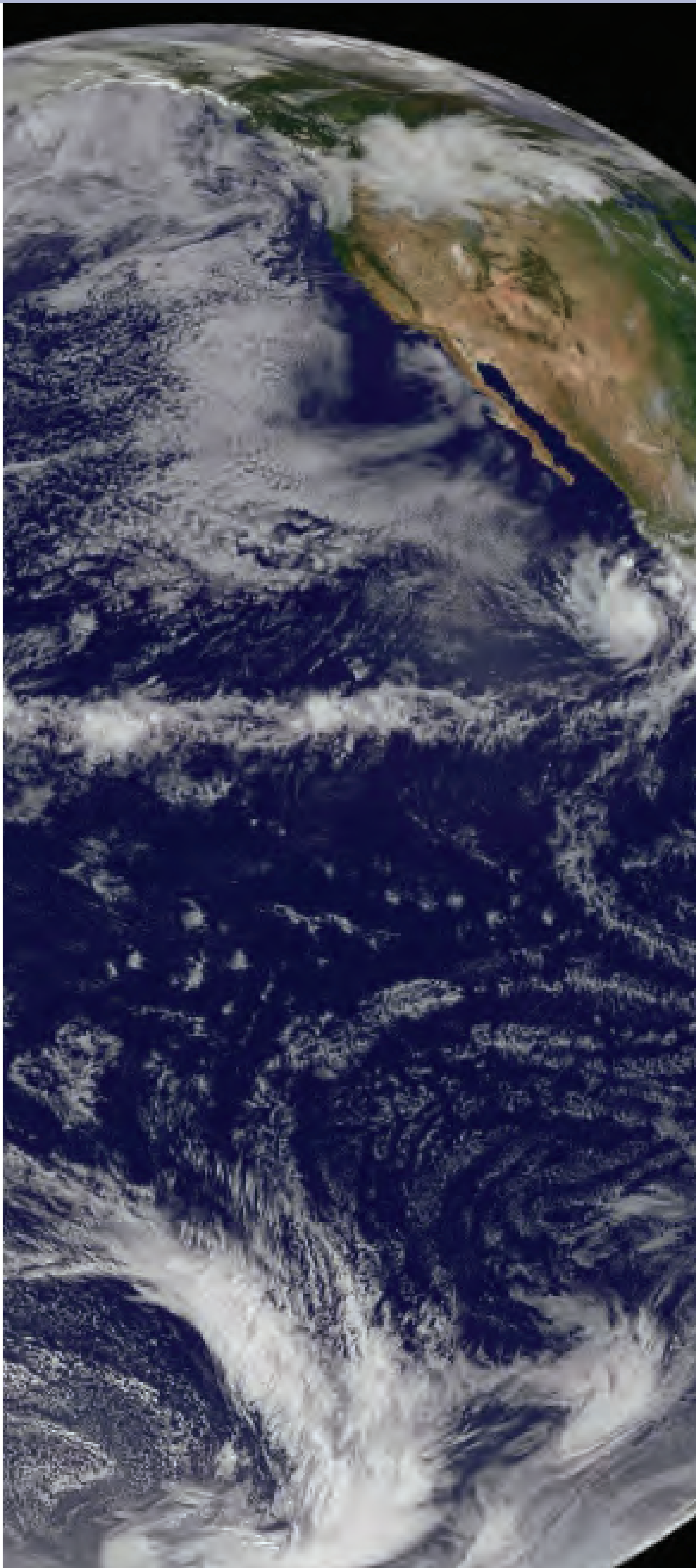
El Niño and La Niña

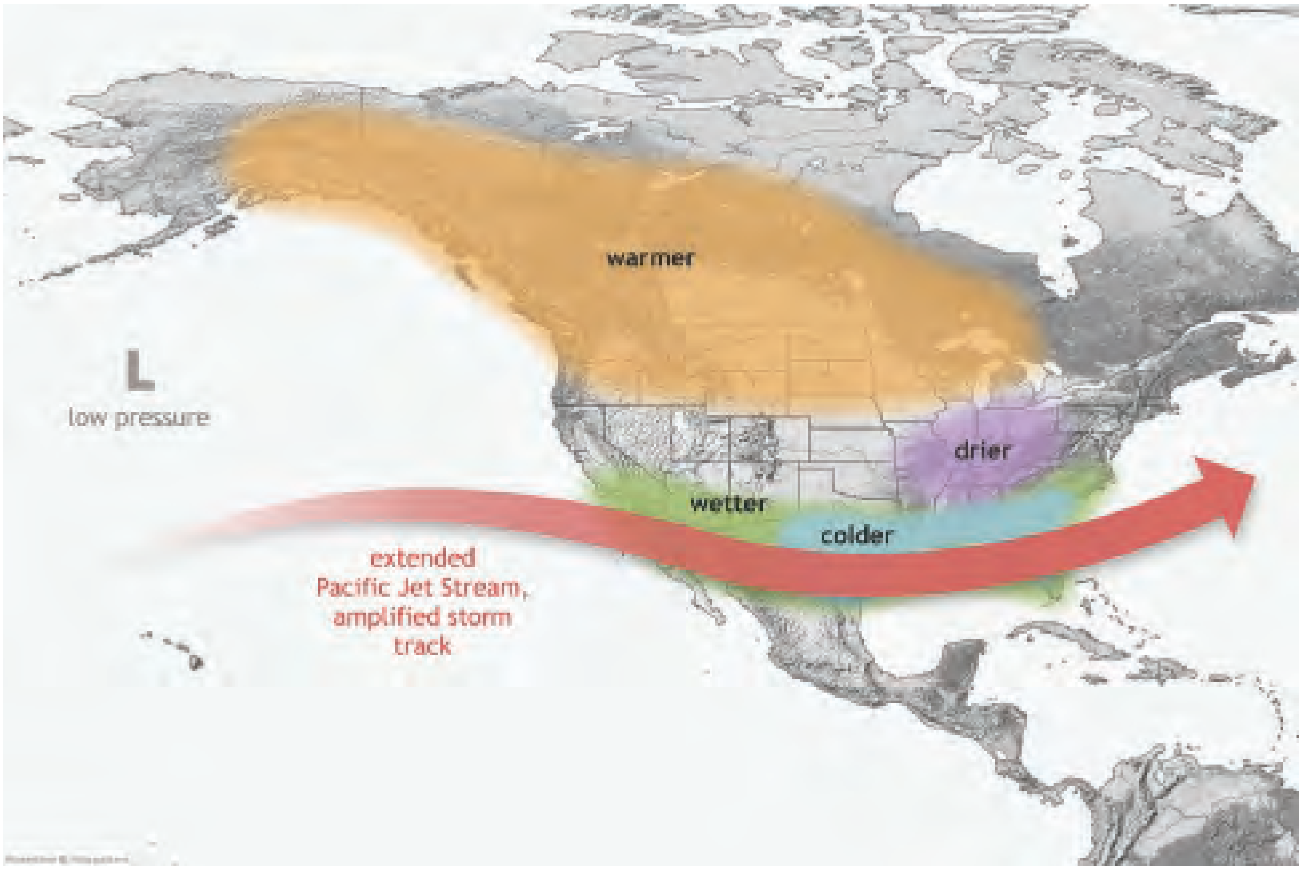
The Pacific Ocean is a major driver of weather and climate, often discussed in terms of El Niño and La Niña. El Niño is the warm phase of these weather patterns. During an El Niño year, the trade winds that usually blow from east to west across the tropical Pacific are slowed or even reversed. At the surface, moisture and heat build up over the central and eastern Pacific. The low pressure over that part of the Pacific means the pressure is higher to the west, over Southeast Asia. This spells droughts in places such as Indonesia, while North America tends to be warmer and wetter. In the United States, the Pacific jet stream drifts to the north, making the southern states wetter than usual while the northern states tend to be drier, especially in winter. During El Niño, less heat in sun-warmed waters near the equator is carried to deeper layers of the ocean. This means the atmosphere overall is warmer.

Dig into Data

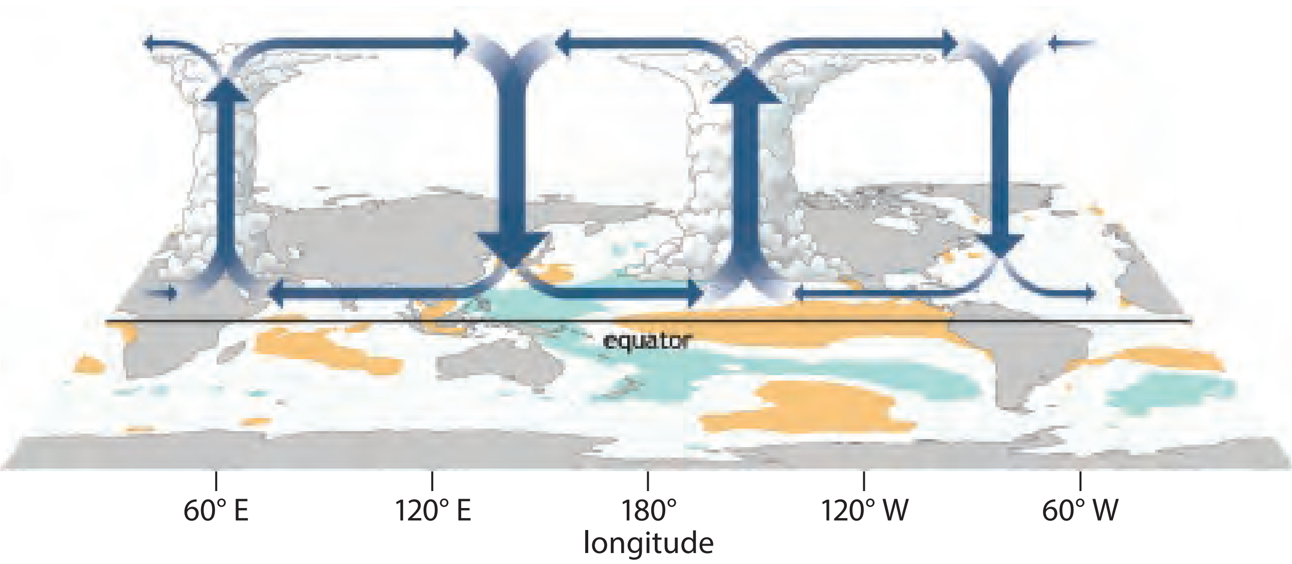
Scientists use a variety of factors to study the effects of El Niño on the planet, including:

- sea surface temperature
- air pressure of the overlying atmosphere across the equatorial Pacific Ocean





El Niño Conditions

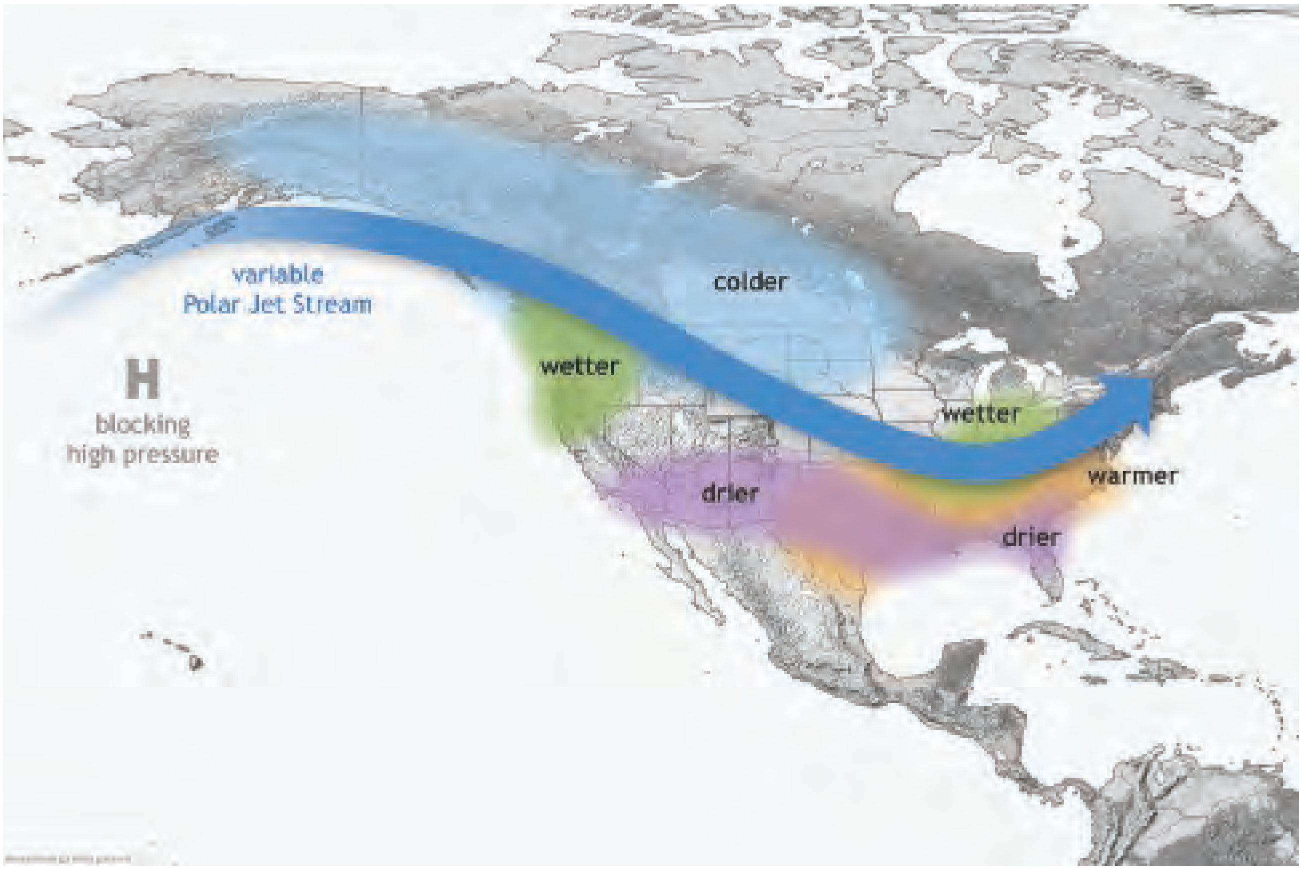


The diagram shows greater evaporation over the eastern Pacific.

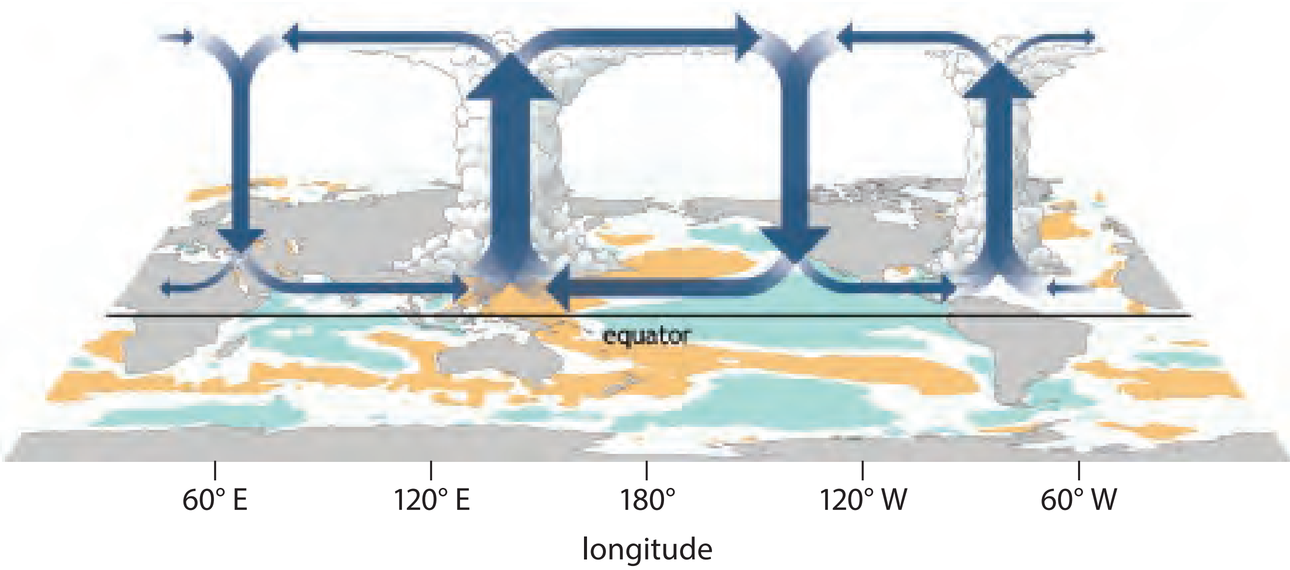
La Niña is the opposite of El Niño. The trade winds are stronger than in a neutral year, making the eastern Pacific quite cool, as cold water from the deep rises to replace warm water blown westward. Pressure is lower over Indonesia, and conditions are wetter and warmer there. In the United States, the polar jet stream meanders to the north, spelling warmer, drier winters in the south while the northern states are colder and wetter. During La Niña, more heat is stashed in the ocean, and the atmosphere is cooler.

Connection

La Niña and El Niño have effects on weather and climate, which in turn means certain industries, such as fisheries and farming, are affected. During El Niño, when anchovy fishing boats have empty nets, less fishmeal can be produced. Less fishmeal affects the livestock and aquaculture industries, from China to Norway to the United States. On the other hand, during a La Niña, there are usually positive impacts on fishing and farming industries due to the increased rainfall throughout the year.



La Niña Conditions



The diagram shows greater evaporation over the western Pacific.

Science Interviews Podcast

Special Climate Bonus Episode

(Begin transcript)

(Intro theme music)

Jordan: Ladies and gentlemen, I'm Jordan, your science correspondent, and I want to thank you, as always, for listening to my Science Interviews Podcast. I've got a very special guest in the studio today. In today's episode, I'm pleased to bring you a conversation with a true snowflake. I mean really, an actual flake made of snow. Snowflake, thanks for joining us on the pod!

Flake: Happy to be here, Jordan! I always welcome the chance to illuminate the world of science. And please, my friends call me Flake.

Jordan: Flake, let's just jump right into some background about you. I understand that you only exist below freezing and that you spend some of your time falling from the sky and the rest of the time just kind of sitting on the ground. So, what are you made of? Where are you from?

Flake: Well, Jordan, I start out as a very small particle of dust very high in the atmosphere . . . anywhere from a half to three miles above Earth's surface. When conditions are right with a cold enough air mass and the right amount of humidity in the air, a little ice forms on me.

After that, it's just a matter of more and more ice building up on me, kind of like how some humans go to the gym to put on more muscle. Unlike a human, my friends and I can keep moving up and down inside a snow cloud, gaining more ice and getting larger. Eventually we get heavy enough and fall to Earth. As long as there is cold and moisture in the air, we have a chance to visit the surface.

Jordan: So Flake, when I heard you wanted to be on the podcast, I was wondering why. What brings you here today? Do you have a new movie or book coming out?

Flake: Nothing like that, Jordan. I just wanted to clear the air about some issues snow seems to be causing humans. A few million of us were sunning ourselves on the top of Mount Kilimanjaro and getting ready to melt, evaporate up into the atmosphere, and go find some cold clouds in which to reform. Anyhow, we got to talking, and you know, snow really gets a bad reputation, and it's always humans complaining about us. I could point you to quite a few polar bears that are huge fans of ours.

Sure it can be inconvenient when we fall during rush hour on the highways, but have you ever tried to snowboard without snow? Or downhill ski without snow? I tried that once. Things went poorly.

Jordan: Good point, Flake. I didn't know snow felt bad about the things we say about it. Is there anything you could add by way of explanation that might make the listeners rethink what they say about snow? What's a real "big picture" understanding of snow's role on Earth?

Flake: Jordan, if your listeners could think about the role we play in Earth's different systems, that might help. When winters are dry and cold, we bring much-needed moisture, which eventually helps producers like plants grow. And with more plants to eat, consumers like rabbits have something to eat. And the things that eat rabbits then have something to eat. Snow helps support the redistribution of matter and energy by getting Earth ready to blossom in the spring.

Snow isn't just part of the water cycle, either. We helped make up the glaciers that created the moraines in Wisconsin. When we get promoted to ice, we get to break up rocks. Jordan, we've been around for billions of years. I have friends and family that have been part of the polar caps since the dinosaurs went extinct. Before there were humans, there was snow. We'll be around well after humans fly to the stars or whatever your game plan is.

Jordan: Flake, that's it? You just want to be treated with respect?

Flake: There's more. I was talking with my friend Flaky Snow. We call him that because anytime you hear a story about something happening because of the snow, he says he was there. Anyhow, the last few years have been interesting for snow. We just go where the cold fronts drop us off. We've noticed those cold fronts sometimes moving into the warmer areas of Earth. I think you humans call it climate change.

Anyhow, lately we've been to some places we rarely if ever go to. It used to be that we'd get lucky every few years and do a snowfall over the orange groves in Florida. Then there was that thing with the politician.

Jordan: A politician? What did a politician do to disrespect snow, write a bill outlawing it?

Flake: Jordan, it was this snowfall we did in 2015 where your government is located. Keep in mind that we just go where the cold front drops us off. When a few million of us do a snowfall, you call it a flurry. When a few billion of us do a snowfall, you call it a snowfall. When a few trillion of us do a snowfall, you call it a blizzard. Anyhow, this guy throws a snowball on the floor of where he works and says, "Climate change isn't happening. It snowed here today." I was outside that day, but Flaky says he was in that snowball.

Jordan: So this politician uses a single data point, the snowball, to say climate change isn't real?

Flake: Right. A single data point is usually not enough to disprove a theory. I mean, if I fell onto your lawn tomorrow, and it was just me, you wouldn't claim there was a blizzard based on one snowflake. I don't know if climate change is real, but in the last ten years, I've been some odd places. We did a snowfall in the Sahara desert. Didn't stay long there because it was so hot and we were as out of place there as the cold front that dropped us off. All of us snowflakes are wondering why the cold fronts have been moving toward the equator more often. We've been doing more snowfalls in places like South Texas, Louisiana, and Mexico, too. Just like the snowball, these are just a few data points, but at what point will there be enough data points to support the theory of climate change? The way we think about it, climate is what you expect; weather is what you get. If you get something unexpected, it does not mean the climate is or is not changing. You need to evaluate more weather over a longer period of time.

Jordan: Scientists do have data from long periods of time to reveal a trend of global warming. Flake, I can't thank you enough for coming into the studio today. It has been a pleasure to have you fill us in on the ins and outs of being a snowflake. The next time you visit the polar bears, tell them I say hi!

Flake: The pleasure was all mine, Jordan. Love your podcast. Keep spreading the science news.

Jordan: Happy snowfalls!

(Closing theme music)

(End transcript)

Vocabulary

climate n. the weather conditions prevailing in an area in general or over a long period

Spot the BS

Heads up! This podcast contains **b ad s** ensemaking. It contains some data and facts, but it also lays out some claims related to climate. How is making a claim tied to a single data point bad science?

Fall Camping in Death Valley

Travel Diary, Death Valley
October 8–12

I had been eager to visit Death Valley since watching the 1924 silent film Greed, which ends on the dry, sun-scorched salt flats. Of course, I did not want to end up like the characters in that film, so I avoided the valley during summertime and instead planned to camp there in mid-October, when the daytime temperature averages 93°F and dips to 61°F at night. A lightweight tent and my basic Season 2 sleeping bag would suffice. I timed the trip to coincide with the Lone Pine Film Festival, which celebrates the valley's role in Hollywood films, with the intent to hit the film festival on the way home to L.A. from Death Valley National Park.

These characters did not fare so well in the end of *Greed*.

How was it? In a word, dry. Death Valley has had years—yes, whole years—in which no rain was recorded. From 1931 to 1934, there was a 40-month stretch with just 0.64 inches of rain. That's about how much water one could wring from a cotton T-shirt after 20 minutes standing in the sun at Furnace Creek in summer, when the temperature can approach 130°F. After a few days and nights of such unrelenting dryness, I was daydreaming about a shower and a winter getaway to rainy Seattle. I only lasted an hour at the film festival, as all of the film scenes shown evoked the dry heat a little too well.

Why is Death Valley bone dry? You can blame the two major mountain ranges that sit between the valley and the nearest major source of atmospheric moisture: the Pacific Ocean. Each range results in a rain shadow.

As moisture encounters the windward, western side of the Coastal Range, it is forced upward. At a higher elevation, the moisture condenses. Rain or snow falls on that side of the range. When the air passes to the other side, much of its moisture has already been removed. This spells a "rain shadow" on the leeward side of the range and in the San Joaquin Valley. This rain shadow effect kicks in again when the air reaches the Sierra Nevada Range. Think of a sponge that's been thoroughly wrung twice. That's what happens to air masses that flow from the Pacific to Death Valley. And that's why the valley is so dry and lifeless, hence the name.

Vocabulary

rain shadow, n. an area of reduced rainfall on the leeward side of a mountain

Dear Weather Detective

Dear Weather Detective,

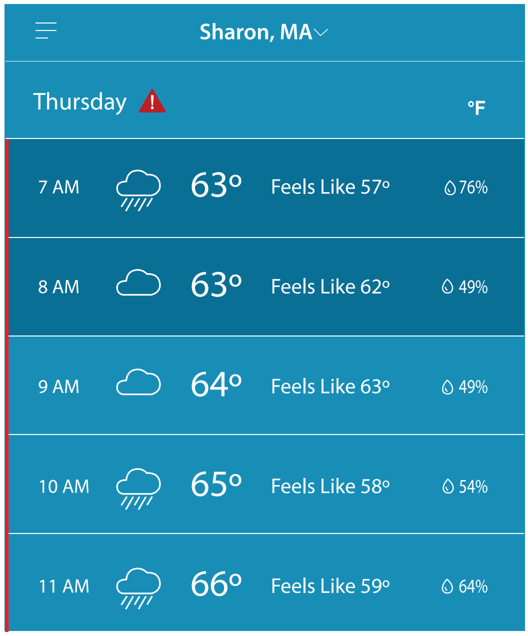
I am trying to better understand how to interpret weather forecasts. The other day, the forecast said there was a 70% chance of rain in the morning, but it never ended up raining (even after I canceled my outdoor plans).

Please help.

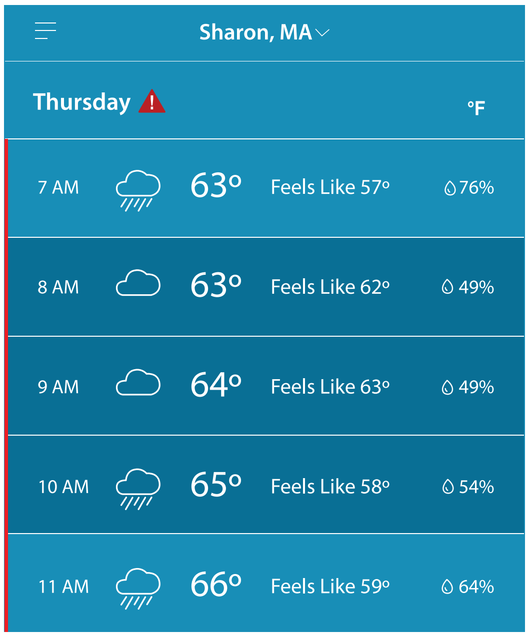
Sincerely,
Weather Curious

Dear Weather Curious,

For a non-meteorologist to make sense of weather data and weather forecasts, visuals can help. What you described has to do with probability. So let's take a closer look at a weather app to better understand how probability works.



Suppose you live in a suburb near Boston, Massachusetts. The weather app on your device shows you this hourly forecast. It indicates that the probability of rain on Thursday is highest at 7 a.m., at 76%. This means there is a 76% chance that rain will fall somewhere between 7:00 and 8:00. It does not mean that 76% of the town will get rain or that it will rain for 76% of the time between 7:00 and 8:00.



The probability drops to 49% for 8:00 and 9:00. The cloud icons also suggest less rain at those times, as the cloud has no rain streaks in those two rows of the display. At 10:00 and 11:00, the probability of rain increases again.

Judging by these data, the driest time of the day would be the two-hour window between 8:00 and 10:00.

In any given location, it's possible that a weather forecast could end up looking very wrong. A rainstorm can dump tons of water on one part of town but leave another part almost dry. Hurricanes can lose energy and turn in different directions. A tornado can touch down on one block and leave another untouched. Many things can happen because weather involves so many variables. That is why forecasts are often based on probabilities.

Sincerely,

Weather Detective

Glossary

accuracy, n. how close a measurement is to the true value

actuary, n. a person who analyzes data to calculate risks and determine what insurance should cost

adhesion, n. the process of sticking to or clinging to another substance

atmospheric pressure, n. the pressure applied by the weight of the atmosphere, which is roughly 14.7 pounds per square inch at sea level

barometer, n. an instrument that measures atmospheric pressure

climate, n. the weather conditions prevailing in an area in general or over a long period

cloud seeding, n. the practice of dispersing substances into the air that promote the formation of precipitation in clouds

cohesion, n. the tendency of a substance to cling together or stick to itself

condensation, n. the conversion of a gas to a liquid

convection, n. the cyclical movement within a fluid of warmer, less dense matter upward and cooler, denser matter downward

cyclone, n. a tropical storm rotating around a center of very low pressure

density, n. the quantity of mass per unit of volume; for example, the density of water is about 1 gram per cubic centimeter

downdraft, n. a downward current of air

drought, n. a prolonged period of unusually low precipitation, leading to a shortage of water

evaporation, n. the conversion of a liquid to a gas

fluid, n. matter that can flow and does not retain its shape, as in liquids and gases

front, n. the borderline where two different air masses meet

glacier, n. a long-lasting mass of dense ice that gradually moves downhill

heat island, n. an urban area that retains heat because of its built environment and is warmer than its surrounding natural or rural area

humidity, n. the amount of water vapor in a region of the atmosphere

hygrometer, n. an instrument that measures humidity of air

ice sheet, n. a stationary mass of ice that covers a large region of terrain

irradiance, n. the intensity of light shining on a surface, which varies with the angle at which the light strikes the surface

jet stream, n. a fast-flowing, narrow current of air in the atmosphere

latitude, n. the measure of a point's distance north or south of the equator

longitude, n. the measure of a point's distance east or west of the prime meridian

mean, n. an average; the central value in a set of numbers, calculated by adding the values and dividing that sum by the number of values

millibars, n. (mb) a measure of atmospheric pressure; one thousandth of a bar

nucleus, n. the small, dense region forming the center of a mass

occluded front, n. the boundary where a cold front overtakes a warm front

precipitation, n. rain, snow, sleet, or hail that falls to the ground

precision, n. the closeness of repeat measurements to each other

pressure, n. the force applied per unit area of a surface

prime meridian, n. the line at zero longitude, which passes through Greenwich, England

probability, n. the chance or likelihood that something will occur

radiosonde, n. an instrument that is carried into the atmosphere and transmits measurement data by radio

rain shadow, n. an area of reduced rainfall on the leeward side of a mountain

rotation, n. the turning of an object around an axis through its center

science literacy, n. the ability to read, hear, and comprehend information about scientific topics and demonstrate understanding in discussion and through writing

severe weather, n. weather conditions with the potential to cause damage

snowpack, n. a mass of snow that is compressed and hardened under its own weight

stationary front, n. the boundary where air masses meet and neither moves the other

stratosphere, n. the second layer of Earth's atmosphere, located above the troposphere

surface tension, n. the property of a liquid's surface causing it to resemble a stretched membrane

tornado, n. a mobile, destructive vortex of violently rotating winds having the appearance of a funnel-shaped cloud and advancing beneath a large storm system

transpiration, n. the release of water vapor through the stomata of plants

troposphere, n. the lowest region of the atmosphere, occurring between Earth's surface (below) and the stratosphere (above)

updraft, n. an upward flow of air, as in a thunderstorm

variable, n. a factor that is able to change or be changed

water cycle, n. the continuous movement of water above and below Earth's surface

Key Sources

Nemo, Leslie. “Welcome to ‘Hail Alley,’ a U.S. Region Prone to Pelting Ice.” *Discover.* January 13, 2021. https://www.discovermagazine.com/environment/welcome-to-hail-alley-a-u-s-region-prone-to-pelting-ice

“Temperature – Mean, 1981-2010 Monthly Average.” Data Snapshots Image Gallery. Climate.gov, NOAA. Accessed November 1, 2021. https://www.climate.gov/maps-data/data-snapshots/data-source-30-yr-averages-month-mean-temp

Bill Schlesinger. “The Fate of Rainfall.” Citizen Scientist. Nicholas School of the Environment, Duke University. September 17, 2018. https://blogs.nicholas.duke.edu/citizenscientist/the-fate-of-rainfall/

Ramirez, Rachel, Javaheri, Pedram, and Drew Kann. “The Shocking Numbers Behind the Lake Mead Drought Crisis.” CNN.cpm Wire Service. Cable News Network, Inc., a WarnerMedia Company. June 12, 2021. https://www.mercurynews.com/2021/06/17/the-shocking-numbers-behind-the-lake-mead-drought-crisis/

”California Central Valley Groundwater Depletion Slowly Raises Sierra Nevada Mountains.” National Science Foundation news release. May 14, 2014. https://www.nsf.gov/news/news_summ.jsp?cntn_id=131393

Brasch, Sam. “What the UN’s Latest Climate Report Means for Colorado.” Colorado Public Radio. August 9, 2021. https://www.cpr.org/2021/08/09/un-climate-report-what-it-means-for-colorado/

“El Niño and La Niña: Frequently Asked Questions.” Climate.gov, NOAA. Updated September 22, 2021. https://www.climate.gov/news-features/understanding-climate/el-ni%C3%B1o-and-la-ni%C3%B1a-frequently-asked-questions

“Death Valley.” National Park Service. Accessed November 1, 2021. https://www.nps.gov/deva

Burt, Christopher. “World and U.S. Lowest Barometric Pressure Records.” *Weather Underground*. The Weather Company. November 20, 2011. https://www.wunderground.com/blog/weatherhistorian/world-and-us-lowest-barometric-pressure-records.html

Core Knowledge®

CKSci™

Core Knowledge Science™

Editorial Director
Daniel H. Franck

Subject Matter Expert

Terri L. Woods, PhD
Associate Professor
Department of Geology
East Carolina University
Greenville, NC

Development Partners

Six Red Marbles
Carri Walters
Executive Editor

Daniel Clem
Writer

Illustrations and Photo Credits

Adrian Chinery / Alamy Stock Photo: 67c
agefotostock / Alamy Stock Photo: 72-75
ALFREDO RUIZ HUERGA / Alamy Stock Photo: 21a
amana images inc. / Alamy Stock Photo: 34b
Andreas Thaller / Alamy Stock Photo: 44
Benoneimages / Alamy Stock Photo: 77
blickwinkel / Alamy Stock Photo: 26
Cavan Images / Alamy Stock Photo: 41c
CBW / Alamy Stock Photo: 35a
Christian Kober 1 / Alamy Stock Photo: 50
Clarence Holmes Photography / Alamy Stock Photo: 43b
Colin Harris / era-images / Alamy Stock Photo: 23b
Colouria Media / Alamy Stock Photo: 76a
Dennis Hallinan / Alamy Stock Photo: 12
Design Pics Inc / Alamy Stock Photo: 17d, 23a, 27a
dpa picture alliance / Alamy Stock Photo: 51
Fairgrieve / Alamy Stock Photo: 67a
frans lemmens / Alamy Stock Photo: 41b
Friedrich von Hörsten / Alamy Stock Photo: 29a
Gaertner / Alamy Stock Photo: 36c
Glasshouse Images / Alamy Stock Photo: 76b
H. Mark Weidman Photography / Alamy Stock Photo: 37c
Homer Sykes / Alamy Stock Photo: 37b
Image Professionals GmbH / Alamy Stock Photo: 20b
Imaginechina Limited / Alamy Stock Photo: 39b
inga spence / Alamy Stock Photo: 38
insta_photos / Alamy Stock Photo: Cover A
Ionut David / Alamy Stock Photo: 42
James Schwabel / Alamy Stock Photo: 43a
Jeff March / Alamy Stock Photo: 5c
Jeffrey Isaac Greenberg 15+ / Alamy Stock Photo: 67b
Jeffrey Isaac Greenberg 19+ / Alamy Stock Photo: 60
Jim West / Alamy Stock Photo: 24
john rensten / Alamy Stock Photo: 57a
John Sirlin / Alamy Stock Photo: Cover C, 37a, 40c
Jonas Nickel / Alamy Stock Photo: 41a
jonathan nguyen / Alamy Stock Photo: 36a
Ken Gillespie Photography / Alamy Stock Photo: 40b
Kevin Eaves / Alamy Stock Photo: 61
Larry Gibson / Alamy Stock Photo: 22a
Lee Rentz / Alamy Stock Photo: 29c, 39a
Loes Kieboom / Alamy Stock Photo: 45b
Marta Demarteau / Alamy Stock Photo: 34a
Martin Valigursky / Alamy Stock Photo: 20a
MBI / Alamy Stock Photo: i, iii
Melanie Blanding / Alamy Stock Photo: 21b
Menno van der Haven / Alamy Stock Photo: 5b, 35b
Michael Willis / Alamy Stock Photo: 45a
Mike Cavaroc / Alamy Stock Photo: 22b
Mike P Shepherd / Alamy Stock Photo: 30
NASA: 67d
National Weather Service: 7c
NOAA: 69, 71a
NOAA Central Library Data Imaging Project: 7a-b
Oleksandr Kharchenko / Alamy Stock Photo: 58b
Organics image library / Alamy Stock Photo: 18
PAINTING / Alamy Stock Photo: 66a
Pande Putu / Alamy Stock Photo: 58a
Phil Degginger / Alamy Stock Photo: 8
PhotoStock-Israel / Alamy Stock Photo: 29b, 56
Pictorial Press Ltd / Alamy Stock Photo: 28
Piotr Wytrążek / Alamy Stock Photo: 27b
Prostock-studio / Alamy Stock Photo: 78
Radharc Images / Alamy Stock Photo: 62
Rainer Lesniewski / Alamy Stock Vector: 59
Ron Niebrugge / Alamy Stock Photo: 4
Rvo233 / Alamy Stock Photo: 36b
Science Photo Library / Alamy Stock Photo: 66b
Sengupta, M., Y. Xie, A. Lopez, A. Habte, G. Maclaurin, and J. Shelby. 2018. "The National Solar Radiation Data Base (NSRDB)." Renewable and Sustainable Energy Reviews 89 (June): 51-60: 17a-c
Sergey Borisov / Alamy Stock Photo: 40a
Simon Dannhauer / Alamy Stock Photo: 54-55
Stocktrek Images, Inc. / Alamy Stock Photo: 68, 70
Sueddeutsche Zeitung Photo / Alamy Stock Photo: 66c
Thom Lang / Alamy Stock Photo: 13
Tim Gainey / Alamy Stock Photo: 35c
Tim Graham / Alamy Stock Photo: 34c
tmyusof / Alamy Stock Photo: 19
Tony Watson / Alamy Stock Photo: 6
Travel Wild / Alamy Stock Photo: 21c
Vova Pomortzeff / Alamy Stock Photo: 16
World History Archive / Alamy Stock Photo: 57b
Zoonar GmbH / Alamy Stock Photo: 5a

CKSci™

Core Knowledge Science™

A comprehensive program in science, integrating topics from Earth and Space, Life, and Physical Sciences with concepts specified in the ***Core Knowledge Sequence*** (content and skill guidelines for Grades K–8).

Core Knowledge Science™
units at this level include:

Light and Matter
Thermal Energy
Weather, Climate, and Water Cycling
Plate Tectonics and Rock Cycling
Natural Hazards
Cells and Systems

www.coreknowledge.org

ISBN: 978-1-68380-787-2

Core Knowledge Curriculum Series™