



UCAR CENTER FOR
SCIENCE EDUCATION

TEACHER GUIDE

TEACHER GUIDE



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What other types of storms cause precipitation?



The purpose of this learning sequence is to continue to build students' understanding of the way storms form. In Learning Sequence 1, students examined temperature and humidity data to identify conditions favorable for isolated storms, which form by convection. They developed a model for explaining what happens in the atmosphere that causes an isolated storm. Learning Sequence 2 begins with a discussion of the limitation of the model that they made to describe an isolated storm. Students find that their model does not fit for a storm that they observe in a time-lapse video—the storm lasts longer than an isolated storm. It's a cold front, which is the investigative phenomenon for Learning Sequence 2. Students investigate other ways storms form in a location, specifically when a cold front or low-pressure system moves through a location. Students leverage existing Model Ideas from Learning Sequence 1 and build new ones to explain these new kinds of storms. For example, they apply what they learned in Learning Sequence 1 about rising air leading to clouds and precipitation to understand why warm air, which is pushed upward at a cold front, leads to clouds and precipitation. They test the fit of their new model by revisiting the Colorado storm that they learned about in the Anchor. This sequence shifts spatial and temporal scales, as students move from examining a single location on a single day to examining a larger region across several days.

SCIENCE IDEAS

Air masses are large bodies of air with similar patterns of temperature and moisture. The boundaries between air masses are called fronts. In a cold front, a cooler, drier air mass moves towards a warm, moist air mass. The warm air is pushed upward, which can cause precipitation along the front. Areas where air is moving upward have low pressure. Areas of high pressure are one factor that cause air masses to move. High pressure areas are characterized by air moving downward and spreading out at ground level.

BACKGROUND SCIENCE CONTENT

WHAT IS AN AIR MASS?

Air over a large geographic area with similar temperature and moisture content is called an air mass. For example, the air mass over the Canadian Arctic is cool and dry because it's at high latitude and over land. The air mass over the Gulf of Mexico and Southeast U.S. is warm and moist because it's at lower latitude and mainly over a warm body of water.

FRONTS ARE THE BOUNDARIES BETWEEN AIR MASSES.

There are several different types of fronts including cold fronts (in which a cold air mass moves into a warm air mass), warm fronts (in which a warm air mass moves into a cold air mass), and stationary fronts (in which a cold air mass and warm air mass are moving but not able to push into each other). While this learning sequence provides examples to focus on cold fronts, different types of fronts typically occur together around areas of low pressure.

A cold front forms at the boundary between a cold air mass and a warm air mass when the cold air is pushing into the warm air. Cold fronts can produce dramatic changes in the weather because cold air is so dense it is able to quickly plow into a warm air mass.

Commonly, when the cold front is passing through a location, winds become gusty, and there is a sudden drop in temperature. Heavy rain, hail, thunder, and lightning can happen. The lifted warm air ahead of the front produces cumulus or cumulonimbus clouds. Atmospheric pressure changes from falling to rising at the front. After a cold front moves through, you may notice that the temperature is cooler, the rain has stopped, and cumulus clouds are replaced by stratus or stratocumulus clouds, or clear skies. A cold front (and the cold air mass that moves in) may not be cold but rather "cooler" than the air it is replacing. During the summer, temperatures might be quite warm but a cold front typically brings cooler weather compared with the previous days.

On weather maps, a solid blue line with triangles along it represents a cold front (see image). The triangles are like arrowheads pointing in the direction that the front is moving. Notice on the map that temperatures at ground level are warmer ahead of the front than behind it. This reflects the two different air masses that are meeting at the front. The air mass behind the front is colder than the air mass ahead of the front.

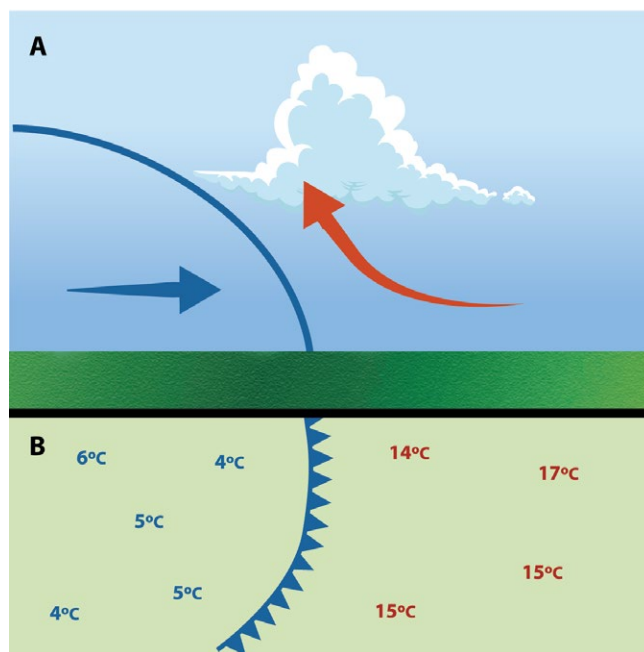
Be on the lookout for student confusion about exactly where precipitation occurs in a cold front. Precipitation happens along a cold front rather than in the air masses themselves because the warm air mass cools and condenses as it moves up higher in the atmosphere.

SPATIAL VARIATIONS IN AIR PRESSURE HELP FRONTS MOVE.

At areas of high pressure (known as "highs" and designated with a capital "H" on weather maps), air from higher altitudes flows downward. At ground level, the downward flow of air spreads out from the high pressure.

At areas of low pressure (known as "lows" and designated with a capital "L" on weather maps), air low in the atmosphere flows upward. At ground level, air rushes in to replace the air that is moving upward.

Overall, surface winds flow from high to low pressure. In the second investigation of this learning sequence, students will learn how differences in atmospheric pressure affect the



A. Cross section of a cold front, where a cold air mass is pushing into a warm air mass. The warm air is pushed upward where it cools and water vapor condenses into clouds.

B. Map view of a cold front. The cold air mass is on the left side, pushing into a warm air mass. The blue line with triangles along it indicates the location where cool and warm air meet.

movement of air masses, creating a cold front as an area of high pressure causes a cold air mass to plow into a warm air mass. (Note: The swirling of air around high and low pressure is due to the Coriolis force, which is covered in Learning Sequence 3.)

Note that while students may grasp that air moves from high to low pressure, they are sometimes challenged to explain why the air is moving. Remind students to think about high pressure forcing air down and low pressure allowing air to rise up. As some air molecules rise, other air molecules move in to fill the space that is left. As some air molecules are pushed downward, the air molecules that were already there are forced to move somewhere else. Drawing and labeling pictures of air moving in high/low pressure systems may be helpful to solidify these concepts.

Fronts and air masses also move because of upper-level movements of the jet stream—the air current at the top of the troposphere that flows from west to east around the planet at the midlatitudes. Because this unit focuses on ground-level weather observations, the jet stream is not included; however, it has an important role in weather. If time allows and if students need an additional challenge, you may wish to include the jet stream in the Explain section of the second investigation.



You can learn more about how different types of fronts form around an area of low pressure by reading the Norwegian Cyclone Model explainer article (NOAA National Weather Service):

[Norwegian Cyclone Model](https://www.noaa.gov/jetstream/synoptic/norwegian-cyclone-model) (<https://www.noaa.gov/jetstream/synoptic/norwegian-cyclone-model>)

COMMON MISCONCEPTIONS:

The following science misconceptions were identified by GLOBE Weather field test teachers. Watch out for them as your students are learning about weather.

MISCONCEPTION	CORRECT EXPLANATION
<p>Cold fronts happen in the winter because it's cold. Warm fronts happen in the summer because it's warm.</p>	<p>Attaching a temperature to a front can be misleading. Fronts happen at all times of the year. The temperature in the name indicates what is happening to the air masses. A front is named after the air mass that moves into another. A cold front forms when a cold air mass pushes into another air mass. A warm front forms where a warm air mass pushes into another.</p>
<p>A warm air mass is as warm as a tropical vacation. A cold air mass is freezing.</p>	<p>The air in a warm air mass can feel quite cool, especially in winter, and the air in a cold air mass can feel warm. The temperature associated with the air mass is relative to adjacent air masses, not an indication of how it feels. Thus, at a cold front in the middle of warm summer weather, a very warm moist air mass may be displaced by a slightly less warm and drier air mass.</p>
<p>Precipitation happens inside an air mass.</p>	<p>Precipitation can happen when there is an isolated storm (as students explored in Learning Sequence 1) within an air mass. But when students are identifying the location of precipitation in the cold front phenomenon explored in Learning Sequence 2, note whether they understand that the rain (or snow) will fall at the front.</p>
<p>Misconceptions about pressure.</p>	<p>In Learning Sequence 2, students will extend their learning about air pressure to include centers of low and high pressure as marked with "L" and "H" on weather maps. Watch for possible misconceptions about pressure including (1) that areas of high pressure are higher in the atmosphere; (2) that where pressure is high, air is rising higher; and (3) that warm air will always be low in pressure.</p>
<p>Warm air holds more humidity because there is more space between molecules.</p>	<p>The space between molecules is not related to the amount of moisture that can be in air. Instead, it is the heat energy of warm air that allows more evaporation, which makes warm air able to have more moisture.</p>



A DIFFERENT KIND OF STORM

What other types of storms cause precipitation?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(30 minutes)	
<p>What's a Cold Front Like?</p> <p>Students share their ideas about types of storms. They view a time-lapse video of a cold front and make observations of this storm. Students then share their initial observations of how a cold front storm differs from the isolated storm they learned about in Learning Sequence 1. Students see an initial forecast for a cold front and make observations of temperature, humidity, and precipitation before, during, and after the front.</p>	<p>Lesson 7: Student Activity Sheet </p> <p>Cold front time-lapse video (https://scied.ucar.edu/weather-timelapse-lyons-colorado-may-8-2017)</p> <p>Whiteboard, smart board, or chart paper and markers (to make the Driving Question Board)</p>



NGSS Sensemaking

In the Engage lesson, students recognize that the model they developed in Learning Sequence 1 is inadequate for explaining some of the observations they have of the Colorado storm. Students notice that the Colorado storm lasts longer than an isolated storm. A new investigative phenomenon is introduced to students: a time-lapse video of a cold front, which is a kind of storm that can last longer and happen at different times of day. Students use existing Model Ideas from Learning Sequence 1 to make predictions about the changing conditions during the cold front and what may be causing those changes.

PERFORMANCE OUTCOME

- Use a model to make predictions about characteristics of air before, during, and after a cold front.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Use a model to predict phenomena.
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Identify limitations of models.

Teacher Procedures

What's a Cold Front Like?

1. **Navigate from the previous lesson.** Ask students to remind the class of important Model Ideas learned during Learning Sequence 1. Briefly review the Consensus Model students developed for explaining moisture available for an isolated storm. Use the prompts below to guide your discussion.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>What did we figure out about temperature and storms?</i>	Temperature warms up during the day on a sunny day and a stormy day. You need warm temperatures for evaporation.
<i>What did we figure out about humidity and storms?</i>	There has to be humidity in the air for a rainstorm to form.
<i>Can anyone explain why the storm happened in the afternoon?</i>	The storm happens in the afternoon after the Sun warmed the land, which heated the air above the land causing it to rise in the atmosphere and causing clouds to form.

End the discussion:

"We know there are other kinds of storms, and our model only helps us explain precipitation in one kind of storm, so we have some more investigating to do."

2. **Elicit students' prior knowledge of cold fronts.** Ask students if they've heard of a cold front. If so, what do they know about cold fronts? Just from looking at the term, what would they expect from this kind of a storm? Students may focus on the extreme shift in temperature that happens with a front. Other students may think cold fronts can only happen in the winter. During the Engage lesson, it is okay for students to have incomplete or inaccurate ideas about cold fronts. Take note of what your students know and don't know about cold fronts so that you can return to some of these ideas as this learning sequence unfolds.

LESSON 7
STEP 1

3. **Make observations of the cold front time-lapse video.** Tell students that you have a video of a cold front, and they need to figure out how this storm is different from the videos they've seen about isolated storms. Tell students they will watch the video twice:
 - The first time students watch the video, have them make observations without taking notes. Discuss their initial observations of how this storm might be different from the isolated storm.
 - Watch the video a second time, and have students take notes in *Lesson 7: Step 1* of their student activity sheets. Focus students on monitoring a certain component of weather and the time of day. You can do this by assigning students a component (e.g., precipitation, cloud cover, cloud types, wind direction) to take notes on and by pausing the video at certain moments to look for evidence of time of day.
 - Have students share what they observed from the video to compile a comprehensive description of observations from the video.



Storyline Link

Have students summarize important Model Ideas they developed in the previous unit. Many of these ideas will carry forward in this learning sequence.



Assessment

Use this opportunity to check for understanding. Listen for accurate explanations about temperature and humidity patterns for an isolated storm. If students are struggling to articulate these ideas, revisit the Model Idea Tracker and Consensus Model for an Isolated Storm.



Developing & Using Models

Learning Sequence 2 is motivated by the limitations of the model developed in Learning Sequence 1. Emphasize to students that models are helpful tools but imperfect.



COLD FRONT TIME-LAPSE VIDEO

Time-lapse video of a cold front from Lyons, Colorado on May 8, 2017

(<https://scied.ucar.edu/weather-timelapse-lyons-colorado-may-8-2017>)

Video break down and time codes:

0:00-0:52 — Sunrise-Noon

0:52-1:26 — Noon-4:00 p.m.

1:26-1:59 — 4:00 p.m.-Sunset

In the video you can see a few high-level cirrus clouds right after sunrise (starting at 20 seconds). Then mid-level clouds, lower and more uniform, form (starting at 27 seconds). Small, low-level cumulus clouds can be seen forming later (around 50 seconds). They grow into a cumulonimbus cloud that starts producing precipitation (about 1 min. 15 seconds). The cumulonimbus clouds change over the rest of the day, sometimes producing precipitation and sometimes not.

You may wish to provide some support for how students make observations from a time-lapse video because the cardinal directions are not given, clouds change so quickly, and precipitation can't be quantified.

- **Wind:** Have students look at the direction that clouds are moving (toward/away from the camera, left or right). Remind students that winds might be moving in different directions at different altitudes.
- **Precipitation:** Pause the video at a point when rain is visible.
- **Clouds:** If students have learned types of clouds, pause the video to give students time to identify the cloud type with ID guides such as the [GLOBE Cloud Chart](http://globe.gov/globecloudchart) (<http://globe.gov/globecloudchart>) or the [UCAR SciEd Field Guide to Clouds](https://scied.ucar.edu/apps/cloud-guide) (<https://scied.ucar.edu/apps/cloud-guide>). Or have students note a general trend in the amount of cloud cover.

LESSON 7

STEP 1

1. **Ask the question: *How is the storm in the time-lapse video different from an isolated storm?*** Students should think about the question on their own first. Then discuss as a class and have students record answers on their activity sheet in *Lesson 7: Step 1* (below the video observations box).

Student should notice that, unlike isolated thunderstorms, this storm comes earlier in the day, lasts longer, involves shifts in wind, and involves different cloud types.

LESSON 7

STEP 2

2. **Brainstorm other kinds of storms that don't fit the current model.** Ask students to work in small groups to brainstorm storms they've experienced that are not explained well by the Consensus Model for an Isolated Storm (e.g., thunderstorms at other times of day like the morning or middle of the night, a drizzly rainstorm that lasted all day, a blizzard). Students can record their ideas in *Lesson 7: Step 2*. Have the groups share their ideas aloud. Record important unexplained features of these storms (e.g., time of day doesn't match, the length of the storm doesn't match, the type of precipitation doesn't match).

Use the following questions to elicit student ideas:

- *Did the storm happen in the afternoon, like the one in our model?*
- *Did the storm last a short time (like a few hours), or did it last longer?*
- *How did the storm change the weather? What was the temperature like before, during, and after the storm?*



For guidance on cloud types see [Observing Cloud Types](#) at GLOBE.gov:



Patterns in Data & Cause-Effect

Students begin to learn the patterns in temperature and humidity data before, during, and after a cold front. They will not be able to recognize this as a pattern until later in the learning sequence.

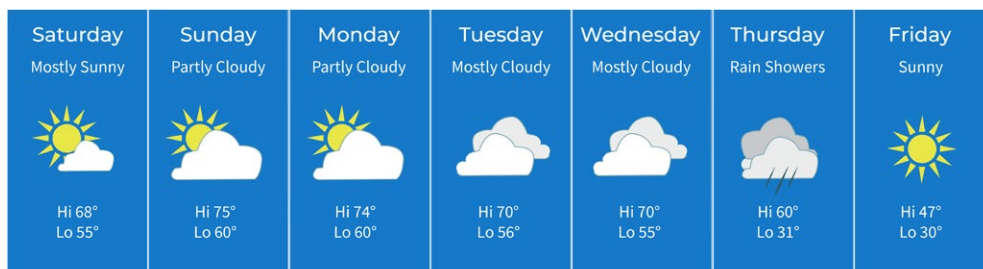


Storyline Link

Ask students to identify the data we need to understand patterns in a cold front. Students will likely bring up temperature, humidity, and precipitation. They may also mention wind and cloud cover data based on the time-lapse video.

LESSON
7
STEP 3

3. **Examine a weather forecast of a cold front.** After students note general patterns in a cold front, project a seven-day forecast that includes a cold front. Orient students to the forecast (*What do you notice? What can we tell about the weather?*). You may want to ask your students to make a claim about when the storm front moved through while just looking at the slide of the seven-day forecast before moving on to *Lesson 7: Step 3* of the student activity sheet. Have students share their claims and the evidence from the forecast that supports their claim. Next, hand out the student activity sheets and in *Lesson 7: Step 3* have students identify the day they think the cold front moved through the area. Record the temperatures before and after the cold front. Using information about clouds forming, ask students to estimate whether they think humidity was high or low. (Note that Fahrenheit is used instead of Celsius to match what is common in U.S. weather forecasts.)



4. **Discuss air patterns before and after the front.** Have students use their observations to discuss what the air was like before the front (Sat.-Wed.), what it was like the day the front passed through the area (Thurs.), and what it was like after the front passed (Fri.).
5. **End the discussion with the following question:**
- *What kind of data would be useful to figure out more about this kind of storm?*

Listen for responses such as:

- *We should explore what's different about humidity and temperature in a cold front.*
 - *We should see how much it rained or snowed.*
6. **Provide time for students to update the Driving Question Board.** Students may want to add questions to the Driving Question Board now that they've thought more about cold fronts. Adding questions to the board can be completed as an Exit Ticket or a concluding activity to the Engage lesson.


Assessment

Using Exit Tickets as a formative assessment provides clues to what your students are thinking and where they might need more instruction.


LESSON 8

WEATHER BEFORE, DURING, AND AFTER A COLD FRONT

How is air changing before, during, and after a cold front?



AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes)	
<p>Data Analysis: Temperature and Humidity in a Cold Front Students examine GLOBE temperature and humidity data for a 10-day period for a cold front that passed through South Riding, Virginia in October 2016. They use patterns from the days before, during, and after the front to characterize what the air was like leading up to the storm and after the storm passes through.</p>	<p>Lesson 8: Student Activity Sheet </p> <p>Whiteboard, smart board, or chart paper and markers (for the Driving Question Board)</p>

LESSON
8

WEATHER BEFORE, DURING, AND AFTER A COLD FRONT

How is air changing before, during, and after a cold front?



NGSS Sensemaking

Students analyze and interpret air temperature and humidity data to figure out how a storm associated with a cold front is similar to, or different from, the convective storm they already investigated. Students identify patterns in atmospheric conditions leading up to the front, during the front, and after the front. They use these patterns to generate a set of Model Ideas that they will use in the next lesson as they develop a Consensus Model for explaining precipitation during a cold front.

PERFORMANCE OUTCOME

- Analyze graphs to describe the changes in temperature and humidity before and after a cold front.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Analyze and interpret data to provide evidence of phenomena and to identify temporal relationships.
- Use graphs to identify patterns in data.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon.
- Patterns of change can be used to make predictions.

Teacher Procedures

Data Analysis: Temperature and Humidity in a Cold Front

1. **Navigate from the previous lesson.** Review the question discussed in the previous lesson to motivate the need to look at data during a cold front:

- *What types of data would be useful to figure out more about this kind of storm?*

Listen for responses such as:

- *We thought it would be important to look at humidity and temperature data during a cold front.*
- *We noticed the wind changing a lot during a cold front.*
- *We wanted to know if the precipitation was a lot and if it rained or snowed.*

Students will begin by examining temperature and humidity data building from their data analysis activities in previous lessons.

2. **Motivate the reason to look at weather data.** Explain that observing a storm in person (i.e., making visual observations, as they did during the Engage lesson) is one way to collect weather data. Using measurements from weather instruments is another way to collect weather data. Ask students to describe the types of measurements they've already found useful for making sense of storms (temperature, humidity).

End with:

Let's see what's going on with temperature and humidity before, during, and after a cold front to see what's similar or different from what we already know.

LESSON
8

STEP 1

3. **Direct students' attention to the Lesson 8: Student Activity Sheet.** Read through the instructions and weather report prompt together. This brief report provides students with useful information to identify when the cold front passed through this location on their graphs.

Prompt students to call out clues from the weather report:

- *What day do we expect the front to move into South Riding, Virginia?*
- *How long do we expect the front to be in the area?*

4. **Preview the new graphs.** Ask students to look at the air temperature graph in *Lesson 8: Step 1* and take note of what's different about this graph compared to the sunny day and stormy day air temperature graphs from Learning Sequence 1 (e.g., now the graph has 10 days and not one day). Consider having students cover up all but one day on the graph to help them notice the connection to the diurnal pattern in the 24-hour temperature graph. Prompt students to notice where the data comes from, how long the data were collected, and other wonderings they have.

Use the following prompts:

- *What information is the graph showing?*
- *Where were the data measured? What time of year?*
- *What do we think the wiggly up and down line means?*
- *How do the ups and downs relate to the temperature ups and downs on our sunny and stormy data graphs?*



Storyline Link

In the previous lesson, students shared ideas about weather data to examine in order to better understand a cold front.



Data Analysis & Interpretation

Students use the I^2 Sensemaking Strategy or comparable graph analysis strategy to analyze temperature and humidity data before, during, and after a front.



Patterns in Data

To support student discussion of the graphs, prompt students to identify patterns in the graphs in terms of before and after the front. The front itself is a disruption to the normal diurnal pattern.

FREEDOM HIGH SCHOOL DATA SET.

This data set comes from Freedom High School (a GLOBE school) in South Riding, Virginia. Data includes the temperature and (relative) humidity from October 16 - 25, 2016. In addition, pressure data from the same location and timeframe is found in Lesson 10. These data come from a WeatherBug automated weather station co-located with this GLOBE school. These automated stations record weather data daily every 15 minutes. These data can be found on the GLOBE Visualization Tool and the GLOBE Advanced Data Access Tool.

5. **Students use the weather report information to circle on the graph when the cold front passes through South Riding, Virginia.** You may also choose to have students label “before,” “during,” and “after,” the front to aid in reading the graph.



6. **Students use the I² Sensemaking Strategy to make observations of the graph and to interpret those observations.** Remind students to make observations before they begin to explain those observations.

- Students write their own What I See (WIS) statements first.
- Have students share their WIS statements in partners or groups. Students can add to their graphs at this time.
- Prompt students to add What It Means (WIM) statements next to each WIS statement. The WIM statements are students' initial explanations of what's happening in a specific part of the graph.
- Ask several students to share their WIS and WIM statements aloud.



STEP 1

7. **Use the questions from the student activity sheet in Lesson 8: Step 1 to guide a discussion about patterns in the graph, focusing on distinctions before, during, and after the front.**

KEY PATTERN: Students should notice a regular diurnal pattern before the front that gets disrupted. This diurnal pattern returns after the front, but it's colder.



STEP 2

STEP 3

8. **Have students circle/label their graphs and use the I² Sensemaking Strategy again as they interpret the humidity graph (Lesson 8: Step 2) and the wind data (Lesson 8: Step 3).** Students will notice changes in humidity before and after the front, which correlate with different air masses. Students will also notice that wind speeds increased as the front moved through. While they may not have all the information to understand the wind data, students should be able to correlate wind with the front.

9. **Conclude the data analysis with a discussion of patterns in atmospheric conditions when the front first arrives on the morning of October 21, 2016:**

- *Why do you think the chances are high for precipitation the morning of October 21?*
- *How is this storm similar to, or different from, the isolated storm?*
- *If you collected weather data at your school, what types of weather events would you likely observe?*

10. **Document Model Ideas to close the lesson.** While students have not developed a model for a cold front yet, now is the time to document Model Ideas (rules of the system) based on their observations of cold front storms—both visual observations from the time-lapse video and data analysis. In this data analysis activity, students learn that humidity is high the morning of precipitation (very much like it was in the isolated storm). This Model Idea should be documented on the Model Idea Tracker.



Developing & Using Models

Use the Model Idea Tracker to document new rules students figured out about a cold front system. Remember these are general rules of thumb that are helpful for explaining a cold front phenomenon. You can consider starting a new Model Idea Tracker for this learning sequence or add to the Model Ideas started in previous lessons.



Going Deeper

Support students in understanding the pros and cons of using a model by debating these ideas in a public setting. Once the Model Ideas are documented, allow students to move around the room between a pro and a con side for each Model Idea. If students think the model did not work to cover the Model Idea, ask them to make suggestions to improve the Model Idea.

Additional Model Ideas you may want to add at this time include:

- Temperatures are warmer before a cold front and follow the normal up/down pattern for a sunny day.
- Temperatures are colder after the front but also follow the normal up/down pattern for a sunny day.
- Humidity is higher before a cold front and follows the normal up/down pattern for a sunny day.
- Humidity is lower after a cold front but also follows the normal up/down pattern for a sunny day.


 LESSON 9

STORMS AND PRECIPITATION ALONG A FRONT

What causes precipitation along a cold front?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(100 minutes)	
<p>Warm Meets Cold</p> <p>Using what students know about atmospheric conditions before and after the front, students make observations of what happens when these two kinds of fluids push into each other. Based on the density tank model, students extract additional Model Ideas to add to the Model Idea Tracker.</p>	<p>Lesson 9: Student Activity Sheet </p> <p>Density tank</p> <p>Warm red water, Cold blue water, Slow-motion video recorder (optional), Colored pencils (red/blue).</p>
<p>Consensus Model: Precipitation along a Cold Front</p> <p>Students use the Model Idea Tracker to start to develop a Consensus Model for explaining why there is moisture available along the boundary between cold and warm air and what happens for precipitation to form. Students read more about air masses and fronts and connect this new information back to the data analysis activity and the density tank. Students revisit their Consensus Models to revise then write an explanation using their models.</p>	<p>Whiteboard, smart board, or chart paper and markers (for the Model Idea Tracker and Consensus Model).</p>
<p>Big Picture: Tracking a Cold Front</p> <p>In this activity, students use their models to explain how precipitation along the front moves as the front moves. This transition is important. Students have looked at one location from a cross-section perspective as a front passes through the location. Now they look at a front from a map-view perspective, following the front as it moves across a region.</p>	<p>Colored pencils.</p>



STORMS AND PRECIPITATION ALONG A FRONT

What causes precipitation along a cold front?



NGSS Sensemaking

Students develop a model for explaining moisture available over a location during a cold front and how that moisture source might lead to precipitation along the front. Students critically read a scientific text to gather more information about air masses and fronts that they can use to refine their Consensus Model. Students switch perspectives to follow a cold front across a region, identifying the location of the front and location of air masses using temperature and precipitation data. Students find that not every location has precipitation, which initiates a discussion of the power and limitation of their Consensus Model.

PERFORMANCE OUTCOME

- Develop a model to show how differences in temperature and humidity before and after a cold front interact to cause a storm.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure, causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time and how sudden changes in weather can result when different air masses collide.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events.

Teacher Procedures

Warm Meets Cold

LESSON 9

STEP 1

1. **Students review the previous lesson by drawing weather conditions before, during, and after a cold front.** Direct students to *Lesson 9: Step 1* in their student activity sheets. Ask students to draw a visual depiction of atmospheric conditions the day before, during, and the day after a cold front based on what they have learned in the previous activities (e.g., time-lapse video, weather forecast, data analysis from Freedom High School). Prompt students to include in their representations the temperature and humidity conditions based on prior evidence. This activity will help prime students for the density tank demonstration.
2. **Discuss students' illustrations using the question prompts below:**
 - *What days would you expect more rising warm air and why?*
 - *Would you expect more water vapor to be in the warm air or the cool air?*
 - *If we looked where the two kinds of air "touched," what would we see?*
3. **Figuring out the air at the front.** Set the stage for this activity: *We need to make observations of what happens where warm and cold air meet to help us figure out why there is precipitation in the area where they meet. Since we can't see air with our eyes, let's use warm and cold water to represent the two air masses to figure out why precipitation forms along the boundary (front).* Set the purpose of the demonstration to figure out why precipitation forms along a front by making observations of a place where cold and warm fluids meet.

DEMONSTRATION: PRECIPITATION ALONG A FRONT

Materials:

- Density tank with a plexiglass divider.
- Warm water (using an electric kettle; do not boil).
- Cold water (chilled with ice, but don't include ice in the tank).
- Red and blue food coloring.



Preparation:

- a. Heat enough water to fill half the tank using an electric kettle (do not boil) and add red food coloring.
- b. Prepare a pitcher of cold water chilled with ice (enough to fill half the tank) and add blue food coloring.
- c. Prepare both warm and cold water outside the density tank and stage them near the tank. Placing the tank in front of a white background (a light colored wall or by hanging white paper behind the tank) will make it easier to observe changes inside the tank.
- d. With the class watching, add the cold water to the LEFT side of the tank and the warm water to the RIGHT side. You'll need to add both liquids to the tank quickly to avoid too much seepage between the plexiglass divider.



Storyline Link

In this lesson, students learn about a new mechanism for getting warm, moist air high in the atmosphere. Connect to what they already know about convection and isolated storms.



Disciplinary Core Idea: Water

Students work on their conceptual understanding of how moisture becomes available over certain locations and how this differs between a convective storm and a cold front.

- Orient students to the model.** Before adding water to the density tank, show students the model and explain that the tank represents the atmosphere. (You may wish to remind students that a physical model is a representation of a real-world phenomenon.)

Orient students to the parts of the model:

- The bottom of the tank is the land surface.
 - The water in the tank represents air. This model uses water to simulate air because both air and water are fluids, so they behave similarly, but water can be seen.
 - Warm air ahead of the front will be simulated with warm water that is colored red.
 - Cold air behind the front will be simulated with chilled water colored blue.
- Prepare for observations.** Students will sketch a cross section on their student activity sheets after the demonstration. Note that this is the first time a cross-sectional view is introduced and that students may need to be oriented to this perspective (versus a map view). Also note that the water in the demonstration moves very quickly. Students may wish to make a video or take photos. Consider capturing the demonstration using slow-motion video for students to replay to make more detailed observations or by viewing the Density Tank slow-motion video provided below. Explain that having several ways to document what is happening is a good idea because different types of data can be used together to help us understand what is happening.
 - Predict what will happen.** At the start of the demonstration, have a piece of plexiglass dividing the two halves of the tank. Explain how the demonstration will be completed. Ask students to predict what will happen when the barrier is removed.

LESSON
9

STEP 2

- Add water to the tank.** Simultaneously, pour cold water colored blue into the left side and warm water colored red into the right side of the tank. (Note: You can use ice to cool the blue water, but don't include the ice in the tank because it is not a fluid.) Also, do not wait too long before pulling the plexiglass divider as some water may seep around the divider. Students should draw the demonstration set-up before the divider is removed in *Lesson 9: Step 2* of their activity sheets.
- Make observations.** Remove the barrier and have students document what they see happening in the tank in *Lesson 9: Step 2* of their activity sheets. Students should observe that the cold water flows under the warm water, and the warm water is pushed up. (Note: This happens rather quickly in a small tank, so you may wish to have enough warm and cold water on hand to repeat the model a few times.) Review student-captured videos or play the Density Tank slow-motion video several times as needed to assist students as they record their observations.



DENSITY TANK SLOW-MOTION VIDEO

[Slow-motion video of the Density Tank demonstration](https://scied.ucar.edu/cold-front-density-tank-slow-motion)

(<https://scied.ucar.edu/cold-front-density-tank-slow-motion>)

This video shows, in slow motion, what happens when the density tank partition is removed. Notice that the cold fluid (blue) plows into the warm fluid (red), forcing it upward.

- Making sense of the demonstration.** Ask students to share what they observed and articulate how they diagrammed the phenomenon.

Use the following questions to guide this discussion:

- What happened to the warm fluid? What happened to the cold fluid? Why did this happen?
- What would happen to the warm air ahead of the front and the cold air behind the front when they come together?



Developing & Using Models

Explore the power and limitation of models. Students may notice water ricocheting off the side of the tank—an artifact of the model and not part of the process of cold front formation. This is an opportunity to discuss where the density tank model is useful for observing what happens where warm and cold fluids meet, but it also is limited because it's different from the real world.

Use the Model Idea Tracker to document new rules students figured out about a cold front system. Remember these are general rules of thumb that are helpful for explaining a cold front phenomenon.

- How could this help us explain precipitation along the front?

Students should make the analogy to the atmosphere—at a cold front, cold air goes underneath the warm air because it is denser. The warm air goes higher into the atmosphere because it is less dense. Remind students of how isolated storms form where warm, moist air rises higher in the atmosphere. At a cold front, warm, moist air is also pushed higher in the atmosphere, although the mechanism is different.

Students may need support to understand how the warm air is pushed up in this model since the top surface of the water in the tank remains the same. To help students, have them draw a horizontal line on their drawings or photos in the middle of the tank before the divider was removed and after. Note how much of the red (warm) water was below the middle before (half of it) and after (much less than half) the divider was removed.

- 10. Document a new Model Idea on the Model Idea Tracker.** Students figure out that when cold air and warm air meet, cold air flows underneath while warm air rises.

Model Idea:

- When cold air meets warm air, the cold air flows below the warm air. The warm air rises into the atmosphere.

Consensus Model: Precipitation along a Cold Front

- 1. Navigate from the previous activity.** Based on their observations of the density tank, elicit students' initial explanations for why precipitation happens where cold and warm air meet.

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>Think back to what we know about air temperature and humidity. Which kind of air is able to evaporate more water? Warm air or cool air?</i>	Temperature warms up during the day on a sunny day and a stormy day. You need warm temperatures for evaporation.
<i>When the warm air rises in the atmosphere, describe what happens to the moisture in the warm air.</i>	When the warm air rises, it gets colder. Cold air can't move as much water vapor into the air, so moisture condenses, forming clouds.



Assessment

Students are ready to put the pieces together to explain precipitation along the front. Students' responses to these questions can inform your approach to the Consensus Model (e.g., do they need more or less scaffolding to put the pieces together)



STEP 3

- 2. Small group Consensus Model.** Explain to students that we need to model how precipitation is happening along the front. Direct students to the list of items to include in their model in *Lesson 9: Step 3* of their student activity sheets. Allow students time to discuss this list in groups to brainstorm their ideas. When they are ready, they can diagram and label their models on their activity sheets as a group. They should discuss how best to represent their ideas in the model. (Note: The model has the air before the front on the right side and the air after the front on the left side. This follows the convention of most cold front models; however, it may be counterintuitive to students because the Freedom High School data for the air before the front was on the left side of the graph and the air after the front was on the right side of the graph. Take time to orient students to the transition between the graphed data and the modeling convention.)

LESSON
9

STEP 4

3. **Readings on air masses and fronts.** Use the scientific reading (*Lesson 9: Step 4*) to clarify and challenge students' models. Orient students to the different weather maps in the reading (*What do the different symbols mean? What information does the map show?*). Set the purpose: *Let's read more about this phenomenon of a cold front to help us clarify a few of the questions we still have. Then we'll come back to our models to make some adjustments.* Students can read individually or as a whole group. Prompt students to stop and think as they encounter questions in the text. These questions are to help students make connections between the information they read and their previous investigations.

LESSON
9

STEP 5

4. **Compare two types of storms.** At the end of the reading (*Lesson 9: Step 5*), students are prompted to diagram two different ways moisture becomes available—the first way is in the isolated storm through convection, and the second way is in a cold front through the interaction of two air masses. These diagrams can inform their models for precipitation along a cold front (*from Lesson 9: Step 3*).

LESSON
9

STEP 3

5. **Revise small group Consensus Models.** Say: *Some things in the reading we already knew, but there was new information we read about. Let's go back to our models (Lesson 9: Step 3) and add details using this new information.* This gives students time to discuss new ideas. As students work, circulate around the room prompting students to add to their models.

Use the following prompts:

- *Where in your model is the warm air mass? Where in your model is the cold air mass?*
 - *How can you use what we observed in the tank to explain what's happening right here where they meet?*
 - *Can you label where there is more moisture and what's happening for it to become precipitation?*
6. **Develop a class Consensus Model.** Ask each group to share their models. As you start to notice patterns in the models (e.g., the warm air ahead of the front is a warm air mass, the warm air mass has more moisture) ask students if they agree we should add this to the Model Idea Tracker. Once several ideas have been added to the Model Idea Tracker, transition to creating the Consensus Model. Decide how to represent each Model Idea in the Consensus Model.

Model Ideas:

- Air masses can have different temperatures (warm, cold).
 - Air masses can have different amounts of moisture (a lot or a little).
 - When a cold air mass pushes into a warm air mass, the warm air moves up above the cold air.
 - As the warm air mass moves up, it cools and moisture in the air condenses, forming clouds, which can lead to precipitation.
7. **Revisit the explanation for South Riding, Virginia (Lesson 9: Step 3).** After the Consensus Model is complete, prompt students to use this model to revise their explanation of the temperature and humidity changes in South Riding, Virginia and why precipitation likely occurred along the cold front. This can be done as a class discussion.

**Obtaining Information**

Students read scientific text to obtain information about a phenomenon in the natural world.

**Literacy Connection**

Students read non-fiction texts and are prompted to make connections and to synthesize ideas.

**Assessment**

Ask students to complete the explanations individually. Evaluate students' explanations as a formative assessment of their understanding of front systems.

Big Picture: Tracking a Cold Front

1. **Navigate from the previous activity.** In the previous activity, students learned that precipitation in a cold front forms along the boundary between cold and warm air masses. Have students explain why the precipitation is located along the boundary using the following prompts:

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>How does the moisture turn into precipitation along the front? What causes that?</i>	The warm, moist air is pushed up by the cold air and the water vapor condenses in the colder temperatures.
<i>What would need to happen for more precipitation to happen or for less to happen?</i>	There would need to be more moisture in the warm air for more precipitation. If there is not a lot of moisture, then there probably wouldn't be as much precipitation.

2. **Talk about perspective.** Up until now, students have explored a cold front looking at a single location as the front moves through. They've developed a model for explaining precipitation along the front but from a cross-sectional perspective. Ask students: *After a front passes through a place, where does it go next?* Tell students that we need to zoom out to see how big the front is, how it travels, and what happens to the precipitation along the front. Zooming out will transition students from a cross-sectional view to a map view, so take time to orient students to what they are examining in this new data set.
3. **Plan for mapping the cold front.** Direct students' attention to *Lesson 9: Step 6* of their student activity sheets. Tell students to use data to locate the front on a map and to identify where and why certain locations have precipitation. Point out that students will be considering how conditions changed over four days at each specific location but also how conditions changed over the four days for the entire region. Let students know that by examining a map view we are able to gain a larger perspective over a region, which is different than the localized cross-sectional views from before.
4. **Read through the instructions together for labeling and coloring their maps.** Break students into groups of four and ensure that each student within the group is assigned a different day to map.
5. **Students map their data and combine their maps for analysis.** Students color and label maps individually. In groups of four, students combine their maps into a four-day sequence. Together, students locate the front and label this on each of the four maps. They use the temperature data to locate and color the cold and warm air masses.
6. **Class discussion and reflection.** Ask students to share their observations of the front moving and the location of the warm and cold air masses. Prompt students to use temperature data to back up their decision about the location of air masses. A second line of discussion should focus on why some locations along the front had precipitation while other locations did not.

Use the following questions to guide this discussion:

- *How can we use temperature to figure out the kind of air over a region?*
- *Where do we think the cold air mass comes from? Why?*



Storyline Link

Students will now use the ideas they've developed to explain a cold front. However, there is an important shift in perspective in this activity (i.e., from cross-sectional view to map view) that may make it more challenging for students. Students may struggle moving from the cross-sectional view of the front to the map view of the front.



Assessment

Use this discussion to formatively assess student learning of fronts and air masses.



Storyline Link

Students will build on the movement of fronts across a region in the next lesson. This conversation can be used to elicit some of their initial ideas.



STEP 6

- *Where do we think the warm air mass comes from? Why?*
- *If we predicted the weather for the next day, which direction would the front move?*
- *Let's use our model to figure out why some locations along the front had precipitation while others did not.*

POWER AND LIMITATION OF MODELS: WEATHER PREDICTIONS.

The last question in the set above might lead to a discussion of students' models for explaining precipitation along a cold front. Not all locations along the front have precipitation, so students should consider how their models help them figure out what's happening in the places with precipitation and what might be happening where there is no precipitation. Students may identify that their models are limited—there must be other factors that control the amount of precipitation that their models do not take into account. It's important to talk about how their models are helpful for understanding precipitation along a cold front and where their models might be incomplete.

**Developing & Using Models**

Students think about the lack of precipitation in locations to reflect on the limitations of their Consensus Model.


 LESSON 10

FRONT ON THE MOVE

What causes fronts to move?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(100 minutes before optional extension)	
<p>Under Pressure (50 min.) Students are introduced to air pressure and its role in the movement of air masses and fronts. Students analyze air pressure data to identify areas of high and low pressure around a front. They use this information to identify patterns in areas of high and low pressure and to generate a reason fronts move from high to low pressure.</p>	<p>Lesson 10: Student Activity Sheet </p> <p>Colored pencils (red/blue). Balloons, dry beans, lentils, or small beads. Paper and pencil.</p>
<p>Optional Extension: Barometric Pressure Measurements Students use the GLOBE Barometric Pressure Protocol to make measurements of barometric pressure.</p>	<p>Aneroid barometer or altimeter GLOBE Barometric Pressure Protocol (globe.gov/do-globe/globe-teachers-guide/atmosphere)</p>
<p>Pressure: Data Analysis (50 min.) Students examine pressure and wind data for South Riding, Virginia and continue to develop their ideas about high and low pressure before, during, and after a front. Students add to their Model Idea Tracker and revisit their Consensus Model.</p>	<p>Whiteboard, smart board, or chart paper and markers (for the Model Idea Tracker and Consensus Model)</p>



FRONT ON THE MOVE

What causes fronts to move?



NGSS Sensemaking

In the first Elaborate lesson, students begin to explain movement of air masses and fronts by scaling up ideas about air pressure as they pertain to high- and low-pressure systems. Students begin their investigations by revisiting South Riding, Virginia data, now layering on air pressure before, during, and after the front.

PERFORMANCE OUTCOME

- Analyze patterns in data to describe how pressure changes before and after a cold front.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Analyze and interpret data to provide evidence of phenomena and to identify temporal relationships.
- Use graphs to identify patterns in data.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon.
- Patterns of change can be used to make predictions.

Teacher Procedures

Under Pressure

1. **Navigate from the previous lesson.** Using students' ideas from the Big Picture activity (*Lesson 9: Step 6*), review the following questions from the previous discussion:

SUGGESTED PROMPTS	SAMPLE STUDENT RESPONSES
<i>If we predicted the weather the next day, which direction would the front move?</i>	The front would probably move to the right because we saw that in the Big Picture.
<i>What do we think is causing the front?</i>	The wind is causing the front.

2. **Set the purpose for this activity.**

Explain to students:

Now that we know more about how a front works, let's see if we can figure out why it's moving and where it's headed next. If we can figure this out, we know which communities should expect precipitation from the front when it arrives in their areas.

3. **Remind students about air pressure by physically modeling air pressure.** *Tell students that barometric pressure measurements are another weather measurement needed to figure out the direction of movement. Use beans or an equivalent item (lentils, beads, etc.) to have students model what air at high pressure might feel like compared to air at low pressure. Give students 20 beans to hold in one hand compared to five beans in the other hand. Have students close their eyes and pay attention to the pressure the beans are putting on the surface of their hands. (Note: The beans do not do a good job modeling the distance between the grains and whether the air is rising or sinking in the column. However, it can be used to help students understand that what's in the column of air above a surface exerts pressure onto that surface.)*
4. **Optional extension: Measure barometric pressure using the GLOBE Barometric Pressure Protocol.** The GLOBE Barometric Pressure Protocol is another excellent opportunity for students to make measurements of their environment and to provide experience with barometers as tools for measuring the weather. Introduce the GLOBE Barometric Pressure Protocol at this time if students will be making measurements. You will use an aneroid barometer or altimeter along with the protocol. If you have a digital barometer in your classroom or any other equipment for measuring barometric pressure, it would be valuable to take readings from those as well.



[The Barometric Pressure Protocol](https://www.globe.gov/do-globe/globe-teachers-guide/atmosphere)

(<https://www.globe.gov/do-globe/globe-teachers-guide/atmosphere>)

LESSON
10

STEP 1

5. **Connect air pressure to rising and sinking air.** Direct students' attention to *Lesson 10: Step 1* of their student activity sheets. Have students read the page and then, as a class, discuss the image (below) that shows how air moves in areas of high and low pressure. Ask students to think about how the density of the sinking air in an area of high pressure is different than the density of the rising air in a low-pressure area. Point out that a large, blue "H" is used on a weather map to indicate the center of high pressure, and a large, red "L" is used to indicate the center of low pressure. (Note: It's okay if students do not know why air turns in different ways for high and low pressure. This can be revisited again after the Coriolis effect is taught in Learning Sequence 3.)



Storyline Link

Students continue to build an understanding of the movement of a cold front through a region, adding in the role of areas of low and high pressure.



Disciplinary Core Idea: Air Pressure

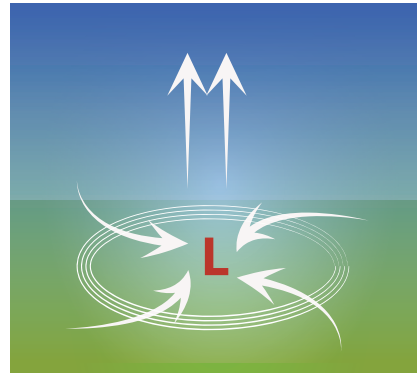
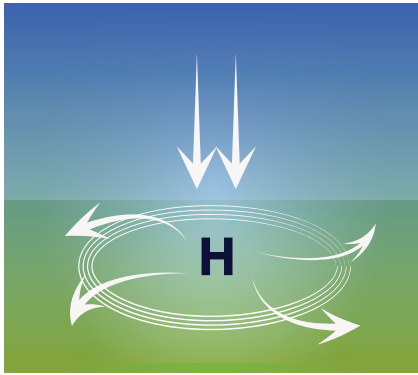
The content of this activity depends on whether your students have learned about air pressure prior to this unit. If so, leverage what they know to explore air pressure in more depth. The current version of the activity is written without this expectation.



GLOBE Connection

GLOBE schools also collect barometric pressure data. If your students are familiar with making the measurement, help them make the connection between the data they collect and the data they are investigating.

LESSON
10
STEP 1



- 6. Connect the vertical up and down movement of air pressure with the horizontal toward and away movement.** Using the same graphic, transition to focusing on the arrows moving toward the area of low pressure and the arrows moving away from the area of high pressure.
- 7. Make a hands-on connection to air movement in high and low pressure.** Break students into pairs. Give each pair a balloon filled with a golf-ball-sized amount of dry beans (or lentils, beads, etc.). Tell students that the beans inside the balloon represent molecules of air. They are to place their balloon on a piece of paper and trace a circle around the edges of their balloon. Have one student push down on the balloon, simulating high pressure. The other student should trace a new circle around the edges of the “pressurized” balloon. Next simulate low pressure by releasing the balloon. Compare the size of the two circles. Students can take turns simulating high pressure on the balloon and low pressure by releasing the balloon.

Students should take turns explaining to each other what happens to air under high pressure and low pressure, using the following prompts:

- *What happens to air when there is high pressure? Where does it go?*
- *The circles you drew show how air moved at the ground level. Why was the circle bigger for the air under high pressure?*

Refer to the diagrams in *Lesson 10: Step 1* to help students make connections between air in the atmosphere and the balloon activity.

- 8. Demonstrate our understanding of air under high pressure and low pressure.** Consider using a back-to-back strategy here to get students up and moving as they discuss their ideas. Students reflect on how the up and down movement of air influences the movement of air across the surface.
 - Form two lines, standing back-to-back with a person from the other line.
 - Listen to the question the teacher asks related to the activity:
 - *If air at an area of low pressure is rising, why would these arrows move toward it?*
 - *If air at an area of high pressure is sinking, why would these other arrows move away from it?*
 - Ask students to individually reflect until the teacher calls: Turn (usually about 30 seconds). Then say: *Turn*.
 - Students discuss their reflections with the student with whom they were back-to-back.



Data Analysis & Interpretation

Students analyze barometric pressure data around the front from the Big Picture.



Using Models

Using the filled balloon to simulate air in high- and low-pressure systems provides a kinesthetic connection to the concepts.



Going Deeper

Blow up a balloon. Sketch what high pressure inside the balloon looks like compared to the low pressure outside the balloon. Ask students to predict what would happen if you popped the balloon. Would air rush in or would the air inside rush out? Ask students to diagram the direction the air would move (from high pressure inside to low pressure outside). Then pop the balloon!

9. **Use pressure data to figure out which direction a front is moving.** Direct students to *Lesson 10: Step 2* of their student activity sheets. Read through the instructions together and orient students to the air pressure map.

LESSON
10
STEP 2

10. **Ask students to make predictions:** *If areas of high pressure and low pressure were in the same region, how would you predict air to move between the two of them?* Then give students time to complete the activity.
11. **Discuss the patterns students see and how air pressure relates to movement.** Keep the columns of cold air and warm air projected for students. Using the discussion prompt at the bottom of the student activity sheet, facilitate a discussion where students generate a claim about which way the wind blew. Students will continue to develop this explanation in the next activity.

Suggested question to discuss:

- *The front is moving from the west (left side of the map) to the east (right side of the map). The arrows on the cold front point in the direction it is moving. Using the barometric pressure measurements, why might the front move in this direction?*

PRESSURE: DATA ANALYSIS

1. **Navigate from the previous activity.** Students started to develop an explanation for pressure by examining barometric pressure readings around a front. Have students review what they learned from this activity focusing on where high pressure was located (behind the front) and where low pressure was located (along the front and at the northern end).
2. **Set the purpose for looking closer at pressure.**

Ask students:

If we go back to Freedom High School in Virginia and were expecting a cold front to come through, how would we expect pressure to change before, during, and after the front?

Tell students to use what they learned from the previous lesson (*Lesson 10: Steps 1 & 2: Under Pressure*) to predict what the pressure might be like as the front moves through a location. Elicit students' initial ideas in response to this question.

LESSON
10
STEP 3

3. **Direct students to Lesson 10: Step 3 on their activity sheets.** Read through the instructions together. Prompt students to use the I² Sensemaking Strategy (What I See/What It Means) to analyze the barometric pressure graph. Remind students that they are now looking at a single location as the front moves through. Orient students to the graphed data as needed before they analyze the graph.
4. Students analyze and interpret the graph. Give students time to work together to analyze the barometric pressure graph. Prompt students to discuss and then answer the analysis questions below the graph.
5. **Discuss the data to generate Model Ideas.** Discuss students' observations of the graph. Focus students on sharing What I See statements first before transitioning to What It Means statements. As students share observations of low pressure and high pressure, ask them to make connections to the pressure regional map (*Step 2*) and where the areas of low and high pressure occurred around the front (e.g., near the front, behind the front).



Assessment

Listen to how students explain their thinking to their partner as a formative assessment.



Data Analysis & Interpretation

Students analyze pressure data from Freedom High School to identify where the low and high pressure is located around a cold front.



Storyline Link

Students viewed pressure data from a map perspective across a region. They will now view pressure data for a single location across time. Make this shift in perspective explicit to students.

Generate patterns to explain pressure and turn these patterns into Model Ideas for the Model Idea Tracker.

- **Model Ideas rooted in the spatial, map view data may be:**
 - Areas of high pressure are usually behind the cold front.
 - Areas of low pressure are around the front and at the northern end.
- **Model Ideas rooted in the analysis of temporal data may be:**
 - After a cold front moves through, a location may experience high pressure associated with cooler, sinking air that has less moisture.
 - Just before and during the storm, an area may experience low pressure, which is associated with warm, rising air and precipitation.
 - Air moves from high to low pressure.

**Developing & Using Models**

Add to the Model Idea Tracker new ideas about areas of high and low pressure and how air is moving between the two.

LESSON 11

A CLOSER LOOK AT LOW-PRESSURE SYSTEMS

What could cause a front to stall?


ENGAGE

EXPLORE

EXPLAIN

ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(75 minutes)	
<p>Explaining the Colorado Storm Students revisit the Colorado storm from the Anchoring Phenomenon (Lesson 1), examining rainfall data and interpreting a storm report to develop an initial model of the storm. Students use their models to develop a Consensus Model to describe how exceptional moisture from the Gulf of Mexico and Pacific Ocean made its way to Colorado (e.g., through the interaction of air masses along a stalled front and influences of areas of high and low pressure on the movement of the front).</p>	<p>Lesson 11: Student Activity Sheet </p> <p>Video from the Anchoring Phenomenon (Lesson 1).</p> <p>Whiteboard, smart board, or chart paper and markers (for the Model Idea Tracker, Consensus Model, and Driving Question Board).</p> <p>Video of storm water vapor.</p> <p>NASA videos showing storm movement across the U.S.</p>



A CLOSER LOOK AT LOW-PRESSURE SYSTEMS

What could cause a front to stall?



NGSS Sensemaking

Students use general Model Ideas to develop a case-based model for the Anchoring Phenomenon. Students analyze rainfall data and interpret a weather report to piece together the major factors that caused the Colorado storm in 2013. They use their knowledge of air masses, fronts, and areas of high and low pressure to explain why Boulder and the surrounding region received exceptional precipitation. Students identify Model Ideas that are useful for explaining a wide variety of storm phenomena and also the case-specific things happening in the Colorado storm that made it unique.

PERFORMANCE OUTCOME

- Analyze pressure and humidity data to describe the movement of air and moisture from one place to another.
- Develop a model to show how differences in pressure cause the movement of moisture that leads to a storm.

NGSS DIMENSIONS (GRADES 6-8)

- Air masses flow from regions of high pressure to low pressure causing weather (defined by temperature, pressure, humidity, precipitation, and wind) at a fixed location to change over time. Sudden changes in weather can result when different air masses collide.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Analyze and interpret data to provide evidence of phenomena and to identify temporal relationships.
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (3-5) (REINFORCING)

- Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon.
- Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequently and regularly occurring events.
- Patterns of change can be used to make predictions.

Teacher Procedures

Explaining the Colorado Storm

- Navigate from the previous lesson.** Have students summarize the ideas added to the Model Idea Tracker from the previous lesson. Consider doing this by asking students to stop and jot down big ideas they learned in the previous lesson. Use the discussion of these ideas to help you assess what big points students took away from the previous pressure activities.

 - Model Ideas rooted in the spatial, map view data may be:**

 - Areas of high pressure are usually behind the cold front.
 - Areas of low pressure are around the front and at the northern end.
 - Model Ideas rooted in the analysis of temporal data may be:**

 - After a cold front moves through, a location may experience high pressure associated with cooler, sinking air that has less moisture.
 - Just before and during the storm, an area may experience low pressure, which is associated with warm, rising air and precipitation.
 - Air moves from high to low pressure.
- Revisit the Anchoring Phenomenon.** Set the stage for using these models to figure out what's happening with the Colorado storm. Replay the video.



CASE STUDY: COLORADO FLOODS

In September 2013, a storm stalled over the region around Boulder, Colorado bringing a weeklong deluge of rain, resulting in dangerous floods.

[How the City's Resilience Strategy Saved It](https://scied.ucar.edu/video/boulder-colorado-flood-how-citys-resilience-strategy-saved-it)

(<https://scied.ucar.edu/video/boulder-colorado-flood-how-citys-resilience-strategy-saved-it>)

[What Flooding Looked Like in Boulder, Colorado](https://scied.ucar.edu/boulder-floods)

(<https://scied.ucar.edu/boulder-floods>)

The video is six minutes, 48 seconds in length and provides a case study. To help students focus on what happened in the flood, note the following time codes:

0:00-2:08—Introduction to the 2013 flood in Boulder and past floods in this same area. Some effects are shown.

2:09-4:11—Engineering considerations related to managing future floods based on past experiences are addressed.

4:12—End of video on the 2013 flood and community resilience.

6:13—A cause is mentioned.

- Explain that the Colorado storm was unusual.** Explain to students that this storm was different from an isolated storm and a cold front. Tell students that their job is to examine data from the Colorado storm and compare it with what they know about typical isolated storms and cold fronts.



Assessment

Ask students to jot down some of the big ideas we came up with in the last lesson. Listen to the ideas that students share and how closely they match the Model Ideas added to the Model Idea Tracker on the previous day. This provides useful information about how close individual student's main takeaway ideas match the Model Ideas developed collaboratively by the class.

LESSON
11
STEP 1

4. **Students analyze rainfall data from the Colorado storm to learn how long it lasted.** Read the instructions at the top of the *Lesson 11: Student Activity Sheet* together. Arrange students in groups to do an analysis activity in *Lesson 11: Step 1*. After examining the rainfall data, students make a claim about whether the Colorado storm was an isolated storm, a cold front, or something different. Students should use evidence from throughout the unit to support their claim. Use a show of hands to see which claims the students initially support.
5. **Ask students to think about how the Colorado storm is different from other storms they have learned about.** This storm is different from isolated storms and typical cold fronts because of the length of time it rained and the lack of movement (stalling).

LESSON
11
STEP 2

6. **Students determine important factors in the storm.** Students read a storm report (*Lesson 11: Step 2*) to collect information about why the storm stalled and lingered over one area for so long. Guide students to use what they have learned about how areas of high pressure can push air masses. Cue students to consider the balloon model we used in Lesson 10 as they think about how air pressure could stall a front. In the case of the Colorado storm, areas of high pressure boxed in the front, so it couldn't move, which is why so much rain fell.
7. **Have students construct a Consensus Model for the Colorado storm in small groups.** Tell students to use the weather report to create a model on the map (*Lesson 11: Step 2*) showing the different forces at play in the Colorado storm. They should label where high pressure and low pressure are located, the front, and the air masses involved as well as where the moisture is coming from.

LESSON
11
STEP 3

8. **Develop a whole group Consensus Model.** Have small groups present their models to the class. As each small group presents, prompt students to ask questions about each other's models. Note areas where groups seem to agree on what's happening, and also note areas of differences. After all groups present their models, transition to developing a class Consensus Model. This model should reflect agreed upon ideas. Start with ideas that students agree on before moving to areas of disagreement or incomplete ideas. Students should use the model to answer the questions in *Lesson 11: Step 3* about the Colorado storm.
9. **Reflect on the new model.** After students build the new model, prompt them to think about what this new model helps to explain that the other models could not explain. Remind students that the Colorado storm was an unusual storm with all these unique variables. Look at the Consensus Model and identify a few underlying, general Model Ideas that would happen in most storms and a few unique, case-based ideas that happened in the Colorado storm specifically.

General Model Ideas:

- A warm, moist air mass got pushed up by a cooler air mass.
- Low pressure was pulling air toward it.
- High pressure was pushing air away from it.

Specific Model Ideas—Colorado storm:

- Three areas of high pressure “trapped” the front and it stalled.
- The low pressure kept pulling in moisture from the Gulf of Mexico and Pacific Ocean.

Power and limitation of models: Discuss how some Model Ideas can be useful for explaining parts of a storm but how there are also unique things that could be happening in any one storm that make it more difficult to predict.



Developing & Using Models

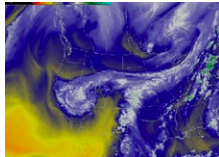
Students create an initial draft of the Colorado storm model that they will use for constructing the Consensus Model. As students work in groups, they do not need to agree upon all parts of the model. They should bring their disagreements and uncertainty to the Consensus Model discussion. Have the Model Idea Tracker and evidence from previous cold front and air pressure activities ready to revisit during the consensus discussion to help resolve disagreements.



Storyline Link

To motivate the need for further investigation in Learning Sequence 3, scale out from the storm and watch it using satellite imagery of the water vapor in the atmosphere. There's a lot of vapor traveling long distances and in somewhat predictable ways. Take it one step further to look at regional patterns in how storms move across large areas. Ask students to think about the direction of these storms and whether they notice patterns in the movement (west to east). Explain to students that we still need to investigate why storms tend to move in certain directions and how moisture travels over long distances.

- 10. Revisit the Driving Question Board.** Give students time to revisit questions on the Driving Question Board. Students should share and explain questions they now feel they can answer. Students can also share new questions they may have about storms.
- 11. Motivate Learning Sequence 3.** Look at satellite imagery for the Colorado storm to get students thinking about large-scale patterns. Ask students what they notice about the way air was moving across the U.S. when the Colorado storm happened.



SATELLITE IMAGERY: COLORADO FLOODS

This satellite imagery shows water vapor over the U.S. during September 11-12, 2013.

[The 2013 Boulder Flood](#)

<https://www.bouldercast.com/the-2013-boulder-flood-two-years-and-three-billion-dollars-later/>

- 12. Broaden from Colorado to another region.** Choose one of the NASA videos below to preview with students. Use the video to notice patterns in the way air and storms move across the U.S. Ask students to identify the direction the storm moves and where the moisture for the storm could come from. This will help you set the stage for student learning in Learning Sequence 3 as they dive into latitudinal patterns of heating, precipitation, and prevailing winds.

SATELLITE IMAGERY: NASA IMAGERY OF STORMS IN THE UNITED STATES

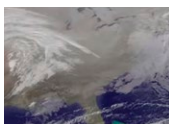
These videos capture storms in the U.S. in different regions in 2016 and 2017. The imagery is made by NOAA's GOES-East satellite (NASA/NOAA GOES Project). Select a region that might be most interesting for your students, or if time permits, view all three videos to notice similar and different patterns.



Option 1: [NASA Sees Severe Weather from Central to Eastern US](#)

(<https://www.youtube.com/watch?v=V-euF5ScXbY>)

Dates: April 29-May 1, 2017



Option 2: [Major Winter Storm Nearing Mid-Atlantic Region](#)

(<https://www.youtube.com/watch?v=awVjB2VQxdU>)

Dates: January 20-22, 2016



Option 3: [Southern California and U.S. West Coast Storms](#)

(<https://www.youtube.com/watch?v=estSuHF3Vwk>)

Dates: January 5-7, 2016

- 13. Assess student learning with the Learning Sequence 2 assessment.** You can find the assessment item bank and rubric in the Assessments section of *GLOBE Weather*.



Assessment

See the GLOBE Weather Assessments section for the Learning Sequence 2 assessment.