Makeup of the Atmosphere

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

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The atmosphere is made of different components whose properties and interactions produce weather.

Water is a component of the atmosphere that contributes the most to weather.

Understanding the physical processes at work between the components and energy in the atmosphere helps us to understand current and future weather.

ESSENTIAL QUESTIONS

1. How does the atmosphere create weather?

LEARNING GOALS

Students Will Know

- Weather is a product of the properties of the atmosphere
- The various gases that compose the atmosphere
- Of the atmospheric gases, water vapor has the greatest effect on weather
- Atmospheric layers and the layers most impacting weather formation
- Every weather process is associated with a heat exchange

Students Will Be Able To

- *Make observations* of the current weather. (DOK-L2)
- *Differentiate* among the various components of the atmosphere. (DOK-L3)
- *Draw conclusions* about the role of atmospheric water in creating weather. (DOK-L3)

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 conditions to determine whether it's a good day to fly.

Formative Assessment
Students will work individually, then in pairs, then as a group to describe the atmosphere and its impact on flying.

Summative Assessment
Students will work individually to recall the core components of the atmosphere, its properties, and the role of water vapor in creating weather, and then apply that knowledge to a hypothetical scenario.

LESSON PREPARATION

MATERIALS/RESOURCES

- Makeup of the Atmosphere Presentation
- Makeup of the Atmosphere Student Activity 1
- Makeup of the Atmosphere Student Activity 2
- Makeup of the Atmosphere Student Activity 3
- Makeup of the Atmosphere Student Activity 4
- Makeup of the Atmosphere Teacher Notes 1
- Makeup of the Atmosphere Teacher Notes 2
- Makeup of the Atmosphere Teacher Notes 3
- Makeup of the Atmosphere Teacher Notes 4
- Student Daily Weather Diary

Build a Barometer Activity (per group)

- Empty, clear, 2-liter soda bottle, or equivalently sized clear container
- Food coloring
- Ruler
- Marker (permanent)
- Sticky Tack or “mounting putty”
- Clear plastic tube with a small diameter, approximate length of the bottle
- Tape (clear)
- Scissors or utility knife

Build a Hygrometer Activity (per group)

- Two identical spirit (liquid) thermometers that provide access to the “bulb” at the base of the liquid
- 1-liter bottle or milk carton
- Sturdy string
- J-cloth or equivalent water-absorbent, cotton material
- Electrical tape
- Scissors
- Relative humidity table (see https://www.nasa.gov/centers/langley/pdf/245887main_MeteorologyTeacherRes-Ch11.r3.pdf)

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

This three-session lesson will begin with a warm-up in which the students will discuss their current local weather and their understanding of atmosphere, its effect on weather, and its importance to aviators. This will segue into a discussion of the atmosphere and its properties.

Students will learn that the atmosphere has physical properties, including mass and shape, and is made up of gases, including nitrogen, oxygen, water vapor, and trace gases. During the next part of the lesson, students will see that heat exchange drives all weather processes and learn why the effects of heat exchange on atmospheric water are critical to the creation of important weather phenomena.

Students will go on to look at the various layers of the atmosphere and the role each layer plays in weather. They will consider the role of density and pressure. To help bring their learning to life, students will build a hygrometer, barometer, or both. These instruments can be used in upcoming lessons as students continue to observe the weather and atmospheric conditions around them.

Finally, students will complete a **Summative Assessment** that tests their learning and allows them to apply what they've learned to a flight-related scenario.

BACKGROUND

A comprehensive understanding of weather is important for the safety of flight. This lesson will address weather at its most fundamental, answering the question, "What about the atmosphere causes weather?" This core understanding will help future aviators comprehend the impact of their environment on their ability to conduct safe flight operations.

In order to fully understand how weather can affect flight, students need a good understanding of the fundamentals of weather. In this lesson, students will consider the role of the atmosphere in weather. In upcoming lessons in this unit, they will delve more deeply into specific weather phenomena.

By understanding the makeup of the atmosphere, students will gain a greater understanding of the environment in which aviators operate.

All weather phenomena are driven by heat exchange. Energy from the Sun warms the Earth. This process not only warms the air—it also adds water to the air through evaporation, the process by which liquid water changes to water vapor, a gas. The warm air then rises until it cools, at which point the water vapor may condensate or precipitate out; the cooler air then descends. This is one basic weather pattern. The other basic weather pattern is that uneven heating from the sun causes different air masses to have different pressures, some lower than others. Nature seeks equilibrium, so areas of high pressure will "flow" to areas of low pressure. When an air mass moves in this way, it creates wind. Combine wind with temperature and the water cycle, and you have the building blocks of the weather we experience every day. This lesson will expand on the underpinnings of these concepts to help students understand why various weather processes occur, and why they are important to pilots.

MISCONCEPTIONS

Students may assume that as you rise through the atmospheric layers into space, temperatures continuously drop. In some layers of the atmosphere, the temperature decreases as you climb higher. This happens most notably in the first layer closest to the Earth's surface, which is where most people, including aviators, spend their time. However, in other atmospheric layers, the temperature actually increases with an increase in altitude. For example, in the stratosphere, which contains the ozone layer, atmospheric temperatures increase with altitude because of ultraviolet radiation absorbed from the sun. Within the ozone layer, temperatures can reach 2,000 degrees Celsius.

DIFFERENTIATION

To help students better recall key vocabulary words, have them construct a list of weather words and other frequently used terms as their own reference dictionary. To increase retention, have students look up the etymology of words that may be derived from other languages. For example, the root word for meteorology is the Greek word *meteoros*, which means "high in the air."

ENGAGE

Teacher Material: Makeup of the Atmosphere 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 this 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:

What is the humidity like today? What are the winds? What is the temperature, and how and where was it measured? What do you think these conditions would mean if you were to go flying today?

Answers will vary based on the actual weather conditions.

[DOK-L2; *observe, describe*]

Slide 5: Ask the following questions to determine students' current understanding of Earth's atmosphere. Summarize and record student responses on a board or display where they can be seen. Students can later compare their initial understanding to what they have learned during the course of the lesson.

Questions

What is the atmosphere?

What about the atmosphere causes weather?

Why is understanding this relationship important to aviators?

Answers will vary based on the students' current understanding of the atmosphere. Possible responses include:

The atmosphere is the air (oxygen and other gases) that surrounds the Earth. It is the medium or substance in which weather happens, so the composition of the atmosphere will influence the weather. (This is a common and generally correct response, but it is oversimplified.) Aviators need to understand the fundamentals of weather and the atmosphere because they fly through it, and with proper knowledge they can perform a reasonable risk analysis and avoid situations that might be dangerous due to bad weather.

Looking at today's conditions, how do you think the atmosphere is contributing to today's weather?

Answers will vary based on the students' current understanding of the atmosphere and local weather.

EXPLORE

Teacher Material: Makeup of the Atmosphere Presentation

Slide 6: The atmosphere can be thought of as an "envelope" of gases that surrounds the Earth. It has mass, weight, and even a bit of a shape. It begins at the surface of the Earth, and its upper boundary is indefinite, though it is scientifically defined as approximately 350 miles from the Earth.

Slide 7: The major properties of the atmosphere are characterized by **gas**, **water**, **temperature**, **layers**, and the physical properties of **mass**, **volume**, **density**, and **pressure**. We will talk about each of these in turn in upcoming slides. (An index appears in the top-right corner of subsequent slides to help students keep track of the topic area.)

EXPLAIN

Teacher Materials: Makeup of the Atmosphere Presentation, Makeup of the Atmosphere Teacher Notes 1
Student Material: Makeup of the Atmosphere Student Activity 1

Slide 8: Because the atmosphere is made up of gases, it shares the properties of gases. Variations in these properties influence the weather we experience.

Questions

What are some of the properties of gases? How do these properties apply to the atmosphere?

Possible responses: The atmosphere has mass, volume, temperature, density, and pressure. It is compressible. The atmosphere "flows," and it has resistance, or "viscosity." The atmosphere conforms to the "shape" of the Earth, just as a gas conforms to the shape of its container, and it has friction with the surrounding surfaces (i.e., land and water).

The pie chart on the slide shows the makeup of the Earth's atmosphere: 78% nitrogen, 21% oxygen, and "trace gases" such as argon and carbon dioxide. The air also contains water vapor (the gaseous form of water), which varies from zero to 5%. Besides the presence of nitrogen and oxygen, both basic elements that support life on Earth, the third most-prominent component of the Earth's atmosphere is water.

Slide 9: Much of the atmosphere's effect on aviation and on weather is about the water within it. Water exists in the atmosphere in all three physical states (solid, liquid, gas), depending on the temperature. The slide graphic depicts water in its three states and the energy transfer necessary to transition from one state to another.

Questions

How have you experienced or seen water in the atmosphere? Come up with examples of each physical state.

The liquid forms of atmospheric water include rain and dew. The solid forms include snow, hail, and ice. Students may say that gaseous forms include steam and fog/clouds.

This response is common but technically incorrect, as explained below.

Water vapor (gas) is actually invisible, so when you're looking at a cloud or fog, you're not actually seeing water as a gas. A cloud is actually part solid, part liquid, and part gas. Liquid moisture condenses from the invisible water vapor onto solid particles (often dust or ice) to form a visible cloud.

Slide 10: Even though it is no more than 5% of the atmosphere by volume, water has the greatest effect on weather of all the atmosphere's component gases. In aviation, we see atmospheric water as clouds, rain, snow, hail, and icing. Each of these can have a significant impact on aviation, including aircraft performance and flight safety.

Since water is such an important part of aviation, it is useful to know how much water is in the atmosphere. The amount of water in the atmosphere is known as *relative humidity*. The higher the humidity, the more water is in the atmosphere.

Perfectly dry air, with no water vapor in it, would have a relative humidity of 0%. Saturated air, which cannot hold any more water vapor, has a relative humidity of 100%. Relative humidity is related to temperature. Warm air holds more water vapor, while cold air holds less. Depending on where you live, you may see this during the change of seasons, as the local weather is generally more humid during the summer and drier during the winter.

In its liquid form water is *more* dense than air. This is one reason liquid water in the atmosphere—that is, rain—descends. But in its gaseous form—that is, water vapor—it is *less* dense than air. The impact is that when the relative humidity is higher (there is more water vapor in the air), the density of the overall atmosphere is lower.

Questions

Recall from your prior lessons what you learned about density altitude. How does higher relative humidity affect weather and flight?

Possible responses: Higher relative humidity tends to translate to higher density altitude, which has a detrimental effect on aircraft performance. However, the effect of humidity alone is not as significant as the higher temperatures or other environmental conditions that normally accompany humidity.

Slides 11-12: While water is an important part of the atmosphere, it's temperature that will determine what form water will take. Temperature is a measure of energy content. The flow of that energy, known as heat exchange, is the primary driver of weather patterns. Every physical process of weather is accompanied by, or is the result of, a heat exchange. "Heat exchange" is the transfer of energy from one form or place to another.

The graphic on **Slide 12** shows the general effects of a heat cycle, with energy from the sun warming the Earth's surface, causing liquid water to evaporate and warm air to rise; then, as warm air cools, its water vapor condenses back into liquid water and precipitates, or falls back to the ground. The graphic also shows that uneven heating causes differences in surface air pressure. As the air masses move from high pressure (H) to low pressure (L) to seek balance, wind is the result.

Slide 13: Show this video to help explain the layers of the atmosphere.

- "What are the layers of the atmosphere?" (Length 1:49)
  https://video.link/w/vyTo

The video shows that the "envelope" of air that forms the atmosphere is composed of four layers that are defined by their temperature characteristics, composition, movement, and density.

These layers are the troposphere, stratosphere, mesosphere, and thermosphere. The tropopause is the invisible boundary between the troposphere and stratosphere.

Slide 14: The **troposphere** is the layer of the atmosphere closest to the Earth's surface. It extends to an average height of 36,000 feet (nearly 11 km), ranging from 6–20 km above the poles to 48,000 feet (14.5 km) over the equator. Most weather occurs here. Within this layer, the temperature steadily drops as altitude increases at a rate of approximately 2° C every 1,000 feet, down to as much as 60 degrees below zero at the top of the troposphere. In tenth grade, students learned about this temperature change, which is called the "standard lapse rate." Pressure decreases at a rate of 1 inch Hg per 1,000 feet of altitude gain.

This layer of the atmosphere is where most pilots operate.

Questions

Why do most aircraft operate only in the troposphere, even though they are often capable of climbing higher?

Possible response: Aircraft that fly high in the troposphere are generally powered by jet engines. Jet engines become increasingly efficient at higher altitudes due to the lower air temperature; thus, flying at a higher altitude burns less fuel and is more cost-effective. However, once the aircraft climbs out of the top of the troposphere, there is no further decrease in temperature with climb; in fact, the temperature could rise. The aircraft would see a penalty (fuel burned in a climb) with no reward. Thus, for commercial purposes with an emphasis on fuel efficiency, a climb to the top of the troposphere, where it is coldest, is the most cost-effective plan. (In some unique circumstances, aircraft could fly slightly higher to try to take advantage of the jet stream, if it is advantageous.) Certain special-use aircraft that are unconcerned about efficiency (for example, military or scientific aircraft) routinely fly higher than the troposphere.

Slide 15: The graphic shows a depiction of the troposphere and stratosphere, with icons representing different types of clouds and aircraft; note that weather such as thunderstorms happens in the troposphere. Also point out the red scale on the right depicting temperature: temperature decreases with altitude in the troposphere, but remains relatively constant as altitude increases through the tropopause and into the stratosphere.

Slides 16-19: The **tropopause** is not really a layer; rather, it is a boundary at the top of the troposphere that traps moisture and weather in the troposphere. The jet stream is located at the tropopause, making this region a significant contributor to weather. The temperature is constant within the tropopause.

The **stratosphere** is the layer that extends from the tropopause to a height of about 160,000 feet (50 km or about 30 miles). There is little weather, and the air remains stable; certain types of clouds occasionally extend into this layer. The temperature increases with altitude within the stratosphere because of ultraviolet radiation absorbed from the sun (as noted earlier).

The **mesosphere** and **thermosphere** are two layers above the stratosphere which have little influence on weather. However, it is notable that after increasing with altitude in the stratosphere, temperature again decreases with altitude in the mesosphere, and then increases again in the thermosphere. The thermosphere is the location of the *aurora borealis* (Northern Lights).

Slide 20: Complete the **Formative Assessment**.

> **Formative Assessment**
>
> Distribute a copy of **Makeup of the Atmosphere Student Activity 1** to each student.
>
> Have students write their answers to the questions in small groups. Then, have each group share their answers with the class.
>
> Correct responses are provided in **Makeup of the Atmosphere Teacher Notes 1**.
>
> [DOK-L3; *cause/effect*, *explain*]

Slide 21: Recall from prior lessons that density is defined as the mass of an object divided by its volume. The slide graphic shows the mathematical relationship of mass (m), volume (v), and density (d):

mass (m) = volume (v) x density (d)

Therefore, density (d) = mass (m) / volume (v).

We understand the concept of density easily when it comes to solids: a brick and a loaf of bread are about the same size, but a brick is heavier—it is more dense. Similarly, aluminum is less dense than iron, which is one reason so many airplanes are made of aluminum: For the same volume of material, the lower density metal (aluminum) weighs less than the higher density metal (iron).

The same principle applies to a gas, except that the molecules in a gas are moving, which means their density can vary in different conditions.

In the atmosphere, the air molecules near the surface of the Earth are compacted by the air molecules above them, all of which are subject to the Earth's gravitational pull. Thus, the air nearer the surface is at a higher density than the air at higher altitudes. As altitude increases, there is less air above to press down on the lower air, so density decreases with increasing altitude.

The higher air pressing down on the lower air, which creates the higher density, is atmospheric pressure. Pressure is a measure of the height of the air column above us. High pressure means there is more air above us; low pressure means there is less. Thus, as altitude increases and there is less air above, pressure decreases.

EXTEND

Teacher Materials: Makeup of the Atmosphere Presentation, Makeup of the Atmosphere Teacher Notes 2, Makeup of the Atmosphere Teacher Notes 3
Student Materials: Makeup of the Atmosphere Student Activity 2, Makeup of the Atmosphere Student Activity 3

Slide 22: Atmospheric pressure is associated with weather systems. The graphic on the slide shows that low pressure draws in air from surrounding air masses, forcing the air up into the atmosphere, where it cools and forms clouds or a storm system. This causes instability in the atmosphere, which is why low pressure is generally associated with "bad" weather. By contrast, high pressure pushes air out, which draws stable air down to the Earth's surface. High pressure is normally associated with more favorable weather.

A barometer is used to measure atmospheric pressure. Another useful weather tool is the hygrometer, which is used to measure relative humidity, discussed earlier in this lesson.

Slides 23-24: Divide the class into small groups. Give some groups **Makeup of the Atmosphere Student Activity 2** (the barometer), and give the other groups **Makeup of the Atmosphere Student Activity 3** (the hygrometer); each group

should complete its assigned activity. (If there is enough time, each group may complete both activities.) Instructional details and potential responses to the questions are available in **Makeup of the Atmosphere Teacher Notes 2 and 3**.

EVALUATE

Teacher Material: Makeup of the Atmosphere Teacher Notes 4
Student Material: Makeup of the Atmosphere Student Activity 4

Slide 25: Conduct the **Summative Assessment**.

Summative Assessment

In this activity, students recall important details related to the properties of the atmosphere. Then, they analyze a scenario to apply what they learned in this lesson.

Distribute a copy of **Makeup of the Atmosphere Student Activity 4** to each student, and direct them to answer the questions individually. Correct responses are provided in **Makeup of the Atmosphere Teacher Notes 4**.

[DOK-L3; *assess*, DOK-L2; *summarize*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Student work shows:
    - Ability to identify and describe the components of the atmosphere.
    - An understanding of the physical properties and effects of those components.
    - An accurate comprehension of how the atmosphere contributes to weather.
- Contributions show in-depth thinking including synthesis of lesson objectives.

Summative Assessment Scoring Rubric

Points **Performance Levels**

9-10 The student correctly identifies the components and layers of the atmosphere. The student identifies that temperature decreases in the troposphere. The student identifies that a heat exchange occurs with every weather process. The student understands the concept of pressure as a function of the height of the column of air above the point of measurement. The student accurately and thoroughly responds to the scenario-based question to convey the expected seasonal weather and atmospheric water considerations.
7-8 The student identifies the majority of the components and layers of the atmosphere. The student identifies that most weather exists within the troposphere and that weather is the result of heat exchange. The student sufficiently responds to the scenario-based question to communicate understanding of the weather and moisture impacts.
5-6 The student correctly identifies less than half of the components and layers of the atmosphere. The student does not identify the role of heat exchange in weather and does not understand the concept of pressure. Many gaps in understanding are evident. The student attempts to respond to each scenario-based question, but does not fully understand the impact of water in the atmosphere on the flight.
0-4 The student is unable to identify nitrogen, water vapor, and the troposphere as correct

answers. The student does not identify that temperature decreases in the troposphere or that a heat exchange occurs with every weather process. The student does not identify that density decreases with increasing water vapor, or inaccurately explains that water vapor is less dense than air. The student shows little or no understanding of the expected seasonal weather and atmospheric water considerations on a pilot's flight.

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-Dimensional Learning

- HS-ETS1-2 - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
    - Science and Engineering Practices
        - Asking Questions and Defining Problems
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.A: Defining and Delimiting Engineering Problems
    - Crosscutting Concepts
        - None

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

PRIVATE PILOT

- **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** Atmospheric composition and stability

REFERENCES

https://earthobservatory.nasa.gov/images/7373/the-top-of-the-atmosphere
Pilot's Handbook of Aeronautical Knowledge
https://socratic.org/questions/how-does-temperature-affect-the-atmosphere-and-cause-weather
What are the layers of the atmosphere?: https://youtu.be/LPHF323XlWw, https://video.link/w/vyTo