Clouds and Precipitation

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

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Clouds are part solid, part liquid water, and part invisible water vapor; they form when the air is saturated.

A small spread between the temperature and dew point signifies saturation of the air and likely formation of clouds.

Atmospheric stability is a measure of air's ability to resist vertical motion and is a prime indicator of the type of clouds, precipitation, turbulence, and visibility that pilots will experience.

ESSENTIAL QUESTIONS

1. Why do clouds form?
2. Why are there different types of clouds?

LEARNING GOALS

Students Will Know

- How atmospheric stability affects flying.
- What causes clouds.
- How clouds are associated with precipitation.
- Conditions causing different types of fog.
- The significance of an inversion.

Students Will Be Able To

- *Categorize* different types of clouds. (DOK-L2)
- *Predict* weather conditions based on cloud type. (DOK-L2)
- *Predict* the height of a cloud base. (DOK-L2)
- *Assess* if the freezing level will affect a flight. (DOK-L3)
- *Differentiate* among different types of precipitation. (DOK-L3)

ASSESSMENT EVIDENCE

Warm-up
Students will complete their daily weather diaries and discuss current weather conditions and compare the day's weather with the week's weather.

Formative Assessment
Students will look up the current local temperature and dewpoint to calculate the estimated cloud base elevation. Students will then calculate this value and then answer the questions that summarize material up to this point in the lesson.

Summative Assessment

Students will identify cloud types by looking at images of different clouds. Next, students will answer questions about precipitation.

LESSON PREPARATION

MATERIALS/RESOURCES

- Clouds and Precipitation Presentation
- Clouds and Precipitation Student Activity 1
- Clouds and Precipitation Student Activity 2
- Clouds and Precipitation Student Activity 3
- Clouds and Precipitation Student Activity 4
- Clouds and Precipitation Student Activity 5
- Clouds and Precipitation Teacher Notes 1
- Clouds and Precipitation Teacher Notes 2
- Clouds and Precipitation Teacher Notes 3
- Clouds and Precipitation Teacher Notes 4
- Clouds and Precipitation Teacher Notes 5
- Student Daily Weather Diary

Dew Point and Moisture Activity (per group)

- Cup (metal is ideal, but glass or hard plastic works)
- Cup (any material) of ice-cold water
- Warm water (8 ounces at about 85 °F)
- Syringe (any type)
- Thermometer

Create a Cloud in a Bottle Activity (per group)

- Water
- Transparent plastic bottle with lid
- Matches

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

In this lesson, students will take a close look at atmospheric stability, clouds, and precipitation. The lesson will begin with a warm-up in which students examine their weather diaries, determine whether or not it's a good day to fly, and consider their current local weather pattern with regard to atmospheric stability. To help students relate the idea of atmospheric stability to concepts they have already learned, they will quickly review the three types of aerodynamic stability—positive, negative, and neutral—that they learned about in tenth grade. They will then apply these types of stability to the atmosphere. In this section they will learn about the factors that cause instability as well as the effects of temperature on stability, including the effects of temperature inversions.

In the next section of the lesson, students will focus on the role of moisture in the atmosphere. They will begin by looking at the processes of that add moisture to the atmosphere and will learn the definition and importance of dew point. Next, they will learn how to calculate cloud bases and will calculate the weight of a cloud before covering how air becomes saturated.

Next students will learn about the five different types of fog and its effects on flight safety before going on to learn about other types of clouds. In this section, students will learn about the conditions needed to form clouds, and how clouds are categorized by their altitude and vertical development. They will then learn the characteristics of different types of clouds that can form at various altitudes and the terms, such as nimbus and castellanus, that are used to describe those cloud types. Students will then perform a "cloud in a bottle" activity to help demonstrate the importance of pressure and condensation nuclei in the development of clouds. Finally, students will learn how meteorologists describe ceilings and visibility as they relate to clouds.

In the next section of the lesson, students will learn about precipitation, including the various forms it takes and how they may affect flight.

In the final section of the lesson, students will review questions from the FAA's Private Pilot Knowledge Test as they relate to what they've learned before completing a summative assessment in which they identify and describe different types of clouds and precipitation.

BACKGROUND

In tenth grade, students learned about aerodynamic stability. Recall that with positive static stability, an aircraft that is disturbed tends to return to its original attitude. With neutral static stability, an aircraft that is disturbed tends to continue in its new attitude. And with negative static stability, an aircraft that is disturbed tends to deviate further and further from its original attitude, amplifying the disturbance. Just like an aircraft has aerodynamic stability, the air in which we fly has atmospheric stability. Its stability depends on how well it resists vertical motion. Vertical movement is less likely in a positively stable atmosphere, where any disturbances tend to dampen out and disappear. Vertical movement is more likely, and occurs with greater intensity, in an unstable (negatively stable) atmosphere. Negative stability results in turbulent airflow (turbulence), vertical cloud development, and possible severe weather with convective activity.

Temperature determines if the air is stable or unstable. When warm air is on top of cooler air, the warm air tends to stay put, causing the atmosphere to remain stable. Conversely, when warm air is below cooler air, it "wants" to rise; the atmosphere becomes unstable as the warm air moves to trade places with the cooler air above it. This instability creates clouds, and the moisture content of clouds works with the air temperature to produce various types of precipitation. This lesson explores how all these variables affect aircraft and pilots.

MISCONCEPTIONS

Students may have learned most of what they know about the weather from watching forecasters on television. While television forecasts provide a sufficiently clear picture of the weather for the majority of the public, they are insufficient for fliers and the aviation industry in general. There are significantly more variables that go into mission planning and evaluating weather conditions while in flight. Students should understand, as this lesson progresses, how to better analyze and interpret weather patterns as they relate to cloud formation, atmospheric stability/instability, and precipitation.

Students might assume that clouds are water vapor, but that is not quite right: water vapor is an invisible gas. A cloud is actually what forms when water vapor condenses on tiny particles of dust or ice in the atmosphere; these particles are called *condensation nuclei*.

DIFFERENTIATION

To promote comprehension and retention, in the **EXPLORE** section of the lesson, have students take notes on air stability and the adiabatic process. Instruct them to take a piece of paper and fold it in half vertically. In the left column, have students write down the key concepts and ideas. In the right column, have students take notes, including any drawings or sketches to help them remember concepts.

LEARNING PLAN

ENGAGE

Teacher Material: Clouds and Precipitation Presentation
Student Material: Student Daily Weather Diary

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

Slides 4-6: Conduct the **Warm-Up**.

Warm-Up

Students will begin by discussing the current weather conditions of the day. Have them look at their weather diaries (started in Lesson 1) and compare the day's weather with the weather they've recorded for previous days. How is it the same or different? Then ask the students questions that prompt them to consider, based on their existing knowledge and experience, why the weather conditions are remaining the same or changing.

For example:

- If it's a rainy day, what do students think caused the clouds to form and become saturated with moisture?
- If it's a warm, sunny day, what is causing the increase in temperature and lack of clouds?
- If it's a cold day, what is causing the decrease in temperature? How are the winds (likely high in the atmosphere) affecting the temperature? How is the angle of sunlight striking the earth at this time of year affecting the temperature?

This conversation is simply to engage students in the upcoming lesson, so it is not necessary to correct any incorrect statements; instead, encourage students to write down their assumptions and ideas and check them against the information in this lesson.

Proceed to the next slide, and ask the students the following questions:

- *Is today a good day to fly?*
- *Has it been a good week to fly?*
- *Which day during the past week provided the most ideal flying conditions?*
- *Why? What aspect of the weather drove you to this conclusion?*

Again, do not expect correct answers or refute incorrect answers. The goal here is simply to challenge students to consider weather as it relates to flying and flight planning.

Proceed to the next slide. As a class, construct a simple table on the whiteboard. Start by asking the students:

- *Do you think today's weather pattern is stable or unstable?*
- *What factors might be contributing to the stability or instability in your area?*

Now create a table with two columns: one for stable air and one for unstable air. Ask students to predict how both stable and unstable air might affect a flight. Write down their predictions in the table and post where the entire class can see it. Students can refer back to these ideas as they increase their understanding throughout the lesson.

[DOK-L2; *observe, describe, explain*]

EXPLORE

Teacher Materials: Clouds and Precipitation Presentation, Clouds and Precipitation Teacher Notes 1
Student Material: Clouds and Precipitation Student Activity 1

Slide 7: Remind students that in Grade 10 (Lesson 5.A.1), they learned about aerodynamic stability, which can be negative, positive, or neutral. Ask students the following questions and discuss their responses.

Questions

What is aerodynamic stability?

Aerodynamic stability is the tendency of an aircraft to return to a condition of equilibrium (steady flight) after being displaced by pilot input on the controls or by an outside force such as wind or turbulence.

What are negative, positive, and neutral stability?

Positive stability is the tendency of an object to return to its original attitude when displaced, while negative stability moves the object farther away from its original attitude; neutral stability produces no movement either toward or away from the displacement.

Slide 8: The graphics on this slide illustrate the different types of stability. Recall that with positive static stability, an aircraft that is disturbed tends to return to its original attitude. With neutral static stability, an aircraft that is disturbed tends to continue in its new attitude. And with negative static stability, an aircraft that is disturbed tends to deviate further and further from its original attitude, amplifying the disturbance. Just like an aircraft has aerodynamic stability, the air in which we fly has atmospheric stability.

Slide 9: Atmospheric stability depends on how well air it resists vertical motion and, as with aerodynamic stability, there are three main kinds:

- Positive stability, or stable air: Disturbed air returns to its starting point, with very little vertical motion.
- Negative stability, or unstable air: Disturbed air becomes increasingly disturbed as it moves; we see this when an air mass is warmer than the surrounding air and rises.

- Neutral stability: Air stays put unless it is disturbed.

Unstable air can result in turbulence, cloud development, and hazardous weather.

Slide 10: A simpler way to think about the concept of *resistance to vertical motion* has to do with whether air tends to rise. There are four main processes that cause air to rise:

- Surface heating: The sun's rays contact the earth's surface, warming and heating the surrounding air, which then rises into the atmosphere.
- Mountains: Air traveling horizontally (i.e., as wind) is forced upward as it flows along the slopes of mountains. This process forces air upward more rapidly and aggressively than typical surface heating does, which is why aircraft often encounter turbulence over mountains (known as mountain wake turbulence).
- Convergence: This process, though less common, occurs when winds blowing in opposing directions near the earth's surface collide. The collision forces warmer air up into the atmosphere.
- Frontal lifting: This occurs along weather fronts, as incoming colder air gusts forward, lifting warmer air above it. The warmer air is pushed upward until it lifts above the front.

Slide 11: Each of these four processes is an example of atmospheric instability. Emphasize that air temperature plays a crucial role in surface heating and frontal lifting. When warm air is on top of cooler air, it "wants" to stay put, causing the atmosphere to remain stable. Conversely, when warm air is below cool air, the warm air "wants" to rise; as the air moves to trade places with the cooler air above it, the atmosphere becomes unstable.

Questions

Why do the majority of thunderstorms occur during the hotter months of the year?

The sun more directly impacts the earth's surface during the hotter times of the year. This heating of the surface causes the air near the ground to be significantly warmer than that of the cooler air above it. That hot air wants to rise, increasing the instability of the atmosphere, which causes more turbulence, cloud development, and severe weather potential.

Why do you think a warm front typically brings fair weather and a cold front brings stormy weather?

The warm front typically pushes warmer air aloft, which means the air higher in the atmosphere is warmer than the slightly cooler air on the surface; this creates an inversion, which will be explained later in the lesson. Meanwhile, the cold front adds more cool air aloft; the warm air ahead of or below the frontal boundary wants to trade places with the cold air, creating further instability. The added moisture behind the cold front further amplifies this instability and the potential for severe weather.

Slide 12: Now that students have a general understanding of stability versus instability, dig deeper into the adiabatic process, which explains the upward/downward transfer of air in the atmosphere. (*Adiabatic* refers to processes that do not involve a net loss or gain of heat. Individual air masses may warm or cool, but the overall system does not.) Adiabatic heating and cooling occur when rising warm air expands and then cools as altitude increases because atmospheric pressure decreases. Conversely, descending, cooler air compresses and warms, as altitude decreases, because atmospheric pressure increases.

Rising, warm air expands into a larger volume as it fills a lower pressure area; as the air molecules move farther apart, they lose energy, which lowers the air temperature. Said another way, when a given volume of warm air rises, its pressure continues to decrease as its volume increases, causing its temperature to decrease. The inverse is true when air descends.

Slide 13: The rate at which temperature decreases as altitude increases is known as adiabatic lapse rate. The average lapse rate typically works out to approximately a 5.5 °F decrease per 1,000 feet of altitude increase. (This average may change based on atmospheric conditions, and it does not account for inversion layers.) This rate applies as long as the water vapor in the air hasn't condensed into a cloud. Once the air is saturated with moisture (i.e., there is a cloud), the lapse rate is between 2 and 5 degrees F, depending on how much moisture was in the air.

As seen from the dashed lines on the chart on Slide 13, adiabatic lapse rates are straight lines, meaning that the air is cooling at a standard rate: 5.5 °F per 1,000 feet (or 1 °C per 100 meters) for unsaturated (dry) air. However, the environmental lapse rate—the rate at which the temperature of non-rising, or stationary, air changes with altitude at a given time and location—isn't a straight line; it varies from day to day depending on atmospheric conditions and altitude. To know what the actual environmental lapse rate is, we must measure it.

As this chart indicates, warm air rises until it reaches the dew point/condensation level, at which point it forms a cloud. The air then continues to rise until the environmental and adiabatic lapse rates converge, at which point the air temperatures will match and the rise will cease. This environmental lapse rate is important because it drives atmospheric stability.

Slide 14: While temperature affects air movement, air moisture level also affects atmospheric stability and the adiabatic process. Moist air is described as *saturated*, since the air is full of water vapor. Water vapor is lighter than air (which is why evaporated water rises into the atmosphere); therefore, as air becomes more moist, it becomes less dense and rises above drier air. Conversely, as air moisture decreases, the drier air becomes denser and sinks. However, moist air cools at a slower rate and is typically less stable than dry air; this is because the moist air must rise higher before its temperature cools to match the surrounding air. Therefore, the dry adiabatic lapse rate is greater than that of the moist adiabatic lapse rate per every 1,000 feet of altitude increase.

This combination of temperature and moisture cooperatively determine the atmosphere's overall stability and resulting weather. Cool, dry air is stable and resists vertical movement, which generally means fair, clear weather. Warm, moist air has significant vertical movement (instability); this helps to explain why daily thunderstorms are common in tropical region during the summer.

Questions

What places have you been that are good examples of atmospheric stability or instability? How did the place's location on the globe, its geography, and the season when you visited affect atmospheric stability there?

Answers will vary based on students' experiences. For example, students who have traveled to or lived in humid, tropical climates may be familiar with the instability that leads to afternoon thunderstorms. While students who have spent time in dry, temperate climates may be accustomed to the stability that produces blue skies for weeks on end.

The following video provides further explanation and clarification of the adiabatic process:

- "Adiabatic processes, lapse rates and rising air" (Length 4:38)
  https://video.link/w/Ycxp

For teachers who are unable to access Safe YouTube links, the unedited video can be found at: https://www.youtube.com/watch?v=ObnWb7yspxA Unlike the Safe YouTube link, this video is unedited and has a run time of 10:56.

Slide 15: Temperature most often decreases as air rises and expands in the atmosphere. However, an anomaly sometimes occurs which does not follow this typical pattern. As described in the video students just watched, a temperature inversion happens when air temperature *increases* with altitude. Inversion layers are commonly shallow layers of smooth, stable air that remain relatively close to the earth. The temperature of the air in the layer increases with altitude until reaching a certain point, which is the top of the inversion. This lid—the warmest air at the top of the layer—traps cool air, weather, and even pollutants underneath. If the relative humidity of the air trapped underneath is high, the inversion can also cause clouds, fog, haze, and smoke to build up, resulting in reduced visibility.

Surface-based temperature inversions often occur on cool, clear nights when the air closest to the earth is cooled by the ground's lowering temperature. This causes the air within the first few hundred feet of the ground to become cooler than the air above it. In contrast, a frontal inversion occurs either when warm air spreads over a cooler air layer, or when cooler air is forced under a warmer air layer. This explains much of the atmospheric stability that occurs behind a warm front.

Session 2

Slide 16: To begin session 2, as a class, refer back to the table from the Warm-Up to check answers against what students have learned.

Questions

As pilots, why should we care about stability versus instability?

Answers may vary, but students should note that stable air is generally smoother and easier to fly in. They may also note that very stable air can result in reduced visibility.

Based on what we have learned, would you like to change, or add to, any answers in the table?

Answers may vary, but correct answers include the following:

Effects of Stable Air
Smoother air
Less gusty (more predictable winds)
Fair to poor visibility (accumulation of particles)
Stratus/flat clouds (this will be discussed later in this lesson)
Light but continuous precipitation

Effects of Unstable Air
Turbulence (updrafts and downdrafts)
Gusty/shifting winds
Good visibility, but weather changes quickly
Cumulus/nimbus clouds (this will be discussed later in this lesson)
Heavy but less-predictable precipitation, hail, thunderstorms

Slide 17: Earth's atmosphere contains moisture in the form of water vapor; the amount of moisture depends on air temperature. The potential amount of moisture that air can hold doubles with every 20 °F increase in temperature. Conversely, a decrease of 20 °F cuts this capacity in half.

As the graphic illustrates, there are solid, liquid, and gaseous forms of water in the atmosphere. All three forms can rapidly change into another. Heat exchange occurs as water changes from one state to another through a variety of processes: evaporation (liquid to gas), sublimation (solid to gas), condensation (gas to liquid), deposition (gas to solid), melting (solid to liquid), and freezing (liquid to solid). However, the only processes that increase the amount of moisture in the atmosphere are evaporation and sublimation. (Conversely, condensation and deposition decrease the amount of moisture.)

Slide 18: Evaporation occurs when liquid water transforms into water vapor. As water vapor forms, it absorbs heat from the nearest available source. This heat exchange is known as the latent heat of evaporation. A good example of this exchange is when we sweat and it evaporates, leaving our skin feeling cooler because heat is being extracted from the body.

Similarly, though not as commonly seen in our day-to-day lives, sublimation occurs when solid water (ice) transforms directly into water vapor, bypassing the liquid stage. For an example of sublimation, think of dry ice, which turns from a solid to a gas at room temperature, without passing through the liquid stage. Another example, found in nature, is when snow cover atop a mountain sublimates directly into the atmosphere. This process requires a combination of low relative humidity, temperature, and air pressure, strong and dry winds, and direct sunlight.

Questions

Under what flight conditions could sublimation occur?

If an aircraft flew through icing conditions, causing ice to cling to its surface, then flew above the clouds into clear skies, the ice could be removed through sublimation even if the outside temperature was still below freezing (though this would be a slow process). This would occur due to the forces of the opposing air and direct sunlight, which act to transform the ice directly into vapor.

Slide 19: The dew point is the atmospheric temperature (varying according to pressure and humidity) below which water droplets begin to condense and dew can form. Humidity is measured by the amount of water vapor in the atmosphere. Relative humidity is the actual amount of moisture in the air compared to the total amount of moisture the air could potentially hold; it is expressed as a ratio or percentage.

For example, if the relative humidity is measured to be 40 percent, the air contains 40 percent of the moisture that it is capable of holding. Temperature and pressure help determine this value of total moisture capacity, also known as the dew point. When the temperature of the air matches the dew point, the air is completely saturated, and moisture condenses in the form of fog, dew, frost, clouds, rain, or snow.

Slide 20: As moist, unstable air rises, clouds begin to form at the altitude where the temperature and dew point values meet. Unsaturated air cools at a rate of 5.4 °F (or 3 °C) per 1,000 feet; the dew point temperature decreases at a rate of 1 °F (or 0.56 °C) per 1,000 feet. Therefore, temperature and dew point rates converge at a decrease of 4.4 °F (2.5 °C) per 1,000 feet. If you apply this convergence rate to the reported temperature and dew point, you can use the “spread” (the difference between the temperature and dew point) to determine the cloud base elevation, as shown in the equation:

When temperature and dew point are in Celsius, use this equation: (Temperature-Dew point)/2.5 x 1,000 = Cloud Base

When temperature and dew point are in Fahrenheit, use this equation: (Temperature-Dew point)/4.4 x 1,000 = Cloud Base

Slide 21: Complete the **Formative Assessment**.

Formative Assessment

Provide students with **Clouds and Precipitation Student Activity 1**.

Students will calculate the cloud base using the local weather report (www.weatherbug.com) and then answer the questions that summarize material up to this point in the lesson.

Sample answers and additional support are provided in **Clouds and Precipitation Teacher Notes 1**.

[DO-L3; *investigate*]

EXPLAIN

Teacher Materials: Clouds and Precipitation Presentation, Clouds and Precipitation Teacher Notes 2, Clouds and Precipitation Teacher Notes 3, Clouds and Precipitation Teacher Notes 4
Student Materials: Clouds and Precipitation Student Activity 2, Clouds and Precipitation Student Activity 3, Clouds and Precipitation Student Activity 4, Student Daily Weather Diary

Session 3

Slide 22: To begin Session 3, give each student **Clouds and Precipitation Student Activity 2**. Sample answers and additional support are provided in **Clouds and Precipitation Teacher Notes 2**.

Teacher Notes

This activity illustrates several scientific principles:

- Dew point is the temperature that air needs to be cooled to in order for condensation to occur. Students have probably noticed that on warm, humid days lots of condensation will develop on the outside of a cup containing an ice-cold beverage. If the cup's temperature is below the dew point temperature, moisture will condense out of the air because the maximum amount of moisture that can be in the air decreases as the temperature decreases.
- Dew point allows a meteorologist to assess the amount of moisture in the air. As dew point increases, the amount of moisture in the air increases.

Slide 23: As shown in the graphic, a parcel of air reaches the saturation point when it can no longer contain any more water vapor. Note that moister (more humid) air is less dense than drier (less humid) air; this is because water vapor weighs less than other molecules that make up air.

Air can reach a saturation point in four different ways:

1. Warm air moves over a cold surface, causing the air temperature to drop and reach the saturation point.

2. Cold air and warm air mix together, causing saturation.

3. Air contacts the cooler ground at night, causing it to cool as well and reach its saturation point.

4. Air is forced upward and lifted into the atmosphere, where adiabatic cooling occurs.

No matter what causes the air to reach its saturation point, the resulting saturated air brings clouds, rain, and other weather conditions, which students will now explore.

Slide 24: Sometimes, cooling ground temperatures can cause the temperatures of the surrounding air (that is, the air close to the ground) to cool below the dew point. This typically happens on nights that are clear, calm, and relatively cool. Then the moisture in the air condenses and sticks to surrounding objects. This is similar to what happens when a glass containing a cold drink is covered with condensation from the warmer air surrounding the outside of the glass. The condensation that appears on the ground, often on the grass in the morning, is known as dew. Frost forms in a similar process, except that temperatures near the ground are below freezing and therefore create a thin, icy coating.

While dew does not cause any threat to an aircraft, frost is a potential hazard because, as all ice does, it disrupts the flow of air over the wing and reduces lift while increasing drag. This can be a significant safety hazard during critical phases of flight such as takeoff, approach, and landing. This is why it is recommended that pilots clean off all frost from their aircraft (especially lift and control surfaces) prior to flight.

Slides 25-26: Fog is formed under similar conditions as dew, except that when the cool air near the ground condenses, it becomes visible water vapor that remains aloft without rising into the sky. That said, it may be easier to think of fog as simply a cloud that is at the earth's surface. Fog is formed when the air just above the ground cools to the dew point, causing the air to become fully saturated with moisture. However, there are different classifications that are based on the manner in which the fog formed:

- **Radiation fog** forms on clear nights with little or no wind. It typically forms in mountain valleys and similar low-lying areas when the ground cools rapidly due to terrestrial radiation (emitted by the earth's naturally radioactive materials such as uranium, thorium, and radon). When the sun rises and air temperatures increase, radiation fog lifts or simply dissolves. Winds may also help to dissipate radiation fog. Radiation fog that is fewer than 20 feet thick is defined as ground fog.
- **Advection fog** forms when warm, moist air layers move over a cold surface. Unlike for radiation fog, wind is required to form advection fog. Winds of 15 knots or less will help to form and intensify the fog; typically, winds above 15 knots will lift the fog to become low-level stratus clouds. This fog is most common along coastlines where moist sea breezes blow over cooler landmasses. Eventually, sunlight burns off advection fog, though this process may be delayed if winds remain steady.
- **Upslope fog** forms when moist, stable air is forced upward into hills, mountain ranges, or similar sloping surfaces. Like advection fog, upslope fog also requires wind to both form and maintain it. Like advection fog, upslope fog may not burn off with sunlight; under the correct conditions, it may persist for days. It can also climb to higher elevations than radiation fog can.
- **Steam fog** forms when cold, dry air moves over warm water. It's also referred to as "sea smoke" because as the warm water evaporates, it rises slowly and looks like smoke. Steam fog is typically seen over lakes, oceans, and other bodies of water during the coldest seasons. Some steam fog threats for aircraft include icing and low-level turbulence.
- **Ice fog** forms when the air is well below freezing and water vapor forms directly into ice crystals (i.e., deposition). It forms in the same manner as radiation fog, except that the ambient temperatures are typically at or below –25 °F. Although it is most common in arctic regions, it can occur in slightly warmer climates during harsh winters.

Slide 27: Lead a class discussion about the hazards of fog.

Questions

What do you think is the most common hazard that fog poses to pilots for day-to-day operations? How does fog affect takeoff? How does fog affect approach and landing?

The most common hazard that fog poses is reduced visibility. Pilots may not have enough visibility to takeoff in dense fog. A more significant safety threat would occur if a pilot were approaching an airport for landing, only to suddenly fly into fog near the ground and lose sight of the runway.

Which type of fog poses the most serious aerodynamic threat to aircraft? Why is it such a serious threat?

Freezing fog is most serious. When an aircraft flies through temperatures that are at, below, or even slightly above the freezing point, the moisture will cling to the aircraft's surface and accumulate as ice. As we learned in Grade 10, icing poses one of the most significant threats to pilots due to airflow disruption, decreased lift, increased drag, and windscreen obstruction.

Slide 28: Distribute **Clouds and Precipitation Student Activity 3**. Students will watch the following video, which introduces the four main categories of clouds and the types of clouds within each category. These categories and types correspond to the table in **Clouds and Precipitation Student Activity 3**. The top row of the table contains a cell for each category, and the bottom three rows contain cells for the different types; each column identifies all the types of cells within a particular category. As they watch the video, students should use the information in the table to identify each category and type of cloud. (The video covers a lot of information quickly, so you may wish to show it twice.)

- "How To Predict The Weather By Looking At The Clouds" (Length 6:56)
  https://video.link/w/mf3p

For teachers who are unable to access Safe YouTube links, the video also can be found at: https://www.youtube.com/watch?v=I00vcHLJXCc

Slide 29: Next, students should follow the instructions in Part 2 of the activity by reviewing the weather data they have already recorded in their Daily Weather Diaries and categorize the clouds according to the information they have learned.

Correct answers for the activity are provided in **Clouds and Precipitation Teacher Notes 3**.

Teaching Tips

After students have completed the activity, lead a class discussion about the relationship between clouds and weather. Have different students share their weather data and cloud categorizations for the same day. Did any students have different observations or answers? Try to arrive at a consensus regarding the clouds that appeared for every day during which students recorded weather data.

Slide 30: During the next part of the lesson, students will learn about the different types and categories of clouds. But what are clouds? Students may assume that clouds are water vapor, but that is not quite right: water vapor is an invisible gas. A cloud is actually what forms when water vapor condenses on tiny particles of dust or ice in the atmosphere; these particles are called *condensation nuclei*. In other words, clouds consist of matter in all three phases: solid, liquid, and gas. Scientists have calculated that the average cumulus cloud (the stereotypical "cotton ball" shape) weighs 1.1 million pounds.

Clouds are one of aviation's greatest hazards. They restrict visibility, signal turbulence, and can produce dangerous precipitation, such as hail and ice; when low to the ground (including as fog), they can close airports and ground even well-equipped aircraft. But clouds are also crucial sources of information for pilots. Clouds are often visible indicators of future weather, if you know how to properly interpret them. For clouds to form, there must be sufficient water vapor in air that is cooling. The air cools until it reaches its saturation point, at which point the invisible water vapor condenses into liquid water droplets on condensation nuclei.

Slide 31: Low clouds are one of the four main categories of cloud. They can extend from the earth's surface up to about 6,500 feet AGL (above ground level). Due to their low altitude, they typically consist of normal water droplets; depending on the ambient air temperature, however, they sometimes contain supercooled water droplets that can cling to aircraft surfaces and cause icing. Remember that aircraft surface temperature may be lower than the outside air temperature (OAT), which is why aircraft ice accumulation may occur at OATs greater than 32 °F.

The varieties of fog that students learned about in previous slides are all classified as low clouds. The primary aviation hazards regarding low clouds are low ceilings, reduced visibility, and sudden changes in type, size, and intensity. Low clouds are of the greatest concern in the takeoff and landing phases because they can make getting in or out of an airport challenging, dangerous, or even impossible.

Questions

Have you ever flown into or out of an airport when the flight was either delayed or cancelled due to weather? What were the weather conditions, and what types of clouds were associated with them?

Answers will vary based on experience, but the cloud categories were likely either low or vertical growth.

Slide 32: Middle clouds may be composed of water, ice crystals, or supercooled water droplets. Pilots should understand that lower-performance aircraft may encounter these types of clouds during cross-country flights at higher altitudes, and higher-performance aircraft may encounter them when transitioning between the takeoff/landing and cruise phases (i.e., the enroute environment). There are two types of middle cloud:

- Altostratus clouds may produce turbulence and moderate icing.
- Altocumulus clouds, which usually form when altostratus clouds disperse, may produce light turbulence and icing.

Slide 33: Since high clouds form at high altitudes, they require smooth, stable air to develop. As a result, they are not associated with turbulence. Because they are primarily made up of ice crystals, they do not adhere significantly to an aircraft's surface and therefore pose no serious icing threat.

Questions

Which cloud type can indicate the direction in which a front is moving? How can you tell the direction of movement?

Cirrus clouds, while they indicate fair weather, also indicate a changing weather pattern. The streaks point in the direction in which the front is moving.

Slide 34: Clouds with vertical development are cumulus clouds that build into towering cumulus or cumulonimbus clouds. The bases of these clouds typically form in the low region, though they may also begin in the middle region, and then extend well into high-altitude regions, often much higher than the cruising altitude of airliners. Pilots must always be mindful of the freezing level by reading their outside air temperature (OAT) gauge when approaching visible moisture, because anytime temperatures are 10 °C or below (especially when below 0 °C), icing is possible. Because towering cumulus clouds indicate atmospheric instability (a requirement for rapid vertical development), the air surrounding and especially inside these clouds is turbulent. They often develop into cumulonimbus clouds or thunderstorms.

The following video shows how downdrafts can counteract the updrafts that cause cumulus clouds to build:

"Cumulonimbus updrafts & downdrafts" (Length 1:14)
https://video.link/w/My7p

For teachers who are unable to access Safe YouTube links, the video also can be found at: https://www.youtube.com/watch?v=ivVaTH8xMsw

Cumulonimbus clouds contain even greater concentrations of moisture and unstable air, which is why they produce some of the most hazardous weather phenomena, including lightning, hail, tornadoes, gusty winds, and wind shear. Pilots must rely on their weather radar (if equipped), keep in communication with air traffic control, and execute thorough mission planning in order to circumnavigate such areas. This is critical, especially because these extensive vertical clouds are frequently obscured by other cloud formations (since the surrounding atmosphere is already unstable), causing them to be hidden from pilots. These hidden storms, enveloped by surrounding clouds, are known as embedded thunderstorms.

Due to the unique and perilous threats that thunderstorms pose, we'll learn more about thunderstorms in the lesson devoted to thunderstorms.

Slide 35: The graphic on this slide illustrates the process of vertical development and dissipation in clouds.

Slide 36: Clouds may be further classified into specific types based on their appearance and composition. Pilots who know these terms are able to better communicate to fellow pilots or air traffic controllers (via pilot report, or PIREP) what clouds they are experiencing along their route of flight. The upcoming slides will cover these terms:

- Cumulus
- Stratus
- Cirrus
- Alto
- Castellanus
- Lenticularis
- Nimbus
- Fracto

Teaching Tips

When progressing through these classification slides, pause on each slide so that students may compare the information and image with their table from **Clouds and Precipitation Student Activity 3**.

Encourage students to think about:

- Which types are familiar, and which are new?
- Why were some not specified in the table?
- Can some of these classifications be grouped into our existing table under multiple categories?

Slide 37: Cumulus clouds form “heaps” or ”piles,” like cotton balls. They may form at all altitudes.

Slide 38: Stratus clouds form layers, like sheets or blankets. They also may form at all altitudes.

Slide 39: Cirrus clouds form only at high altitudes, typically above 20,000 feet. They may appear as ringlets, wisps, or fibrous bits.

Slide 40: “Alto” is a prefix denoting all clouds that form at middle altitudes. Think of music: the term *alto* refers to mid-range instruments. (An alto saxophone is smaller and higher than a tenor saxophone but larger and lower than a soprano saxophone.)

Slide 41: Castellanus (“castle-like”) clouds share a common base from which separate vertical developments happen.

Slide 42: Lenticularis (“lens-shaped”) clouds form over mountains in strong winds; they signify turbulence, often severe.

Slide 43: “Nimbus” is used as a prefix or suffix denoting all rain- and snow-bearing clouds. The two main types are nimbostratus (which remain at low altitudes and produce steady precipitation) and nimbocumulus (sometimes called cumulonimbus) (which exhibit vertical growth and produce thunderstorms).

Slide 44: Fracto (“fractured”) clouds appear ragged or broken.

Slide 45: Distribute **Clouds and Precipitation Student Activity 4**. For this activity, each student (or small group) will require a plastic bottle with a lid, water, and matches. The procedure is included in the activity worksheet, or watch the video.

- “How to make a cloud in a bottle” (Length 1:50)
  https://video.link/w/X37p

For teachers who are unable to access Safe YouTube links, the video also can be found at: https://www.youtube.com/watch?v=G70y90BVes4

EXTEND

Teacher Material: Clouds and Precipitation Presentation

Session 4

Slide 46: In addition to the terms used to describe clouds, pilots and weather reports use additional terms to describe cloud cover. Some of these may already be familiar terms; however, we will cover them here as a refresher since they are so critical when determining whether to takeoff, land, circumnavigate, or penetrate existing or impending weather.

In the aviation world, a *ceiling* is the lowest layer of clouds reported as being broken or overcast. In other words, a layer of only a few or scattered clouds would not constitute a ceiling. In the event of fog or haze covering the ground, “ceiling” may also describe the vertical visibility.

- A “broken” cloud deck covers between 5/8 and 7/8 of the sky.
- An “overcast” cloud deck covers the entire sky; however, a few holes in the deck would still constitute overcast as long as more than 7/8 of the sky is covered.

Slide 47: Ceiling information refers to vertical visibility distance. In contrast, the aviation term *visibility* refers to the greatest horizontal distance at which an object can be seen by the naked eye. Although ceilings are reported in feet, visibilities are reported in statute miles (SM) in weather reports and instrument approach/departure procedures. This differs from the typical distance used in aviation procedures and planning, nautical miles (NM), because that is the international standard—whereas SM is the standard in the United States utilized by the National Weather Service.

At some larger airports, especially international/airline service airports, runway visual range (RVR) sensing equipment is utilized, allowing pilots to take off and land in significantly lower visibilities. These indicators measure the visibility to much higher accuracy so that it may be reported through current observations (METARs or otherwise) in feet rather than SM. Pilots must be trained to take off and land in lower visibilities, and aircraft may have special equipment that aids in low-visibility takeoffs/landings.

Questions

What is the ultimate purpose for such equipment? What weather phenomenon would most require such equipment and training?

The ultimate goal is to enable continued operations (traffic flow in and out of airports), even in difficult weather conditions. The weather phenomena that would require this are very low cloud decks, fog, haze, smoke, and dense precipitation such as rain or snow.

Slide 48: Precipitation is defined as water particles of any variety that form in the atmosphere and fall toward the ground. Precipitation is measured by reflectivity on radar scans (both by in-aircraft and ground-based weather radars), because it has the most potential to impact safety of flight. It may reduce visibility, create trace to severe aircraft icing, damage aircraft components (in the event of hail), and affect landing and takeoff performance.

Precipitation begins to form when water or ice particles inside of clouds grow until the atmosphere cannot support them. In other words, the weight of the precipitation overcomes the lifting forces inside the nimbus clouds where they formed. The forms of this precipitation may include drizzle, rain, or virga (see Slide 50), ice pellets/sleet, hail, and snow.

Slide 49: Drizzle is defined as small water droplets that are less than 0.02 inches in diameter. Drizzle is typically found within low stratus clouds or even fog. Drizzle that grows larger than 0.02 inches across is defined as rain. Weather forecasters classify rain as light, moderate, and heavy, which is denoted in METARs and TAFs as –RA, RA, and +RA, respectively.

Typically, restrictions are not placed on pilots or aircraft for flying through light or moderate rain, except insofar as visibility is diminished. However, pilots may be cautioned to avoid heavy rain due to the potential for atmospheric instability and engine airflow intake disruption.

Slide 50: Rain that falls through the atmosphere but evaporates prior to impacting the ground is known as virga. Virga is typically not reported on any observation or forecast, but in flight it appears as a shaft of rain that trails off or fades away before reaching the ground. It doesn't look ominous, but virga may indicate or precede a microburst (intense small-scale downdraft), which pilots should take every measure to avoid. This is because the rain is cooling the air around it as it evaporates, which causes that cold air to plunge toward the earth.

Though not all forms of virga are dangerous, it should be avoided when temperatures aloft are below freezing, when it's falling from towering cumulus or cumulonimbus clouds, or when the virga is dense enough that you cannot see through it.

Slide 51: Freezing rain and freezing drizzle occur when the temperature of the earth's surface is below freezing but the atmosphere is just above freezing. If precipitation falls in liquid form, it will freeze upon contact with the cooler ground. If rain falls through a temperature inversion (i.e., warm air above a cold air layer), it may freeze while passing through the underlying cold air, causing it to fall to the earth as ice pellets (known as sleet by the U.S. National Weather Service). Pilots should avoid this indicator of a temperature inversion, since freezing rain likely exists at a higher altitude.

Hail, a larger form of ice pellets/sleet, occurs within cumulonimbus clouds with significant vertical growth. Powerful updrafts within the storm clouds carry the freezing water droplets up and down (or keep them suspended at the same altitude), causing the precipitation to grow larger as more moisture clings to it and freezes. Once the weight of the hail becomes so heavy that the updrafts can no longer support it, it falls to the earth. Hail may range in size from that of a pea to that of a softball; its size is directly dependent upon the strength of the storm's instability and the strength of its updrafts.

Play the following video, which explains the updraft wind speeds required to form such hail. Have the students imagine the ravaging turbulence these shearing winds from below would cause on an aircraft:

- "Hail Explained in 3D" (Length 2:55)
  https://video.link/w/L07p

For teachers who are unable access Safe YouTube links, the video is also available here: https://www.youtube.com/watch?v=B6fxBN4v_2k

Questions

At what time of year do we typically experience hail? Why?

We typically see hail during spring months. The warming temperatures are a requirement for the instability in the atmosphere necessary to create cumulonimbus clouds with updrafts powerful enough to create hail.

Slide 52: Snow is caused when relatively lightweight ice crystals fall from clouds that are more stable than those with extensive vertical development. This causes snow to either fall at a steady rate or to shower on and off. Snow tends to vary in size from small grains to large flakes.

Questions

What cloud category and type most commonly produces snow? Why do you think this is?

Snow is typically produced from the category of low clouds and the stratus type. This is because snow's consistency is so light and fine that it needs to develop in a more stable atmosphere with less updrafts. Stratus clouds, being flat/sheet-like, indicate such stability.

Slide 53: All forms of precipitation have the potential to pose a threat to flight safety. Significant amounts of rain can contribute to water inside fuel tanks. Precipitation also changes the friction levels of runway and taxiway surfaces, increasing stopping distances for aircraft. These are critical not only during landing, but in the event of an aborted takeoff. (Due to these weight-and-balance considerations, aircraft may take off with significantly lighter gross weights so that they can utilize the runway available.)

In the event of significantly wet runways, the Runway Condition Reading (known as RCR, a measurement of the tire-to-runway friction coefficient) drops from 23 to 10, which significantly increases stopping distances. However, in the event of a significantly icy runway, the RCR value drops all the way to 3; consequently, operations on truly icy runways should be halted except for the most mission-critical, well-equipped aircraft and crew.

The following video illustrates the dangers of planes using icy runways.

- “Planes sliding on ice” (Length 2:31)
  https://video.link/w/2u7p

For teachers who are not able to use Safe YouTube links, the video can also be found here: https://www.youtube.com/watch?v=JmAG-IU0Et0

EVALUATE

Teacher Materials: Clouds and Precipitation Presentation, Clouds and Precipitation Teacher Notes 5
Student Material: Clouds and Precipitation Student Activity 5

Slides 54-69: Quiz students on the Private Pilot Knowledge Test questions.

Slides 70-80: Conduct the **Summative Assessment**.

Summative Assessment

Provide students with the **Clouds and Precipitation Student Activity 5** worksheet.

In this lesson, the students have learned about several categories and varieties of both clouds and precipitation. In this assessment, teachers will quiz the students by providing them with a visual image on the presentation slides. Since students can’t judge what altitude the clouds are at from the pictures, the altitude value will be provided to them in the worksheet.

Next, students will answer the precipitation questions on their worksheets based upon the description provided. In this section, only a description will be provided, and they will write in the type of precipitation because an image would likely make the answer obvious.

Sample answers are in the **Clouds and Precipitation Teacher Notes 5** document.

[DOK-L3; *differentiate,* DOK-L2; *interpret*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Responses:
  - Show knowledge of cloud types and categorization
  - Show understanding of types of precipitation

Points **Performance Levels**
9-10 Correctly identifies 9-10 of the clouds in Part A, and correctly names 7-8 of precipitation types in Part B. A full understanding of the lesson objectives is demonstrated.
7-8 Correctly identifies 7-8 of the clouds in Part A, and correctly names 5-6 of precipitation types in Part B. A sufficient understanding of the lesson objectives is demonstrated.
5-6 Correctly identifies 5-6 of the clouds in Part A, and correctly names 3-4 of precipitation types in Part B. A limited understanding of the lesson objectives is demonstrated.
0-4 Correctly identifies 0-4 of the clouds in Part A, and correctly names 0-2 of precipitation types in Part B. Little or no understanding of the lesson objectives is demonstrated.

STANDARDS ALIGNMENT

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.9-10.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

FAA AIRMAN CERTIFICATION STANDARDS

- **PA.I.C.K3** Meteorology applicable to the departure, en route, alternate, and destination under VFR in Visual Meteorological Conditions (VMC) to include expected climate and hazardous conditions such as:
  - **PA.I.C.K3a** a. Atmospheric composition and stability
  - **PA.I.C.K3b** b. Wind (e.g., crosswind, tailwind, wind shear, mountain wave, etc.)
  - **PA.I.C.K3c** c. Temperature
  - **PA.I.C.K3d** d. Moisture/precipitation
  - **PA.I.C.K3f** f. Clouds
  - **PA.I.C.K3g** g. Turbulence
  - **PA.I.C.K3h** h. Thunderstorms and microbursts
  - **PA.I.C.K3i** i. Icing and freezing level information
  - **PA.I.C.K3j** j. Fog
  - **PA.I.C.K3k** k. Frost

REFERENCES

FAA PHAK Chapter 12–Weather Theory: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/14_phak_ch12.pdf

Sublimation and the Water Cycle: https://www.usgs.gov/special-topic/water-science-school/science/sublimation-and-water-cycle?qt-science_center_objects=0#qt-science_center_objects

Volatile Virga: https://www.aopa.org/news-and-media/all-news/2014/june/03/training-tip-volatile-virga

The Process of Adiabatic Cooling and Heating: https://www.youtube.com/watch?v=XH_M4jItiKw

All the cloud types: https://www.youtube.com/watch?v=B9LyP0C2rsQ

Predicting weather with clouds: https://www.youtube.com/watch?v=I00vcHLJXCc

Clouds to avoid: http://iflyamerica.org/safety_when_pilots_should_avoid_virga.asp