Atmospheric Circulation and Winds

Session Time: Three, 50-minute session(s)

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

All weather is the result of heat exchange; as a result, the uneven distribution of energy provided by the sun is the driver of the earth's weather.

The unequal distribution of heat causes air pressure variations that seek to balance, causing atmospheric circulation and wind.

As air moves, it is subject to forces that create complex circulation patterns.

ESSENTIAL QUESTIONS

1. What makes air move?

LEARNING GOALS

Students Will Know

- Solar radiation is unequally distributed between the earth's equator and its poles.
- Unequal heating leads to pressure differentials in the atmosphere.
- Pressures seeking to equalize causes circulation in the atmosphere (wind).
- Air in circulation is diverted by the Coriolis force.

Students Will Be Able To

- *Summarize* the role of uneven heating on the creation of weather. (DOK-L2)
- *Connect* convective currents resulting from uneven heating to the creation of turbulence. (DOK-L4)
- *Summarize* large scale circulation patterns in the atmosphere. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students will fill in and assess their weather diary, first started in Unit 1, Section A, Lesson 1, and then assess the current conditions to determine whether it's a good day to fly.

Formative Assessment
Students will complete Student Activity 3, a worksheet asking questions about air movement, heat, air circulation patterns, and the sun's uneven heating of the earth.

Summative Assessment
Students will complete Student Activity 5, a worksheet that includes a scenario-based question in which students apply what they have learned about weather to make the best flight plan.

LESSON PREPARATION

MATERIALS/RESOURCES

- Atmospheric Circulation and Winds Presentation
- Atmospheric Circulation and Winds Student Activity 1
- Atmospheric Circulation and Winds Student Activity 2
- Atmospheric Circulation and Winds Student Activity 3
- Atmospheric Circulation and Winds Student Activity 4
- Atmospheric Circulation and Winds Student Activity 5
- Atmospheric Circulation and Winds Teacher Notes 1
- Atmospheric Circulation and Winds Teacher Notes 2
- Atmospheric Circulation and Winds Teacher Notes 3
- Atmospheric Circulation and Winds Teacher Notes 4
- Atmospheric Circulation and Winds Teacher Notes 5
- Student Daily Weather Diary

Student Activity 1: Convection in Action (Per Group)

- Wide, heat safe glass container, such as a baking dish
- 8-12 plastic cups used to create a stand for the glass container
- 1 smaller (shorter) plastic cup to use as a candle stand
- Cool water
- 1 small candle
- Matches or lighter
- Metric ruler
- Food coloring
- Eye dropper
- Stopwatch

Student Activity 2: Uneven Heating (Per Group)

- 3 sheets (approx. 18–24”) of white paper
- Flashlight
- Metric ruler
- Protractor
- Pencil

Student Activity 4: Coriolis Force Activity (Per Group)

- Circular paper disk
- Ruler or straight edge

- Pencil
- Push pin
- Cardboard backing

Student activity 5: Summative Assessment (Per Class)

- Globe or world map
- Yarn and tape

LESSON SUMMARY

Lesson 1: Makeup of the Atmosphere
Lesson 2: Atmospheric Circulation and Winds
Lesson 3: Clouds and Precipitation
Lesson 4: Air Masses and Fronts
Lesson 5: Thunderstorms

The lesson begins with the standard warm-up for the unit, in which students refer to their daily weather logs and answer questions about the current weather and its likely effect on flight safety. This classroom discussion will encourage students to analyze the weather and its effect on visibility, turbulence, wind, and other factors related to flight safety.

During the next part of the lesson, students will learn about convection and uneven heating—both of which play crucial roles in weather—by completing several hands-on activities. Students will learn that the uneven heating of the earth's surface by the sun, and the resultant air circulation, produces areas of high and low pressure that are the root causes of most weather. A formative assessment will then evaluate students' understanding of these topics.

The lesson will then focus on wind, defined as the movement of air between areas of different atmospheric pressures, and the Coriolis effect, which explains why wind does not blow in a straight line between areas of high and low pressure.

Graphical depictions of weather, such as a Surface Analysis Chart, will then be introduced to show how differing pressures produce pressure gradients. Students will also learn how wind direction and speed can be predicted based on knowledge of these gradients and the location of high and low pressure areas, and how three forces—pressure, friction, and the Coriolis Force— influence the speed and direction of winds at the earth's surface. In this context, the lesson will also explain sea breezes and land breezes.

Next, students will learn about mechanical turbulence, with an emphasis on the vertical movement of air caused by terrain and other disruptions on the earth's surface. Wind shear, the abrupt change in the speed or direction of the wind, will also be discussed, along with its importance to pilots. A video on microbursts will be shown to demonstrate the extreme effects of severe convection and the resultant downdrafts.

Finally, students will answer related questions drawn from the FAA Private Pilot Knowledge Exam. In a summative assessment, students will be asked to recap and apply what they have learned in the lesson.

BACKGROUND

Understanding how weather affects flight is one of the essential skills required of pilots. Wind, clouds, precipitation, and thunderstorms are the common weather phenomena that have the greatest impact on flight safety. Weather is caused by the sun's uneven heating of the earth and the resulting effects on moisture in the earth's atmosphere. Pilots must know how to use available weather services to help form an understanding of the weather situation and make better flying decisions.

Weather has been a major factor in aviation since the Wright Brothers first flew their "aeroplane" at Kitty Hawk in 1903. In those first years of flight, wind was the major factor, since aircraft weren't sophisticated enough to fly in clouds or reduced visibility; pilots merely attempted to achieve sustained flight above the ground. Wind pushing these light aircraft up, down, and sideways caused many pilots to lose control and crash.

It soon became clear that, for aviation to achieve its potential, pilots and aircraft designers needed to have a deeper understanding of weather and its impact on flight safety. Many died during those years as a result of the spatial disorientation caused by "flying blind" in clouds and bad weather.

During the following years, the science of meteorology was formalized, and pilot training soon included an extensive study of weather and its effects on flight. Improvements in instrumentation soon made it possible for pilots to fly safely in clouds, but it was still vital for pilots to understand the basics of weather theory and to learn to predict when the weather might create conditions in which it was simply too dangerous to fly.

Fortunately, the science of aviation weather has progressed quickly. Today, all pilots are schooled in weather theory and possess at least a working understanding of weather formation and the implications of different kinds of weather for flight. Pilots are taught how to use available weather reporting and forecasting data to make appropriate "go/no-go" decisions concerning flight. Avoiding dangerous weather scenarios is a top priority for good pilots, and their understanding of the causes and characteristics of various weather phenomena helps keep them safe.

MISCONCEPTIONS

To students, weather may appear to be a mysterious force, driven by a wide variety of environmental factors. Students may not realize that all weather, even winter weather like snowfall, is driven by the sun and a relatively few, simple physical principles well-understood by meteorologists. At its most basic level, the sun's uneven heating of the earth's surface is the driving force behind all weather phenomena.

Another misconception about weather, especially as it relates to aviation, is to associate weather solely with storms and consequently assume that all weather events are bad for flying. In truth, some weather events can be helpful; pilots often look for certain weather conditions to help make flying faster, more efficient, or even more fun. Pilots may seek out weather that provides a tailwind: a wind that pushes the aircraft from behind, enabling it to fly faster, get to the destination sooner, and save fuel. Glider pilots often look for turbulence and lifting air, conditions that enable them to fly higher and remain aloft longer. The best pilots use their knowledge of weather to their advantage for better, safer, and faster flights.

DIFFERENTIATION

To help students organize and retain information, consider providing a notes sheet that includes key graphics from the presentation with some or all of the labels removed. Students can then write in the labels as the material is covered in each slide.

LEARNING PLAN

ENGAGE

Teacher Material: Atmospheric Circulation and Winds Presentation
Student Material: Student Daily Weather Diary

Slides 1-3: Introduce the topic and learning objectives of the lesson.

Slide 4: Conduct the **Warm-Up**.

Warm-Up

Ask: Is today a good day to fly?

Discuss the day's weather. Students should refer to the weather diary they started in Unit 1, Section A, Lesson 1.

Questions for discussion:

Will there be rain or other precipitation? Will there be strong winds or turbulence? Will the atmosphere be stable or unstable? Would you feel comfortable flying in today's weather? Why or why not?

Answers will vary based on the actual weather conditions.

[DOK-L2; *observe, describe*]

EXPLORE

Teacher Materials: Atmospheric Circulation and Winds Presentation**,** Atmospheric Circulation and Winds Teacher Notes 1
Student Material: Atmospheric Circulation and Winds Student Activity 1

Slide 5: One of the most important drivers of weather is a physical process called *convection*. Convection is the circulatory action of fluids, including gases. Heated air rises into the atmosphere where it cools, causing it to descend back toward the surface of the earth. This process creates patterns of rising and sinking air. (The same process happens with water in the ocean.) Convection is responsible for the development of clouds, thunderstorms, rain, and most weather relating to precipitation.

Slide 6: Distribute **Atmospheric Circulation and Winds Student Activity 1** and divide students into small groups; each group should follow the procedure outlined in the activity and answer the questions. (Sample answers are located in **Atmospheric Circulation and Winds Teacher Notes 1**.) Students should note that as the water is heated it becomes less dense, rises, and forms an area of lower pressure. The denser, cooler fluid nearby is then drawn into the low-pressure area, where it is itself heated and rises, drawing yet more surrounding fluid into the low-pressure region and creating a circulating motion. As long as heat is applied, the circulating motion will continue. Convection is an important factor in weather, creating clouds, precipitation, and turbulence.

Slide 7: Just as the heat from the candle provided the energy needed to begin convection in the activity students just completed, the sun provides the energy that causes the earth's weather to form and change. But not all the energy that enters the earth's atmosphere ends up in the same place.

Of the energy that reaches the planet's surface, some is reflected back into space; the rest is absorbed by the land, plants, and water that form the surface of our planet. This energy is used to fuel plant and animal life; it also warms the earth's diverse surfaces and its atmosphere, driving weather processes. Because the earth is a constantly rotating sphere, sunlight strikes and is reflected from the ground at different angles, warming the planet's surfaces and atmosphere differently at different locations. This uneven heating of the earth is the root cause of all weather.

Slide 8: The graphic illustrates the ways in which incoming solar radiation, or energy, is distributed across the earth. Thicker arrows represent greater amounts of solar energy, in the form of light or heat. Less than half the incoming solar energy is absorbed by the planet's surface, while the rest is either absorbed in the atmosphere or reflected back into space. Note that the earth also releases, or emits, heat into the atmosphere, and greenhouse gases in the atmosphere (such as carbon dioxide, methane, and water vapor) reflect most of this emitted heat back to the earth.

Slide 9: Remind students of the hot-air balloon experiment they conducted in the ninth-grade class. In the course of that lesson they learned that when air is heated it becomes less dense.

When air is heated, the various gaseous molecules that comprise the air are energized and push outward from each other. When there are fewer molecules in a given space, the density of that space decreases. Therefore, heated air is less dense. The result of this lower density and lower pressure is that heated air rises above, or "floats" on, the surrounding cooler air.

We see these effects every day. Smoke from a fire rides upward on the heated air created by the flames. Hot air balloons float upward because the heated air in the balloon is less dense than the air outside the balloon. (In other words, the weight of the air inside the balloon is lower than the weight of an equal volume of cool air outside the balloon.) This movement of air as a result of being heated is the beginning of all weather on Earth.

Questions

What would happen if you flew into a column of heated air?

You would experience the rising air as turbulence, sort of like running a car over a road full of potholes. The turbulence would probably be light, but it could be severe or even dangerous, depending on the conditions. If the updrafts caused by the rising air were strong enough, they would cause the airplane to climb, the same way birds ride "thermals" to higher altitudes without flapping their wings.

Slide 10: Rising air can be captured by airplanes and birds to improve flight performance and save energy, as illustrated in this video.

- "Birds' Secret to Soaring Super High" (Length 3:08)
  https://video.link/w/Najp

For those who cannot use Safe YouTube links, the video can also be found here: https://www.youtube.com/watch?v=V6tu7dL_MZE

EXPLAIN

Teacher Materials: **Atmospheric Circulation and Winds Presentation**, **Atmospheric Circulation and Winds Teacher Notes 2**, **Atmospheric Circulation and Winds Teacher Notes 3**, **Atmospheric Circulation and Winds Teacher Notes 4**
Student Materials: **Atmospheric Circulation and Winds Student Activity 2**, **Atmospheric Circulation and Winds Student Activity 3**, **Atmospheric Circulation and Winds Student Activity 4**

Slide 11: As rising air creates an area of low pressure, higher pressure air will move into the area as the pressure tries to equalize. This movement of air creates wind. As air is drawn into a low-pressure area, it rises. The air then fans out near the top of the lower pressure area, moving outward and diverging.

High pressure areas do the opposite. In areas of high pressure, air comes together, or converges, near the top of the pressure area; it then sinks (also called subsidence) to near ground level and pushes outward toward lower pressure air in an effort to equalize.

This constant flow of air from areas of high pressure toward areas of lower pressure is what causes wind and moves air masses over great distances. But how do these regions of different pressure form in the first place? The answer comes from the shape of the earth and its interaction with the sun.

Slide 12: Sunlight strikes the earth at different angles at different locations. The most direct—and therefore most intense—sunlight strikes at the equator; the least direct and least intense sunlight strikes at the poles.

When the sun's energy hits at the equator, it is absorbed over a relatively small area, thus generating more heat. Going north and south toward the poles, the sunlight hits the earth at an increasing angle, spreading over a wider area and generating less heat.

Another cause of differential heating is terrain. Land heats faster than water, so land areas tend to be warmer than oceans and large lakes.

As previous slides have explained, differential heating is the root cause of pressure differences and the subsequent movement of air across the earth.

Distribute A**tmospheric Circulation and Winds Student Activity 2** and divide students into small groups; each group should follow the procedure outlined in the activity and answer the questions. Sample answers are located in **Atmospheric Circulation and Winds Teacher Notes 2**.

Slide 13: The movement of air is not restricted to small, localized areas. Air also moves across the entire Earth, from the equator to the north and south poles and back again.

As the air at the equator heats, it rises, creating a low-pressure area. As it rises, the warm air moves toward the closest pole where it cools, sinking and forming a zone of relatively higher pressure. This cooler air then flows back toward the equator to complete the cycle, and the circulation pattern starts again.

This circulation pattern is responsible for the trade winds in the tropics as well as much of the weather at or near the equator.

Slide 14: Complete the **Formative Assessment**.

Formative Assessment

To check for understanding, distribute a copy of **Atmospheric Circulation and Winds Student Activity 3** to each student. Correct responses are provided in **Atmospheric Circulation and Winds Teacher Notes 3**.

[DOK-L2; *describe*]

Slide 15: If the earth did not rotate, winds would blow in a straight line from high pressure to low pressure areas. In fact, the earth's rotation has a significant effect on winds. So does the fact that the planet is a sphere: fatter at the equator and tapering in each direction toward the poles. Consider:

- Every point on the planet's surface must complete one rotation in the same amount of time: it does not take longer for a point at the equator to rotate than for a point at the North Pole.
- However, a point at the equator must travel a much greater distance to complete its rotation than a point at the North Pole must travel.
- Therefore, a point at the equator must be rotating more quickly than a point at the North Pole, and the closer one moves to the equator, the more quickly the earth rotates.

This discrepancy in the speed at which the earth rotates, depending on one's location relative to the equator, has a profound effect on the movement of wind. The name for this effect is the Coriolis effect. The Coriolis effect causes air to deflect either to the left or right, depending on the hemisphere in which it is moving. It can be a difficult concept to grasp, so watch this video for a more detailed explanation.

- "Coriolis Effect" (Length 2:57)
  https://video.link/w/XVwp

For those who cannot use Safe YouTube links, the video can also be found here: https://www.youtube.com/watch?v=mPsLanVS1Q8

As the video shows, when the ball is thrown from one side of the rotating merry-go-round to the other side, it appears to bend or deflect in the direction opposite the direction of rotation. (In fact, the ball has continued to travel in a straight line, but the rotation of the merry-go-round carries someone new into the ball's path.) Applying this concept to the rotating Earth and its atmosphere: As wind blows from the North Pole south toward the equator, it moves from a region rotating more slowly to a region rotating more quickly. Thus, the wind will appear to be deflected as it moves, though in fact it is the ground below the wind that is spinning more quickly.

The Coriolis effect causes wind to deflect to the right in the northern hemisphere and to the left in the southern hemisphere. Remember, "left" and "right" are relative to the direction the wind is moving, so a wind moving from the North Pole toward the equator and a wind moving from the equator to the North Pole will deflect in opposite directions.

Slide 16: Place students in groups of three or four and distribute **Atmospheric Circulation and Winds Student Activity 4** to each student. In this activity, students will simulate the Coriolis effect. Correct responses to the analysis questions are provided in **Atmospheric Circulation and Winds Teacher Notes 4**.

The following video illustrates how this activity should happen:

- "Mr. Aubrey explaining how to demonstrate Coriolis Effect" (Length 1:00)
  https://video.link/w/mjzp

For those who cannot use Safe YouTube links, the video can also be found here: https://www.youtube.com/watch?v=7DVL0ugj1O4

Slide 17: Recall that a few slides ago we discussed how air at the equator rises, moves toward the poles, cools, sinks, and moves back toward the equator, forming a circulatory pattern? This is an oversimplification. Air at the equator does not move *all the way* to the poles and back, forming a single circulation cell in each hemisphere. In fact, there are six circulation cells: three in the Northern Hemisphere, and three in Southern Hemisphere.

Each of these cells covers approximately 30 degrees of latitude. (The equator is located at 0 degrees, while each pole is located at 90 degrees.) Within each cell, a specific wind pattern tends to dominate, creating what are called *prevailing winds* that produce distinctive weather patterns and climates (as illustrated in the graphic). The term *prevailing winds* refers to the direction the wind generally blows at a given location. At the latitudes found in the United States, the prevailing winds tend to blow from west to east; therefore, they are called *westerlies*. Closer to the equator, winds tend to blow from east to west; these winds are called the "trade winds," partly for their role in enabling early explorers to sail from Europe to the Americas.

Slide 18: As discussed earlier, air moves from areas of high pressure to areas of low pressure in an effort to equalize. Consider these scenarios:

- When you suck on a straw, you're lowering the pressure in the straw. The atmospheric pressure pushing down on the soda in the cup tries to equalize by pushing the soda toward the lower pressure in the straw.
- When you untie an inflated balloon, the higher pressure in the balloon tries to equalize with the lower pressure outside; the balloon deflates, releasing air until the pressure inside and outside the balloon are the same.
- When you pick up a hot spoon and hold it in your hand, the higher heat of the spoon flows into your hand in an effort to equalize. At some point, the heat of your hand equals the heat of the spoon and it no longer feels hot.

All these are examples of energy flowing from an area of high energy to an area of lower energy. There are dozens more such examples in everyday life, and the principle is always the same: energy flows in one direction only—from high to low. This principle explains the relationship between atmospheric pressure and wind. Just as the air in the deflating balloon moves from the area of higher pressure (inside the balloon) to the area of lower pressure (outside the balloon), air in the atmosphere does the same thing. Areas of high pressure will try to equalize with areas of low pressure; air at high pressure will move toward air at low pressure until pressure in the regions is equivalent.

The graphic illustrates how the Coriolis effect causes air to deflect as it moves from one pressure zone to another.

Slide 19: Wind doesn't flow directly from an area of high pressure to an area of low pressure; it takes a curved path. Why? Just as the Coriolis effect changes the global movement of air, it also affects air movements on smaller scales: for example, over hundreds of miles. Remind students that they learned about vectors in the tenth grade when they covered the four forces of flight. The Coriolis effect creates a vector that pulls air from the direct path it would normally travel as it moves from areas of high to low pressure.

The graphic illustrates the concept of pressure gradient force, according to which the pull toward a region of low pressure is diverted by the Coriolis effect (which pulls toward the right in the Northern Hemisphere). The resulting airflow from an area of high pressure is a clockwise spiral away from the high-pressure zone and toward the low-pressure zone. Around the low-pressure zone, the forces balance so that the flow toward low pressure follows a similar spiral, but in a counterclockwise direction. This is what gives hurricanes (an area of intense low pressure) their characteristic rotation.

EXTEND

Teacher Material: [Atmospheric Circulation and Winds Presentation]

Slide 20: Weather scientists create maps of pressure areas for use by pilots and others. These maps depict areas of high and low pressure, as well as numerical values for pressure. Some maps also include depictions of weather fronts to provide a more complete view of weather phenomena.

The squiggly lines on these maps are called isobars, and they indicate lines of equal atmospheric pressure. The pressure is the same at all points along each line. Different lines depict different pressures.

The space between lines is an indication of the pressure gradient: how fast the pressure is changing. Lines that are close together depict a quickly changing pressure gradient: they indicate wind. The closer the lines are together, the stronger the wind. Lines that are spaced far apart indicate a shallow pressure gradient, with little or no wind.

Unlike winds close to the surface, winds at higher altitudes (winds aloft) tend to follow the direction of the isobars.

The numbers next to the lines show the atmospheric pressure, expressed in millibars. The higher the number, the higher the pressure, and vice versa.

The letter "H" on the map indicates an area of high pressure, while "L" indicates an area of low pressure. Air will flow from the high toward the low, with a rightward deflection in the Northern Hemisphere, due to the Coriolis effect.

Pilots use these maps and many others when planning long distance flights. The information contained on these maps enables pilots and planners to choose routes with the most favorable winds and conditions, and avoid those areas that are less conducive to efficient and comfortable flight.

Slide 21: Friction is the resistance to movement caused by physical contact between two substances. As wind passes over the ground, friction results, causing the wind to slow down. This friction is most evident at low altitudes, from the ground up to about 4,000 feet.

In addition to ground friction, terrain features and buildings can create additional friction, further slowing and disturbing the air flow. Hills, mountains, trees and structures can all contribute to friction, and may redirect the horizontal flow of the wind upward, creating turbulence and atmospheric instability.

Winds tend to increase in speed with altitude, with the strongest winds being at the higher altitudes, as shown in the graphic. (Longer arrows represent faster winds.) Pilots often plan the altitudes at which they fly based on the winds, seeking the altitude that will provide the most advantageous conditions for flight.

Slide 22: Three important factors affect wind speed and direction:

1. Pressure gradient

2. Friction

3. Coriolis effect

The pressure gradient is the force that pushes air from high pressure areas to regions of lower pressure. The faster the pressure changes over distance (the closer the isobars), the stronger the wind will blow. In areas where pressure is more or less similar, little or no wind is usually present. Air needs a force to get it moving, and the pressure gradient provides that force.

Friction is the resistance to movement that the earth's surface exerts on the air, causing it to slow down at and near the surface. As the wind speed near the ground decreases from friction, the Coriolis effect weakens and can no longer balance the pressure forces. Unlike winds aloft, which tend to follow the isobar lines, surface winds are more affected by the pressure gradient force than by the Coriolis effect; as a result, surface winds blow at an angle (approximately 30 degrees) across the isobars toward the low-pressure area.

Slide 23: Meteorologists produce maps that depict wind direction and speed in graphical format for easy interpretation by pilots and others who need wind data for planning. (A Surface Analysis Chart, for example, depicts winds at ground level.) The most commonly used symbol to depict wind direction and speed on these maps is an arrow, with feathers at one end and a filled circle on the other (the circle is omitted in some presentations). The direction of the wind is indicated by the feathered end. Wind is shown as blowing FROM the feathers TO the tip or circle.

The feathers themselves depict wind speed. A triangle feather represents 50 knots of wind. A long-line feather is 10 knots, and a short-line feather is 5 knots. The feathers are added together to determine wind speed.

Knowing the direction and speed the wind is blowing can be useful in weather forecasting. For instance, in the Northern Hemisphere, if the wind is blowing from the north, cooler air can be expected since the air is generally cooler in the northern latitudes. On the other hand, if the wind blows in from the south, warmer, moist air may be expected. Students will learn more about the characteristics of wind mapping in a later lesson.

Slide 24: Not all weather is determined by large-scale (macro) atmospheric conditions; some is highly influenced by local terrain and large bodies of water. Sea breezes are excellent examples of local weather.

If you've ever been to the ocean, you may have noticed a light wind blowing in from the sea. This is a sea breeze, a common weather pattern in coastal areas. The sea breeze is a major factor in why coastal regions tend to have more temperature stability throughout the year than inland regions.

The sea breeze cycle begins with warm air over the land rising. As the warm air rises, it cools; if it reaches its dew point, clouds may form. The cooler air is then drawn to the lower pressure area over the ocean, where it sinks back down to the surface and spreads out. As it spreads, some of the air is pushed back over the land, where it reheats, rises, and the cycle begins again.

Slide 25: Another example of a local wind pattern is the land breeze. This is the reverse of the sea breeze, and it happens because water retains heat longer than land does. During the day, the land along the shore of an ocean or lake is typically warmer than the water itself. At night, however, the land loses its heat more quickly, and thus becomes cooler, than the nearby ocean or lake.

When this happens, the warmer air over the ocean rises, creating an area of lower pressure. The cooler, denser air over the land is drawn out toward the ocean and the area of lower pressure. As the air warms again, it rises and spreads out, starting the cycle again.

Questions

Many areas have local weather that is not typical of broader wind and weather patterns. Can you think of any weather where you live that is unique to your area?

Possible answers: fog, especially in coastal, valley, or low-lying areas; lake effect snow in the Great Lakes region; thunderstorms in the mountains and prairies; tornadoes in the central part of the country; the Santa Ana winds in Southern California

Slide 26: Mechanical turbulence is the result of wind flowing over terrain or ground-based obstacles and being deflected upward, downward, or sideways. This disturbance to the normal air flow is experienced by pilots as a disruption to smooth flight, and it can be light, moderate, severe, or extreme.

To envision how mechanical turbulence works, think about water flowing over stones in a creek. As the water approaches a stone it is deflected upward, then downward as it passes over the stone and proceeds on its way. Some water is also deflected to the side of the stone, creating ripples and swirls in the water. Some water speeds up as it passes between two adjacent stones, then fans out on the other side, creating circular eddies. That is exactly how air behaves when disturbed by obstacles on the Earth's surface.

Wind approaching hills or mountains is deflected upward, creating updrafts that can push an aircraft to higher altitudes or create an unstable ride. As the wind passes over the lee side of a mountain, downdrafts or rotors are created, forcing the aircraft downward. In areas of multiple ridges, conflicting updrafts, downdrafts, and side loads can create a confusion of rising and sinking air, and can push the aircraft left and right in sudden, unpredictable motions.

The same can occur when wind passes over or between buildings or trees. This type of turbulence is usually light to moderate, and is normally associated with low-altitude flight. In contrast, mechanical turbulence caused by terrain, such as mountains, can extend many thousands of feet above the ground, and can be very disruptive to flight. Severe mechanical turbulence has been known to cause pilots to lose control of their aircraft and, in some cases, crash. Pilots are trained to anticipate turbulence based on the weather information they receive during their pre-flight briefings and in-flight weather updates. Being able to predict where the turbulence might be most disruptive enables a good pilot to avoid those areas, change planned altitudes, or otherwise minimize the effects of the turbulence.

Slide 27: This video provides additional information about turbulence and how it happens.

- "Turbulence Explained" (Length 7:37)
  https://video.link/w/Eb1p

For those who cannot use Safe YouTube links, the video can also be found here: https://www.youtube.com/watch?v=DMDXAcI2IrM

Slide 28: Wind shear is a major concern to pilots, especially during takeoffs and landings. Flight training includes an intensive study of the causes and dangers of low-level wind shear, as well as the steps pilots can take to avoid it, or deal with it should it occur.

Wind shear is any sudden change in the speed or direction of the wind. Airplanes depend on air flowing over the wings to provide lift, so any change in that airflow can change the amount of lift and severely affect flight safety.

Most wind shear is relatively minor and experienced as momentary, light turbulence. At cruise speeds, it is hardly noticed and creates no real challenges to flight. Depending on the type and severity of the shear, it can cause the airplane to speed up, slow down, or change altitude (climb or descend).

If, for example, the wind suddenly shifts from a headwind to a tailwind, there will be less air flowing over the wings, the airspeed will drop, and the airplane will lose lift. If such a shear occurs when close to the ground, the airplane could strike the earth before the pilot can recover, resulting in a hard landing or even a crash.

On the other hand, if the wind shears from a calm wind to a strong headwind, the airflow over the wings would increase, resulting in an increase in airspeed and lift. In this case, the airplane would climb; generally, a less dangerous situation.

Sometimes the wind shear comes from the side, resulting in a rapidly-changing crosswind condition. These types of wind shears have the capacity to push an airplane off the runway during takeoff or landing. Crosswind shears can be quite dangerous and can make it difficult for the pilot to maintain control.

The worst, strongest wind shears come from a weather phenomenon known as a microburst. Microbursts are relatively rare, but very dangerous; they are sometimes called "wind bombs." Microbursts occur in thunderstorms. They produce extremely strong downdrafts and rapidly changing wind shears, causing an airplane to first climb, then descend, then descend even more rapidly. Depending on the plane's altitude, it may crash into the ground before the pilots can recover. We'll cover microbursts in a future lesson, but for now just remember that microbursts can cause catastrophic wind shear-related accidents, especially during the landing phase of flight.

This video recreates a deadly accident caused by a microburst.

- "This is why you don't want to fly into a microburst"
  https://video.link/w/S82p (Length 3:44)

For those who can't access Safe YouTube links, the video is also available here: https://www.youtube.com/watch?v=HDfodeURad0

EVALUATE

Teacher Materials: Atmospheric Circulation and Winds Presentation, Atmospheric Circulation and Winds Teacher Notes 5
Student Material: Atmospheric Circulation and Winds Student Activity 5

Slides 29-34: Private Pilot Knowledge Exam Questions

Slide 35: Conduct the **Summative Assessment**. See **Atmospheric Circulation and Winds Student Activity 5**.

Summative Assessment

Students will refer to **Atmospheric Circulation and Winds Student Activity 5** and answer the questions.

[DOK-L3; *hypothesize*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Student work shows evidence that the student understands the following:
    - Solar radiation is unequally distributed between the Earth's equator and its poles
    - Unequal heating leads to pressure differentials in the atmosphere
    - Pressures seeking to equalize causes circulation in the atmosphere (wind)
    - Air in circulation is diverted by the Coriolis force
- Contributions show in-depth thinking including analysis or synthesis of lesson objectives

Points **Performance Levels**

9-10 Answers at least 10 of the questions correctly. Responds to written response questions using full sentences that reflect full understanding of the lesson objectives.
7-8 Answers 8-9 of the questions correctly. Responds to written response questions using full sentences. There are minor gaps in understanding of the lesson objectives.
5-6 Answers 6-7 of the questions correctly. Many written response questions don't have clear or full-sentence answers. There are many gaps in understanding of the lesson objectives.
0-4 Answers fewer than 6 of the questions correctly. Written response questions are incomplete. There is a lack of understanding of the lesson objectives.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-Dimensional Learning

- **HS-ESS2-3** - Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.
    - Science and Engineering Practices
        - Developing and Using Models
    - Disciplinary Core Ideas
        - ESS2.A: Earth Materials and Systems
    - Crosscutting Concepts
        - Energy and Matter

COMMON CORE STATE STANDARDS

- **RST.9-10.2** - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.4** - Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.
- **WHST.9-10.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

REFERENCES

Birds' Secret to Soaring Super High: https://www.youtube.com/watch?v=V6tu7dL_MZE, https://video.link/w/Najp
Coriolis Effect: https://www.youtube.com/watch?v=mPsLanVS1Q8, https://video.link/w/XVwp
Mr. Aubrey explaining how to demonstrate Coriolis Effect: https://www.youtube.com/watch?v=7DVL0ugj1O4, https://video.link/w/mjzp
Turbulence Explained: https://www.youtube.com/watch?v=DMDXAcI2IrM, https://video.link/w/Eb1p

This is why you don’t want to fly into a microburst: https://www.youtube.com/watch?v=HDfodeURad0, https://video.link/w/S82p