UCAR CENTER FOR SCIENCE EDUCATION

STUDENT ACTIVITY SHEETS

TEACHER ANSWER KEY

THE GLOBE PROGRAM

BSCS SCIENCE LEARNING

NASA

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TEACHER KEY FOR STUDENT ACTIVITY SHEETS

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TEACHER ANSWER KEY
LESSON 1

LESSON 1 What do we know about storms?

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Name Period Date

LESSON 1

What do we know about storms?

STEP 1: What happens in the atmosphere to cause a storm?

Your class will watch a video about a storm that happened in Colorado and how the precipitation affected the city of Boulder, Colorado. After watching the video, think about what you know about the water cycle and how storms form. What do you think happens in the atmosphere to cause rain, snow, and other types of precipitation? Write your ideas below.

Responses will vary. Look for clues about student's understanding of water cycling, cloud formation, and how storms form. This question helps assess students' prior knowledge about weather.

STEP 2: What are my experiences with storms and precipitation?

Think about a time when you experienced a storm. Answer the questions below.

Was it a rainstorm, a snowstorm, or some other type of storm?

Responses will vary.

What time of year did it happen?

Responses will vary.

Did the storm last for a few hours or a day or more?

Responses will vary.

1. How did the precipitation from this storm affect your community?

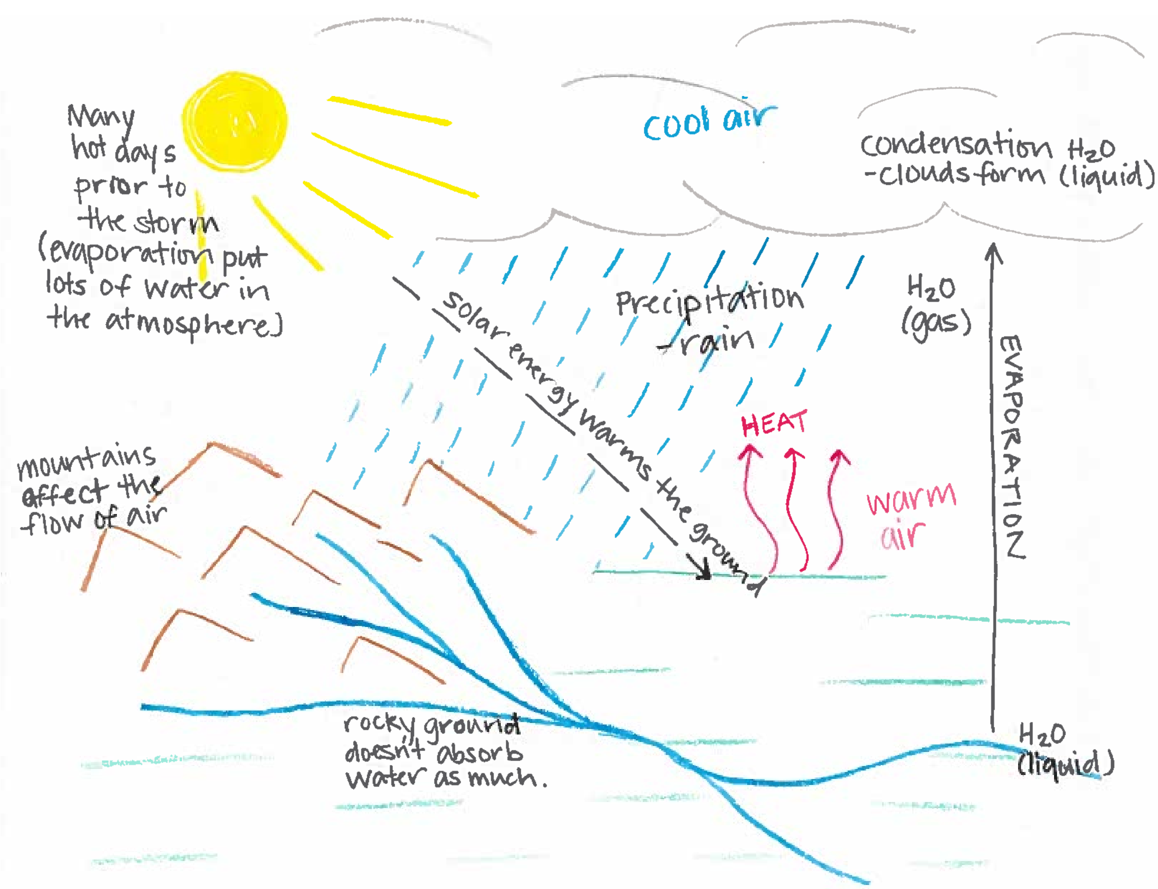
Responses will vary.

What do we know about storms?

STEP 3: Represent what you know about storms.
What caused the rain in the Colorado storm you saw in the video? Draw and label a picture in the box below to answer this question. Your picture is a model of how this storm happened.

- Your picture should show all the factors that led to rain.
- Include labels in your drawing that explain how each factor led to rain.
- Be prepared to share your thinking with the class.

Student drawings will not necessarily look like this one, and likely will not include all aspects represented below. Use drawings to assess students' prior knowledge of vocabulary, phase changes, and water cycling.



What do we know about storms?

STEP 4: How were my ideas similar or different from my peers' ideas?

Describe your model to the other students in your group.

SIMILAR IDEAS	DIFFERENT IDEAS
Student responses should focus on aspects that were represented in some fashion both in their own model and in their peers. ("We both drew the Sun and clouds, even though our clouds didn't look the same.").	*Student responses should focus on aspects that were represented differently or not at all when comparing their own model to a classmate. ("I drew water coming down to the ground from the clouds, but my friend drew water coming up from the ground to the clouds.").*

STEP 5: What questions do I have about storms and precipitation?

What do you wonder about how storms form? List questions that you have about storms and precipitation.

Responses will vary.

C O N G R A T U L A T I O N S ,

you are now part of the GLOBE community!

Now that you have completed Lesson 1 of GLOBE Weather, you are ready to be an active GLOBE student scientist.

GLOBE stands for **G**lobal **L**earning and **O**bservations to **B**enefit the **E**nvironment. GLOBE is an international science and education program that includes students and scientists from all over the world. You now have the opportunity to participate in GLOBE along with other students interested in learning more about the environment through conducting research on topics that are interesting to you. GLOBE has many resources and opportunities for scientists of all ages. Check out how to get involved by viewing a short video (4:26 minutes) on the GLOBE website: https://www.globe.gov/do-globe/for-students/be-a-scientist.

UCAR CENTER FOR SCIENCE EDUCATION

TEACHER ANSWER KEY

LEARNING SEQUENCE 1

LESSON 2 What causes storms to form?

LESSON 3 How does temperature relate to cloud formation?

LESSON 4 What is different about a sunny day and a stormy day?

LESSON 5 How does air move and change when a storm is forming?

LESSON 6 Can we identify the best conditions for storms?

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Name Period Date

LESSON 2

What causes storms to form?

Watching cloud shapes and how they change over time can give you clues about what's happening in the sky.

STEP 1: What can we learn about storms by watching clouds in the sky?
Working in pairs or small groups, write your ideas below. (Use complete sentences.)

Storms happen when there are clouds in the sky. The clouds associated with rain/thunderstorms are different than other types of clouds (dark, gray, tall anvil-shaped clouds are associated with storms). Building clouds in the sky can signal that a storm is likely.

STEP 2: What do you notice about the sunny day compared to the stormy day?
Observe the clouds in the time-lapse videos and record your observations below.

SUNNY DAY

On a sunny day, there can be some clouds that form throughout the day, mostly in the afternoons, but the clouds are small and white.

STORMY DAY

On a stormy day, many clouds develop in the sky throughout the day. By the afternoon, the sky is mostly filled with clouds that appear dark or gray. There is precipitation falling from the sky at least once during the day.

Why do you think that the storm formed on one day and not the other?
Write your ideas below, using complete sentences.

Answers will vary. Look for an understanding of stormy days associated with having many clouds that are dark/gray (compared to a sunny day without many clouds). An advanced understanding would mention the relationship between heat needed for evaporation of water from the surface and cloud formation as well.

LESSON 2

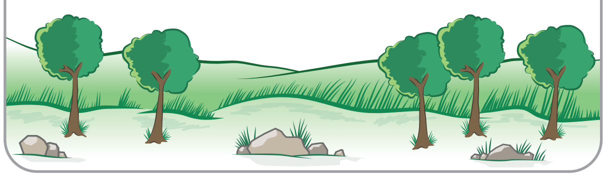
What causes storms to form?

STEP 3: Draw how a storm forms throughout the day.
Think about the time-lapse video of a stormy day. Draw what the weather is like at different times throughout the day, using each of the boxes below. Include what you know about how clouds, water, air, and sunshine move and change throughout the day.

**Drawings should match the descriptions in each of the boxes.*

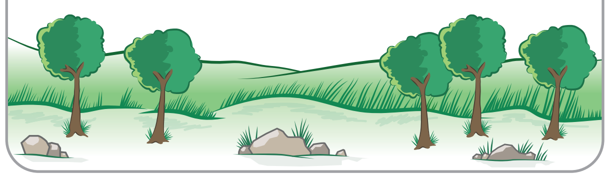
MORNING 9:00AM

Clear sky. Surface and air temperatures are rising as the Sun rises into view, which will lead to the evaporation of water at the surface and the beginning of cloud formation.



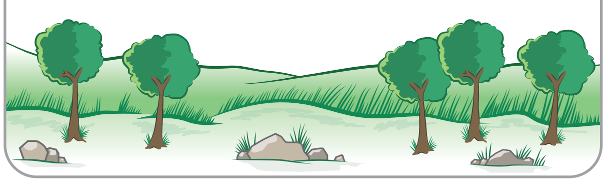
MID-DAY 12:00PM

More clouds develop because water is evaporating from the surface when there is lots of sunlight reaching the ground.



AFTERNOON 3:00PM

The sky is filled with many dark clouds. A rainstorm happens--water moves from the sky to the ground.



NIGHTTIME 9:00PM

After sunset, the air is cooler, and there is less evaporation from the surface. Clouds dissipate. The sky is clear by late evening.

LESSON 2 What causes storms to form?

STOP AND THINK

Answer the questions below.

Clouds and storms are typically high above the ground. If you could investigate the air up high compared to the air near the ground, what do you think you would notice?

Students may know that the air is colder higher up in the atmosphere. This question will document their understanding as they get ready to go into Lesson 3, where they will investigate the relationship between elevation and temperature. Since clouds are made of water, students may reason that the air higher up might contain more water too.

What measurements about the air would you want to take from different altitudes?

Though students have not learned about air measurements at this point, answers might include:

- *Temperature*
- *Air Pressure*
- *Humidity*
- *Wind speed*

How might those measurements help us figure out how clouds form?

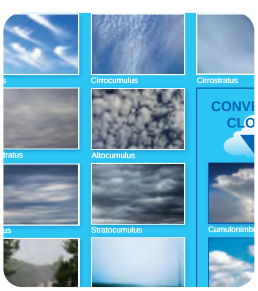
Changes in the air might help us understand what conditions are needed for clouds to form. If clouds always form when the air drops below a certain temperature, or when there is a certain amount of water in the air (relative humidity). This information could provide clues about how clouds form.

STEP 4: Make observations of clouds in the sky!

Watch the sky for clues about what's happening with weather in your community. Follow your teacher's instructions for making observations and remember **to never look directly at the Sun**.

Remember to look for:

- How much of the sky is covered with clouds?
- What types of clouds are in the sky?
- Are the clouds opaque or can you see through them?



Identify clouds using the GLOBE Cloud Chart (globe.gov/globecloudchart).

Download the GLOBE Observer Clouds App (observer.globe.gov) to make cloud observations and take pictures that can be compared with NASA satellite images. This helps scientists understand the sky from above and below.

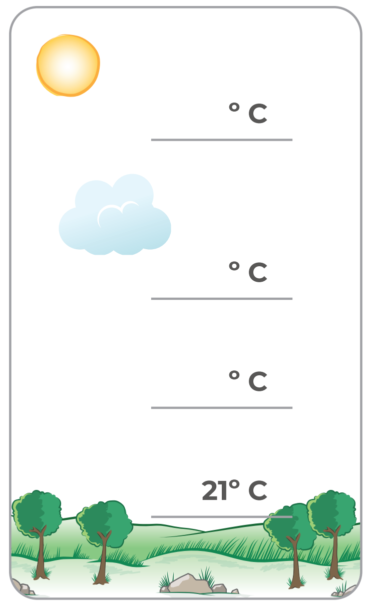
Name Period Date

LESSON 3 How does temperature relate to cloud formation?

Weather balloons carry instruments into the atmosphere to collect temperature data at different altitudes – from near the ground to up where clouds form and even higher. In this lesson you'll explore data collected by a weather balloon to learn about how air changes with altitude.

STEP 1: Use the temperature near the ground to predict the other temperatures.
Fill in the blanks in the graphic at the right to make a prediction about how air temperature changes with altitude.

Predicted values will vary. Look for a pattern in the students' predictions: do they think air gets colder, warmer, or stays the same as altitude increases?



STEP 2: Collect temperature data.
At a computer or tablet, open the Virtual Ballooning interactive (scied.ucar.edu/virtual-ballooning). With this simulation you can launch virtual weather balloons and record the temperature at different altitudes in the atmosphere.

1. **Click "Explore the Troposphere"** to get into the game.
2. **Get to know the graph.** Notice that altitude is on the vertical axis (the y-axis) and temperature is on the horizontal axis (the x-axis).
3. **Choose settings for a balloon launch.** Each balloon you launch will make three measurements of temperature. Set the altitude to start recording the temperature by dragging the "Collect Data" arrow up or down the y-axis.
4. **Click the "Launch Balloon" button** and watch as your balloon collects temperature data.
5. **Record that temperature in the table on the next page.** Read the points that the balloon made on the graph to find the temperature at different altitudes.
6. **Click the "New Flight" button** and choose new settings for another balloon launch to collect more data. Collect as much data as you can with four balloon launches.

LESSON 3

How does temperature relate to cloud formation?

STEP 2 CONTINUED: Collect temperature data.

high clouds ↑ low clouds

ALTITUDE	TEMPERATURE (˚C)
10 km	-38
9 km	-32
8 km	-25
7 km	-19
6 km	-12
5 km	-7
4 km	0
3 km	7
2 km	12
1 km	17
0 km	22

STEP 3: Analyze and interpret the data.

1. Describe the pattern you see in the temperature data from the ground to where storm clouds form.

   Air temperature decreases as you go higher up in the atmosphere.

2. Is this the pattern you predicted? Why or why not?

   Answers will vary. Students should compare observed patterns to their predictions.

3. What do you think is *causing* the temperature pattern?

   Students have not yet learned about air pressure, but look for answers that would explain why it is colder at higher altitudes, such as:
   - *The air at higher altitudes is further from the ground. The ground is warmer than the air because it absorbs heat from the Sun.*
   - *There is less air (because there is less air pressure) at higher altitudes and therefore less heat.*

4. How does the temperature pattern relate to storms forming? (Draw or write your ideas below.)

   Answers will vary. Storms happen when there are lots of clouds in the sky. Clouds form when water vapor condenses into liquid water droplets high in the atmosphere. Air moving from a lower altitude to a higher altitude would have a temperature drop. When the air temperature drops, condensation occurs. So, in order for clouds and storms to form, the air temperature must drop.

How does temperature relate to cloud formation?

STEP 4: How do air and surface temperatures change during a day?

To learn why air temperature changes with altitude, take a look at how the temperature of the ground (surface temperature) relates to the temperature of the air just above the ground (air temperature) in the graph below. Students at Westview Middle School in Longmont, Colorado, collected the data in this graph. Every hour during a day they measured surface temperature and air temperature outside their school.

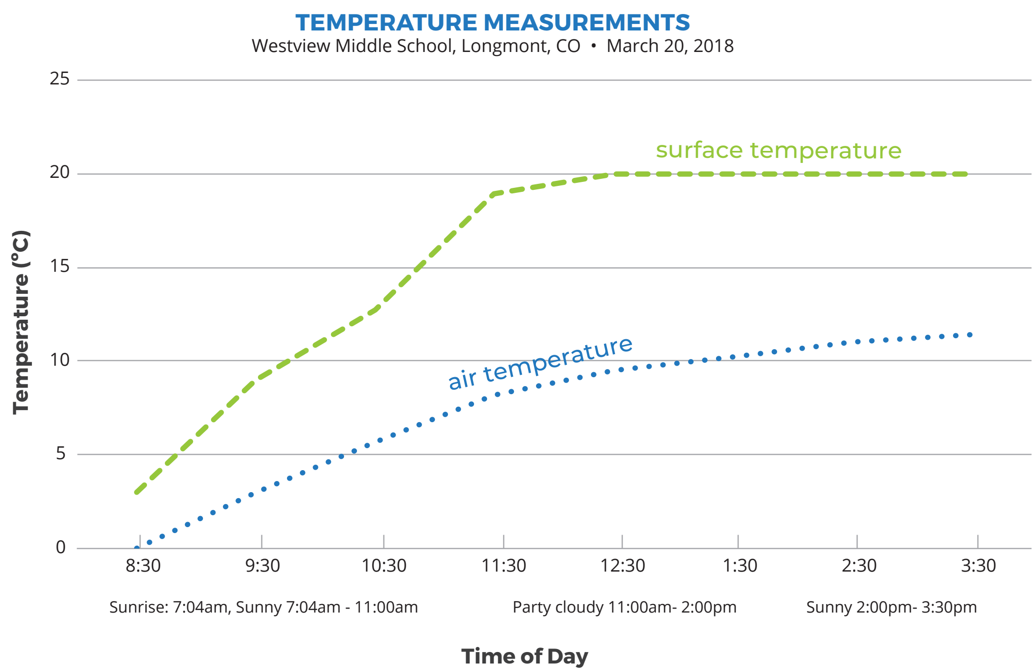
Compare the two data trends in the graph by following these directions:

WHAT I SEE

1. Look at different parts of the graph. Do you notice patterns? Do you notice interesting differences? Write **What I See** statements on the graph to record your observations.
2. Share your statements when directed by your teacher.

WHAT IT MEANS

1. Next to each **What I See** statement, write a **What It Means** statement to explain what you think is happening in each part of the graph.
2. Share your statements when directed by your teacher.



What I see...	*What it means..*
The blue air temperature line is always below the green surface temperature line.	*As the surface is warmed by sunlight, some heat from the surface goes into the air.*
The green line increases until about 11:30 and then starts to level out.	*The surface warms rapidly until about noon and then stays the same temperature through the mid-afternoon.*
The blue line follows a similar, but not identical, pattern to the green line.	*Air temperature is related to surface temperature, but the air continues to warm a small amount even after the surface stops warming.*

Write a caption for the graph that compares the two data trends.

Both surface temperature and air temperature increase from the morning until afternoon, but the surface temperature is always above the air temperature.

LESSON 3

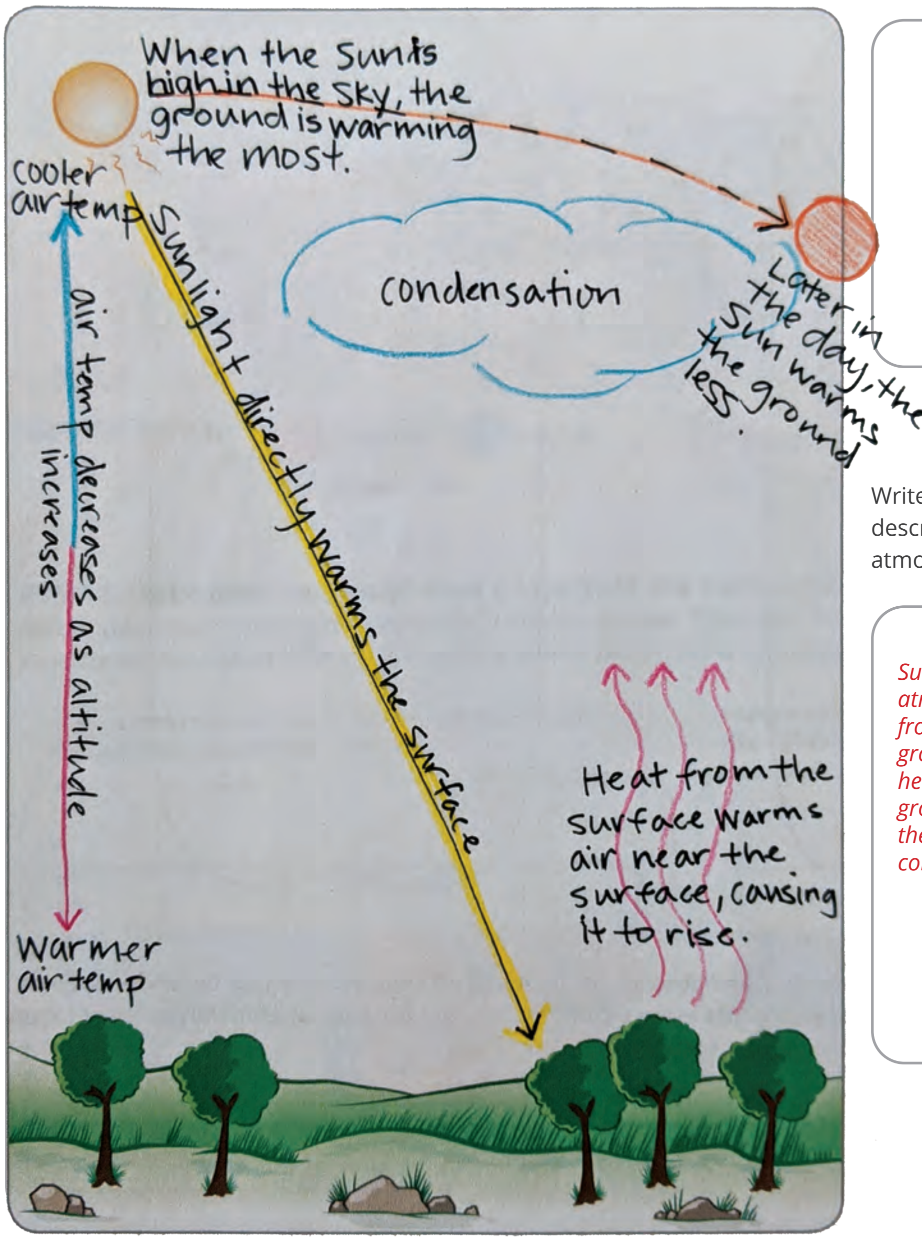
How does temperature relate to cloud formation?

STEP 5: Make a model of how sunlight warms the atmosphere.
Draw a model in the box below that helps to answer the following question:

Why does the surface temperature warm over the day, and why is the surface warmer than the air above it?

Your model should explain:

- How surface temperature is related to the sunlight
- How air temperature is related to surface temperature
- How the air temperature changes from the ground to higher altitudes
- How you know the above three things using evidence from temperature data



KEY
(Choose colors to represent sunlight and temperature.)

☐ sunlight

☐ temperature

Write a caption for your model that describes how sunlight warms the atmosphere.

Sunlight travels through the atmosphere to the surface. Energy from the Sun is absorbed by the ground. This energy is given off as heat, which warms the air near the ground. The warmed air rises into the atmosphere where it cools due to colder temperatures at high altitudes.

LESSON 3

How does temperature relate to cloud formation?

STEP 6: How does your model relate to storms?

There wasn't a storm on the day when the Westview Middle School students collected surface temperature and air temperature data, but it did get cloudy in the afternoon.

The time-lapse video showed that clouds started to build in the morning and by afternoon there was rain.

Write a sentence to answer the question: How do you think temperature relates to the clouds and storm forming?

In order for clouds to form, the ground must get warm enough to evaporate water into the air. At higher temperatures, there is more evaporation of water at the surface. Evaporation of water at the surface leads to the formation of clouds and sometimes storms.

List evidence from your model to support your answer above.

Answers will vary. Look for references to specific aspects from student models created in Lesson 3: Step 5.

For example:

- *Heat rising from the ground.*
- *Air temperature decreasing with altitude.*

Describe the reason that the evidence you listed supports your answer.

Answers will vary. Students should explain how the evidence listed above supports their idea(s) about the relationship between temperature and cloud formation.

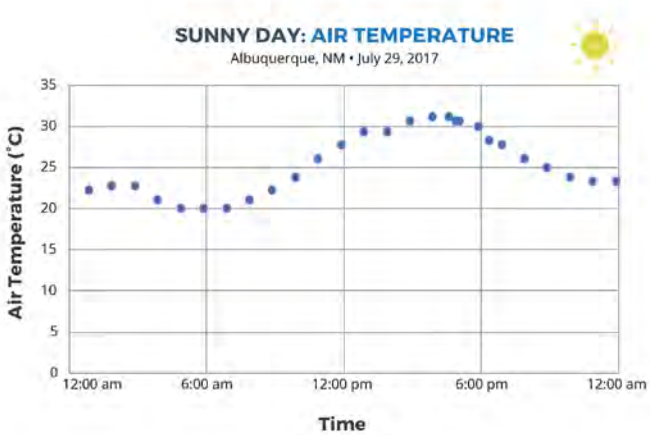
For example:

- *They explain that surface heat allows water to evaporate from the surface.*
- *They explain that decreasing air temperature with altitude is necessary for condensation to happen, which is how clouds form.*

LESSON 4

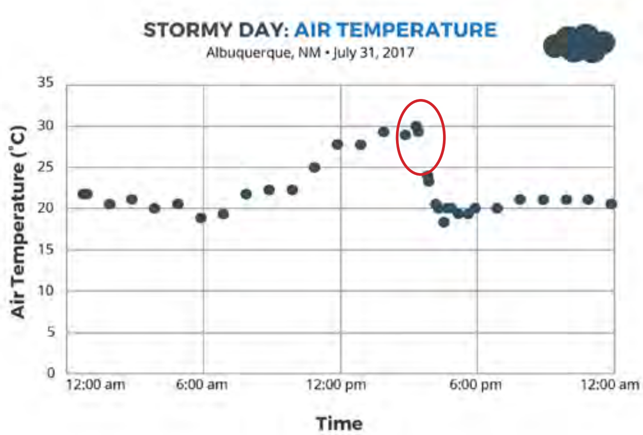
What is different about a sunny day and a stormy day?

STEP 1: Compare air temperatures on a sunny day and a stormy day.
Do stormy days have a different pattern than sunny days? Answer the questions using the graphs of temperature data below.



1. Describe the sunny day pattern.

Air temperature begins to rise as the Sun rises, reaching a peak warmth in the late afternoon, and then cooling as the Sun sets.



2. Describe the stormy day pattern.

Air temperature begins to rise as the Sun rises, reaching a peak warmth in mid-afternoon, and then drops suddenly and drastically around 4 pm. Air temperature remains cooler for the rest of the night.

3. Looking only at the temperature data, when do you think the rain happened, and why? Circle where the rain begins on the stormy day graph.

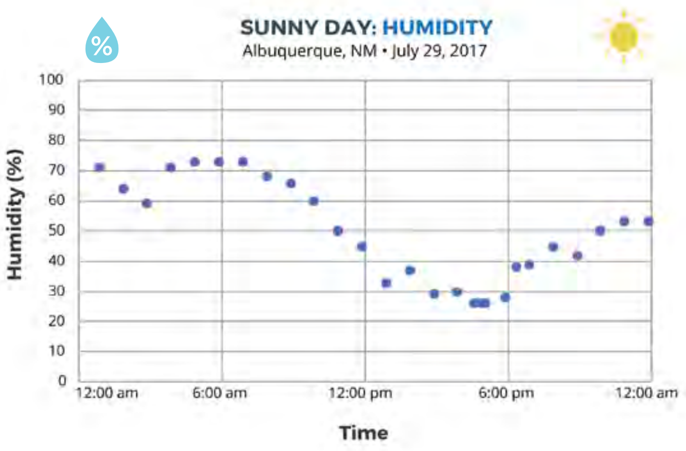
The rain happened between 4:00-5:00 pm, as indicated by the rapid drop in air temperature. By this time in the day, the heat had evaporated lots of water into the air. Students may suspect that the sudden drop in temperature caused condensation and then precipitation. In Lesson 5, they will build an understanding of how and why air moves via convection, which can cause a drop in temperature.

What is different about a sunny day and a stormy day?

STEP 2: Compare the humidity on a sunny day and a stormy day.

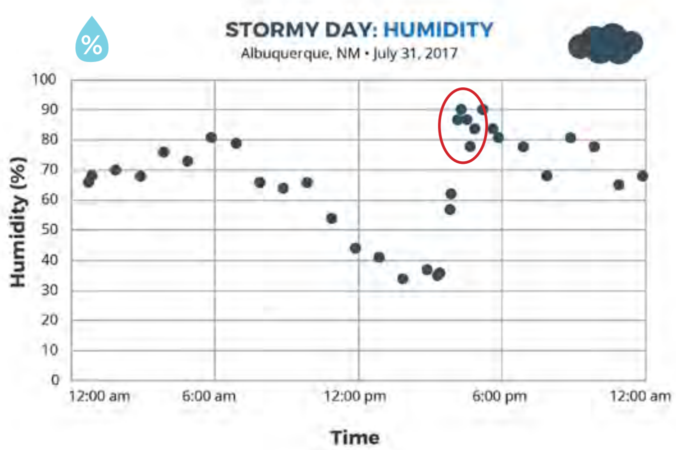
Humidity is the amount of water vapor in the air. If the humidity is 100%, then the air cannot take in any more water vapor (and you are probably in a cloud). If the humidity is less than 100%, then the air could take in more water vapor. Warm air has the energy needed to evaporate more water than cold air. That's why a hot and humid day is more common than a cold and humid day. When humidity is low, people say that the air is dry because it doesn't have much water vapor.

Do stormy days have a different pattern than sunny days? Answer the questions using the graphs of humidity data below.



1. Describe the sunny day pattern.

Humidity is highest in the morning when the air is cool, and decreases as the air warms throughout the day, reaching its lowest point in the late afternoon and then rising again gradually as the air cools into the evening.



2. Describe the stormy day pattern.

Humidity is high in the morning when the air is cool, and decreases as the air warms throughout the day. There is a drastic spike in humidity in the late afternoon at the time of the storm. Humidity fluctuates during the next few hours and into the evening but remains high overall.

3. Circle where the rain begins on the stormy day graph. Considering both air temperature and humidity, what pattern do you think creates the highest chance for storms to form?

Chances are greatest for a storm to form when the air temperature is low and humidity is high, which are the conditions present between 4:00-5:00 pm in our graphs above.

LESSON 4

What is different about a sunny day and a stormy day?

STEP 3: Make a storm in a bottle.
Using what you know about temperature and relative humidity, create a model of a sunny day and a stormy day using clear bottles with different contents.

1. Draw what you put inside each of your bottles. Label the materials that you added.

SUNNY DAY

**No water in the sunny day bottle, air, and sand/ soil only.*

STORMY DAY

**Water, air, and sand/ soil in the stormy day bottle.*

2. Turn on the lamp (to represent the Sun) and observe the bottles for 20 minutes. Add your observations about the temperature and humidity of each bottle to the pictures above. Use the data table on the next page to record temperature and humidity changes in your bottles.

Students should observe a temperature increase in each of the bottles. In the stormy day bottle, they should also observe water droplets forming (humidity) on the inside of the bottle (on the sides and near the top).

LESSON 4

What is different about a sunny day and a stormy day?

Measure the temperature with your thermometer and record. Look for evidence of humidity, such as condensation on the inside of the bottle, and make notes about it in the table below.

	SUNNY DAY BOTTLE		STORMY DAY BOTTLE	
MINUTE	TEMPERATURE (˚C)	HUMIDITY	TEMPERATURE (˚C)	HUMIDITY
2		**Students should not observe any humidity in the sunny day bottle.*		**Students should note when humidity (condensation) is first observed in the stormy day bottle.*
4				
6				
8				
10				
12				
14				
16				
18				
20				

3. Discuss the following questions with your peers:

- Did the sunny day bottle match what you expected? If not, what happened?
- Did the stormy day bottle match what you expected? If not, what happened?
- Using evidence from the bottles and the temperature and humidity data, what conditions are best for storms?

Name Period Date

LESSON 5

How does air move and change when a storm is forming?

Your teacher will demonstrate how air changes as it is heated or cooled. This will help you figure out what happens to air that warms near the surface, and air that cools at higher altitudes.

STEP 1: Observe warmed and cooled air.

Draw the lab set-up and what happens to the balloon during the demonstration. Add your observations to your drawing as you make them. Remember to label what is happening.

LAB SET-UP	MYLAR BALLOON BEING HEATED	MYLAR BALLOON AS IT COOLS
Students should describe the lab set-up, which includes the partially inflated balloon and the hairdryer.	*During heating: The balloon begins to rise up into the air. It expands and appears more inflated.*	*After heating: The balloon begins to sink again. As it sinks, the balloon contracts and appears only partially inflated again.*

1. Why does the heated balloon go up? Think about what is happening inside the balloon.

   Air molecules within the balloon are gaining energy as they are heated. The air within the balloon expands, becoming less dense than the air outside of the balloon, and rises.

2. What is happening inside the balloon when the balloon starts to sink?

   Air molecules within the balloon lose energy as they cool. The air within the balloon contracts and becomes more dense than the air outside the balloon, and sinks.

5 How does air move and change when a storm is forming?

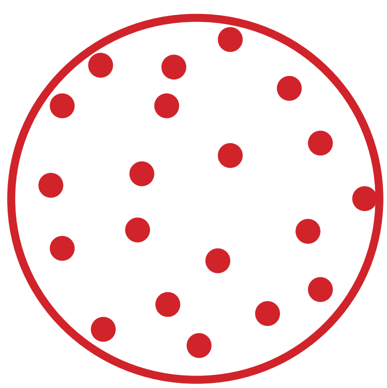
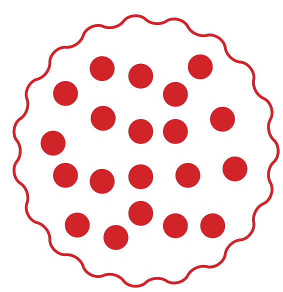
STEP 2: Air on the Move

There is something different between warm and cool air that causes warm air to go up and cool air to go down. When the air inside the balloon was warmed, the balloon expanded and went up. When the air inside the balloon cooled, the balloon started to shrink and go down. Let's think a little more about this air and what is happening when it is warmed and cooled. To understand this, we are going to need to zoom in and think about what's happening to the air molecules.

Imagine you can see a pocket of air molecules heated up. When air is heated, the heat energy is absorbed by the individual molecules, causing them to move around more quickly. The molecules move faster and farther apart. When molecules release their energy, they start to slow down and cluster closer together. This happens when the molecules no longer have a heat source and are "cooling."

COLD AIR WARM AIR

Draw a diagram that shows what 20 warmed air molecules look like inside the mylar balloon compared to 20 cooler air molecules.

BALLOON WITH WARM AIR	BALLOON WITH COOL AIR
Air molecules are spread further apart. 	*Air molecules are closer together.* *Ballon appears less inflated.* 

So, that's how warm air and cool air are different. But why do they move in different directions? To understand that, we're going to need to zoom out and think about the whole planet and gravity.

LESSON 5

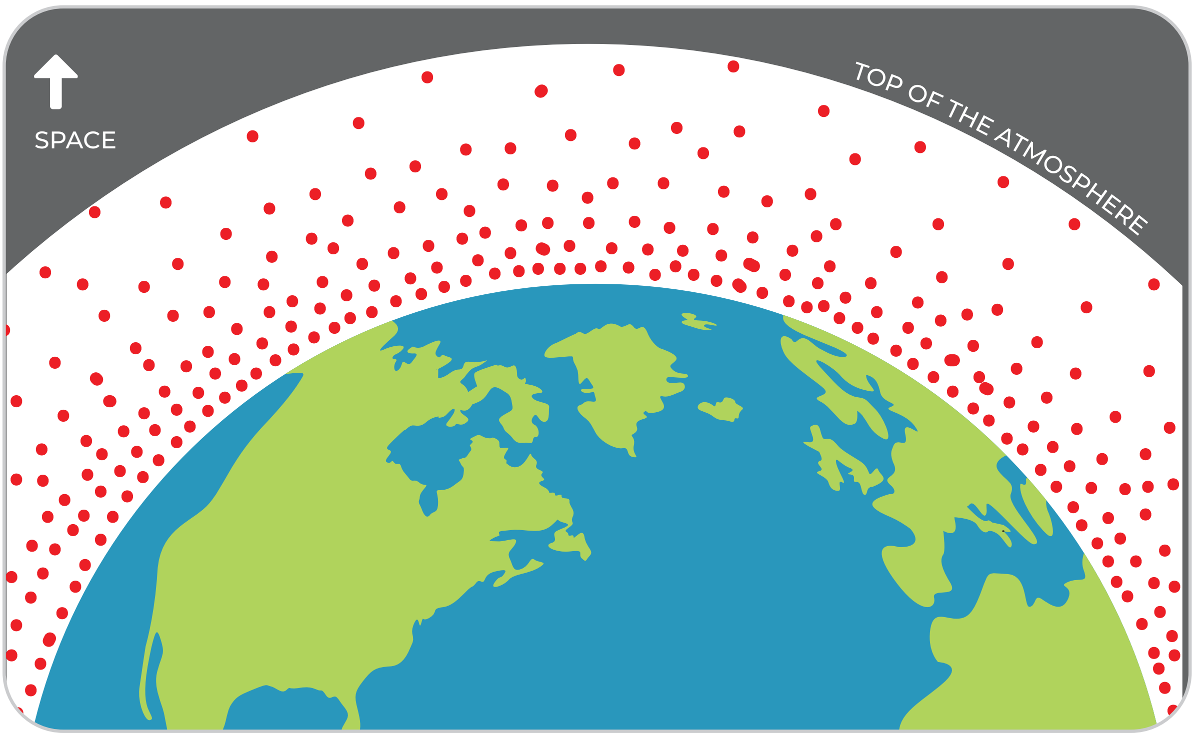
How does air move and change when a storm is forming?

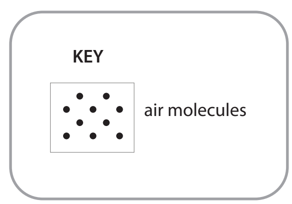
STEP 2 CONTINUED: Air on the Move

Gravity is the force that draws all objects towards the center of the planet. Even tiny things like air molecules are affected by gravity and pulled downward. The weight of the air molecules higher in the atmosphere pushes air molecules lower in the atmosphere closer together. High in the atmosphere, they are spaced farther apart. Air molecules pushed close together are at high pressure. Air molecules spread apart are at low pressure.

Draw air molecules between the planet and the top of the atmosphere. Remember that they will be spaced differently depending on whether they are close to the ground or higher in the atmosphere.

**Air molecules are drawn closer together near the surface and further apart at the top of the atmosphere.*





5 How does air move and change when a storm is forming?

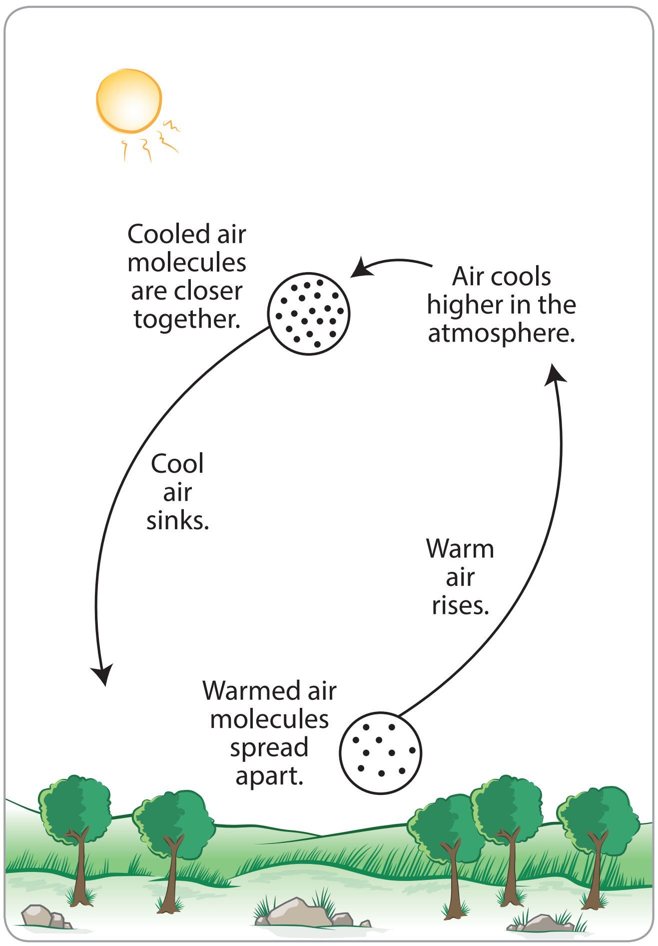
STEP 2 CONTINUED: Air on the Move

When sunlight warms the land, and then warms the air near it, the molecules spread out a bit, taking up more space, just like the air at high altitude. The warmed air has lower pressure than the air around it, so it rises in the atmosphere, like the warmed balloon in the previous activity.

As the warmed air rises in the atmosphere, it cools down, because air at higher altitudes is cooler. Remember that cool air doesn't hold as much water vapor as warm air, so as warm air cools, some of the water vapor condenses into the tiny water droplets that make up clouds.

As air gets cooler, the molecules come closer together. The air has higher pressure than the air around it, so it sinks in the atmosphere, like the cooled balloon in the previous activity. Then, it can be warmed and rise again.

This cycle of rising and falling air is called **convection.**



EXPLAIN: Why does warm air go up and cool air go dow

Heated air molecules move around faster, which causes them to spread apart. When they spread apart, they become less dense than the air around them and rise. Air higher in the atmosphere is cooler than the air near the ground. As the heated air from the surface rises, it cools as it comes in contact with the cooler, high altitude air. The cooled air molecules slow down and move closer to one another, causing the air to become more dense. The dense, cooled air sinks back towards the surface where it is heated once again. The cycle of convection continues in this manner.

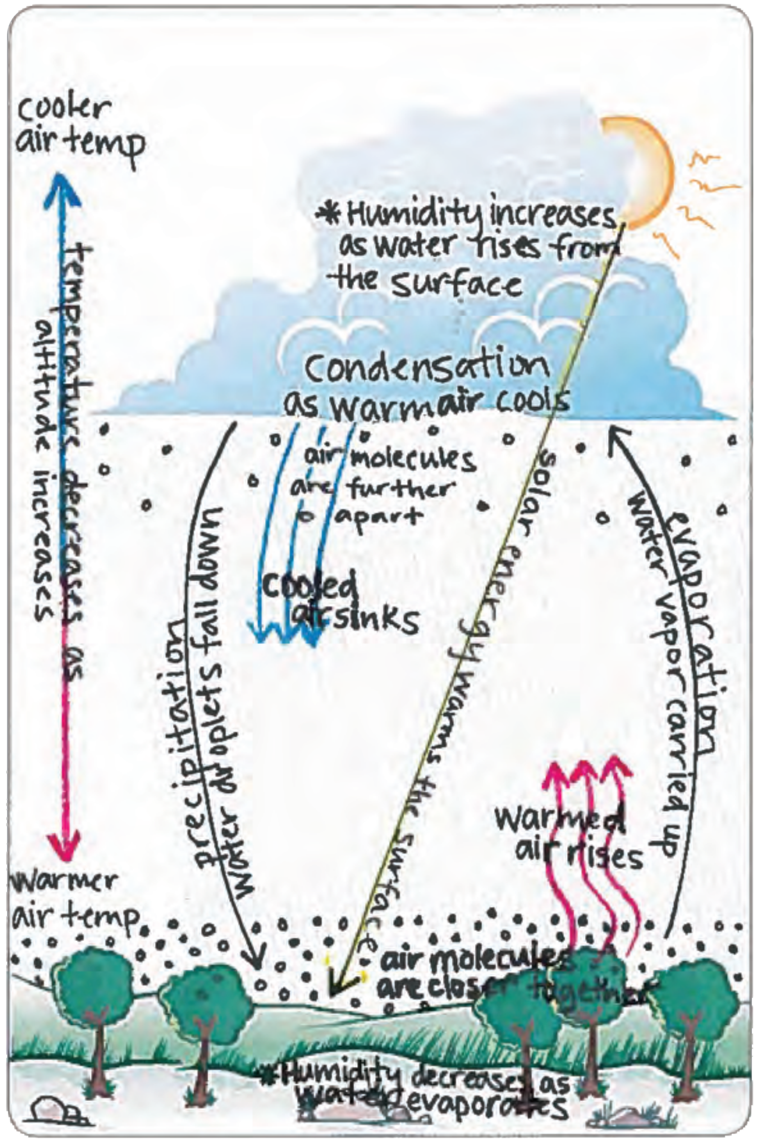
How does air move and change when a storm is forming?

STEP 3: Create a model to describe how precipitation happens in an isolated storm.

To get started, **draw and write** in the illustration to explain how precipitation happens in an isolated storm.

Make sure your model explains:

- What happens to energy from the Sun that leads to an isolated storm?
- What happens to water at the surface and clouds that lead to the isolated storm?
- How does air temperature and humidity change as air moves from the ground to the cloud?
- How does air move between the ground and where the storm forms?



Write an explanation that goes with your model and answer the question below:

EXPLAIN: What has to happen for an isolated storm to form?

Temperatures must we warm enough to evaporate lots of water from the surface so that humidity is high in the atmosphere. The warmed air and water vapor rise up to where the air is cooler (because air temperature decreases as altitude increases), which causes condensation and the formation of clouds. If the temperature drops enough and the humidity is high enough, a storm will occur.

Name Period Date

LESSON 6

Can we identify the best conditions for storms?

STEP 1: Make predictions.
Use your model for an isolated storm, and what you know about temperature and humidity, to predict the very best conditions that would lead to an isolated storm.

A strong storm would form if the temperature high in the atmosphere near the clouds was

- ● **much colder than**
- ○ **much warmer than**
- ○ **about the same as**

the temperature near the ground because *water vapor suspended in the warmer, rising air will condense to form clouds when it rises and reaches the much colder air high in the atmosphere.*

A strong storm would form if humidity was ● **high** ○ **moderate** ○ **low**

because *moisture, or humidity, is necessary to form a storm with precipitation. The more humidity in the air, the more likely precipitation will form.*

LESSON 6

Can we identify the best conditions for storms?

STEP 2: Record and explain your observations.

Now you can test your predictions with the Make a Thunderstorm simulation (scied.ucar.edu/make-thunderstorm). Follow your teacher's instructions for collecting data from the simulation. Record your observations of five trials in the table below. Then explain why a storm did or did not form.

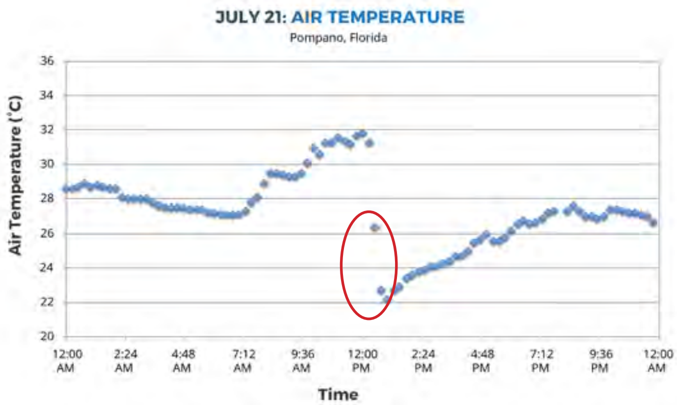
CONDITIONS	OUTCOME	WHY DID THIS HAPPEN? Explain what helped the storm or what was missing.
high-level temp *very cold* humidity *high* low-level temp *warm*	○ no storm ○ small storm ○ medium storm ● big storm	*These are the conditions that result in a big storm. Warm temperatures at the surface allow for lots of evaporation. High humidity means that there is a lot of water available to be evaporated, and very cold high-level temperatures lead to lots of condensation, cloud formation, and a storm.*
high-level temp *cool* humidity *low* low-level temp *cold*	● no storm ○ small storm ○ medium storm ○ big storm	*These are the conditions that result in no storm. Cold temperatures at the surface prevent much evaporation from occurring. Low humidity means that there is not a lot of water available to be evaporated, and cool high-level temperatures will not lead to much condensation, which means no cloud formation and no storm.*
high-level temp humidity low-level temp	○ no storm ○ small storm ○ medium storm ○ big storm	***Note:** The scenarios above represent the extremes (big storm & no storm), but students should record the conditions that make small and medium storms too. Look for explanations that make a connection between increasing the amount of humidity and increasing the difference between low-level and high-level temperatures to affect the size of the resulting storm.*
high-level temp humidity low-level temp	○ no storm ○ small storm ○ medium storm ○ big storm	
high-level temp humidity low-level temp	○ no storm ○ small storm ○ medium storm ○ big storm	

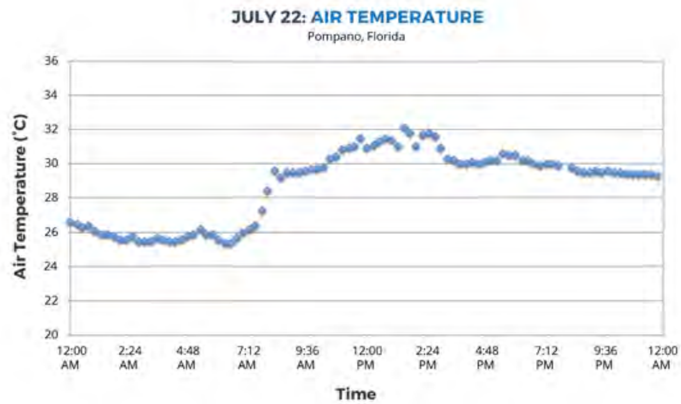
LESSON 6 Can we identify the best conditions for storms?

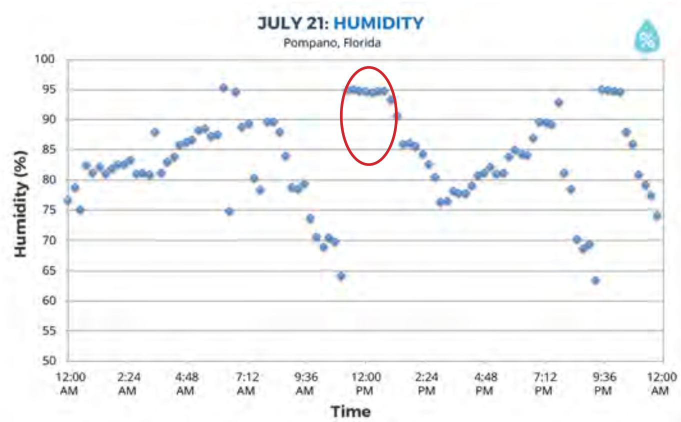
STEP 3: When did it rain?

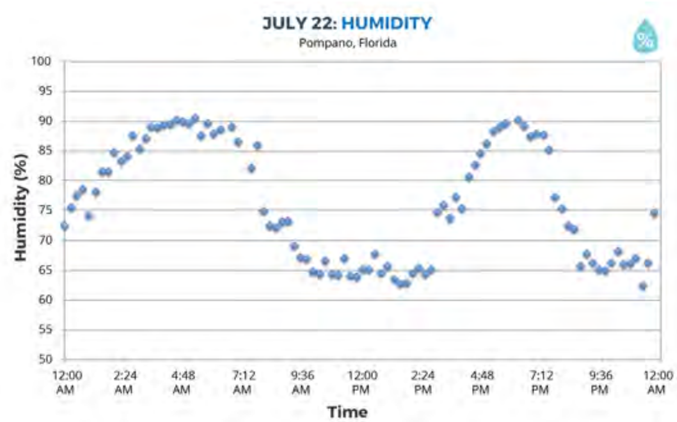
The air temperature and humidity data below is from two days in Pompano, Florida. It rained on one of these days. Identify the most likely day and time it rained.

1. Circle on the graph when the rain happened.









2. Explain what conditions were likely leading up to this rain event, and why you think the rain happened at this time. Use evidence from previous investigations and your model to develop your explanation.

It rained on July 21st. The day started warm and continued to get warmer throughout the day until the rain happened. There was also high humidity throughout the day. When the storm started, the air temperature dropped, and humidity increased rapidly. On July 22nd, there was not enough humidity for a storm to form. Students should mention elements from their model in Lesson 5: Step 3 that support their answer, including convection in the atmosphere, which causes cool air to flow downward. They should also mention learnings from other lessons as evidence to support their answer.

Examples of evidence students might include justifying their answer:

- *In Lesson 4, we learned that the building of heat throughout the day and high humidity is necessary for a storm to form, with a rapid drop in air temperature and a spike in humidity observed at the start of a storm.*
- *In the Make a Thunderstorm simulation, we learned that warm temperatures at the ground, high humidity, and very cold temperatures are ideal conditions for a storm to form.*

UCAR CENTER FOR SCIENCE EDUCATION

TEACHER ANSWER KEY

LEARNING SEQUENCE 2

LESSON 7 What other types of storms cause precipitation?

LESSON 8 How is air changing before, during, and after a cold front?

LESSON 9 What causes precipitation along a cold front?

LESSON 10 What causes fronts to move?

LESSON 11 What could cause a front to stall?

BSCS SCIENCE LEARNING

NASA

THE GLOBE PROGRAM

Name Period Date

LESSON 7 What other types of storms cause precipitation?

STEP 1: What do you notice about the cold front?

Watch the time-lapse video of a day when a cold front moved through Lyons, CO and observe how weather changes over time.

	SUNRISE TO NOON	NOON TO 4:00PM	4:00PM TO SUNSET
WIND Wind speed:	○ high ☒ low	☒ high ○ low	☒ high ○ low
Wind direction: *does it change?*	*No*	*Yes: several changes in direction*	*Yes: less change in wind direction than seen earlier*
CLOUDS Cloud type: *what types are visible?*	*Cirrus & stratocumulus clouds*	*Mid-level cumulus clouds*	*Cumulonimbus clouds*
Amount: *how much sky is covered with clouds?*	*About half of the sky is covered with clouds*	*Clouds completely cover the sky*	*Clouds completely cover the sky*
PRECIPITATION *When did precipitation happen?*	*None*	*Precipitation was just before 4pm*	*Precipitation was on and off into the evening*
Could you tell what kind: rain, snow, or other?		*Rain*	*Rain*
Was there a lot or a little?		*A little*	*More than before, but not a lot*

1. How is the storm in the time-lapse video different from an isolated storm?

STEP 2: Brainstorm different kinds of storms.

Have you been in storms that are different from the isolated storms you investigated before?
Describe storms that you experienced, and explain what made them different from an isolated storm.

DESCRIBE THE STORM YOU EXPERIENCED.	HOW IS IT DIFFERENT FROM AN ISOLATED STORM?
Answers will vary; look for descriptions of storms that lasted for several days and/or examples of severe weather.	

What other types of storms cause precipitation?

STEP 3: Interpret a weather forecast for a cold front.

The seven-day forecast below shows a cold front moving through an area. Work with your group to interpret what is happening before, during, and after the front.

Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Mostly Sunny	Partly Cloudy	Partly Cloudy	Mostly Cloudy	Mostly Cloudy	Rain Showers	Sunny
Hi 68° Lo 55°	Hi 75° Lo 60°	Hi 74° Lo 60°	Hi 70° Lo 56°	Hi 70° Lo 55°	Hi 60° Lo 31°	Hi 47° Lo 30°

	BEFORE THE COLD FRONT (Sat. to Wed.)	DURING THE COLD FRONT (Thurs.)	AFTER THE COLD FRONT (Fri.)
Temperature: The highest temperature was:	*75 (Sunday)*	*60*	*47*
The lowest temperature was:	*55 (Saturday)*	*31*	*30*
Humidity & Clouds We don't have humidity data, but we know clouds form with higher humidity. *When was humidity likely high or low?*	○ high humidity ● low humidity **Increasing humidity*	● high humidity ○ low humidity	○ high humidity ● low humidity
Precipitation *When did precipitation happen? When did it not happen?*	○ yes ● no	● yes ○ no	○ yes ● no

1. What do you think the air was like (temperature and humidity) in this location before the front?

   Though it cools slightly between Sunday and Wednesday, generally, there are warm temperatures with increasing humidity.

2. What do you think the air was like (temperature and humidity) in this location after the front?

   Cooler air temperature, with lower humidity

3. What do you think caused the precipitation during the front?

   *The drop in air temperature decreases the amount of water in the air, which leads to condensation and precipitation. *Note: Students have not yet learned the mechanics of a cold front, so their answers will connect with prior learning in Learning Sequence 1. In Learning Sequence 2, students will learn that the cold air mass pushed the humid, warm air mass higher into the atmosphere.*

Name Period Date

LESSON 8

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

STEP 1: Describe the air temperature before, during, and after the cold front.
Imagine your town has just received a weather report that a cold front is heading your way. Read the weather report and analyze temperature, humidity, and wind data to figure out what happened during this storm.

WEATHER REPORT

A cold front is expected to change temperatures in the area after an extended warm-up. The cold front will arrive in South Riding, Virginia, on the morning of October 21, 2016. Be prepared for a change in temperature over two days as the front passes through the area, replacing a warm air mass with a cold air mass.

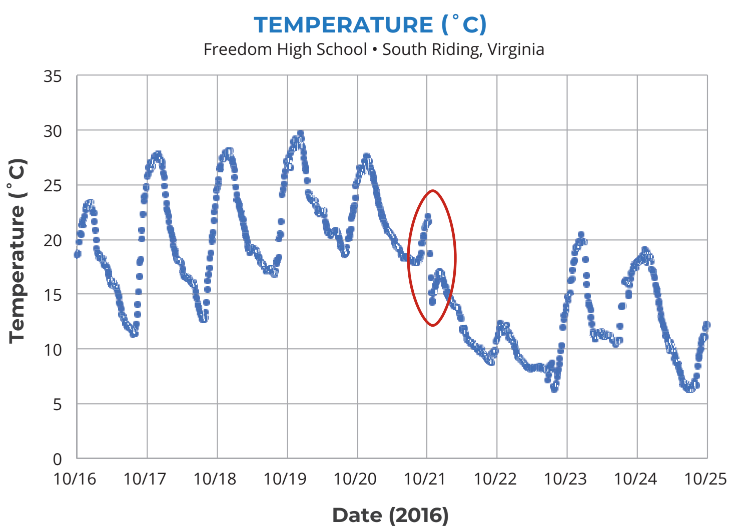
Circle the data on the graph that shows when the cold front passes through South Riding, VA. Describe the graph using the What I See and What It Means statements.

WHAT I SEE: Look at different parts of the graph. Do you notice patterns? Do you notice interesting differences? Write What I See statements on the graph to record your observations.

WHAT IT MEANS: Next to each What I See statement, write a What It Means statement to explain what you think is happening in each part of the graph.

Note: The vertical lines on the graph indicate noon on each of the dates listed on the x-axis.

***WIS**: Air temp goes up and down each day.*
***WIM**: Diurnal cycle due to day/night (because of the rotation of the Earth on its axis).*



***WIS**: Air temp drops sharply at noon on 10/21.*
***WIM**: Storm begins in this location..*

1. Describe the air temperature pattern before the cold front.

   Temperatures rise and fall day-to-day due to warming during daytime and cooling at night, with warmer days before the front than after the front.

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

LESSON 8

STEP 1 CONTINUED: Describe the air temperature before, during, and after the cold front.

2. Describe the air temperature pattern after the cold front.

The diurnal pattern continues, but temperatures are much cooler after the cold front. The highest and lowest daily temps are much lower than before the front.

3. How does air temperature change when the front moves through?

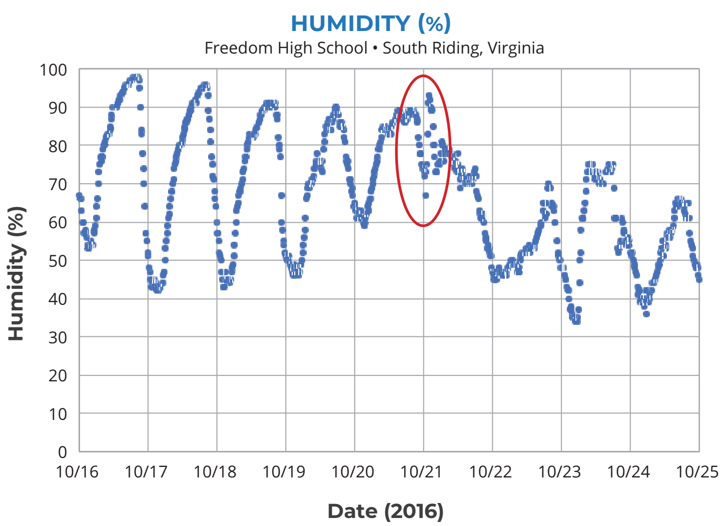
Air temperature drops when the front moves through, and there isn't a diurnal pattern for a couple of days.

STEP 2: Describe the humidity before, during, and after the cold front.

Circle the data on the graph that shows when the cold front passes through South Riding, VA. Write **What I See** and **What is Means** statements on the graph.

Note: The vertical lines on the graph indicate noon on each of the dates listed on the x-axis.

WIS: *Humidity goes up and down each day.*
WIM: *The diurnal cycle is due to the warming of the surface, increased evaporation during the daylight, and cooling/condensation during the nighttime.*



WIS: *A rapid spike in humidity at noon on 10/21.*
WIM: *This was when the storm began at this location. The air became saturated with moisture due to a drop in air temperature at this time.*

1. Describe the humidity pattern before the cold front.
Before the cold front, there is a normal daily fluctuation in humidity as the Sun rises & sets (warming and cooling the air). As the storm begins, humidity stays high.

2. Describe the humidity pattern after the cold front.
The daily pattern of rising and falling humidity re-establishes, but the overall humidity is lower after the front moves through.

3. How does humidity change when the front moves through?
The normal pattern of daily fluctuation is disrupted. Humidity remains higher throughout most of 10/21 when the storm is occurring, and drops as the storm ends on 10/22.

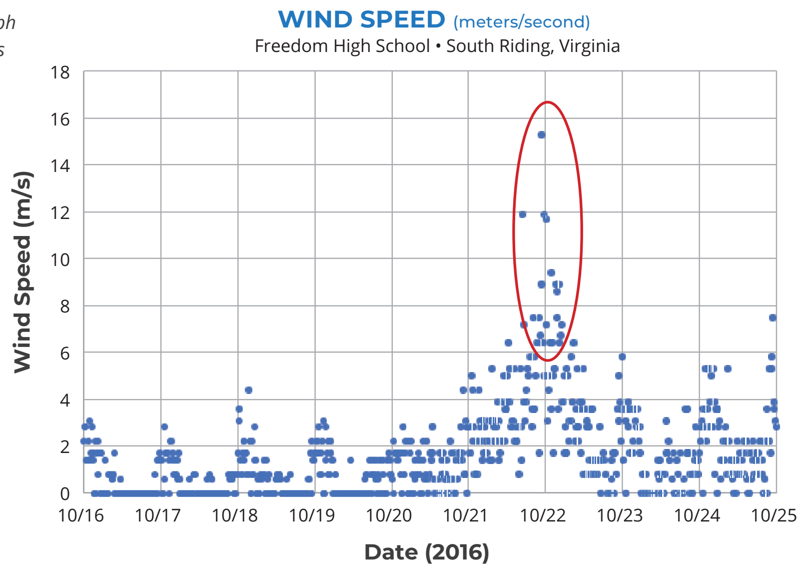
LESSON 8

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

STEP 3: Describe the wind speed before, during, and after the cold front.

Circle the data on the graph that shows when the cold front passes through South Riding, VA.
Write **What I See** and **What is Means** statements on the graph.

Note: The vertical lines on the graph indicate noon on each of the dates listed on the x-axis.



WIS: *Spike in windspeeds on 10/22*

WIM: *Higher windspeeds are associated with the storm.*

1. Describe the wind speed before the cold front.
   There are daily patterns of higher wind speeds as the air warms up and lower wind speeds when air is cooling, with increasing wind speeds as the cold front passes through the area.

2. Describe the wind speed after the cold front.
   The wind speed decreases rapidly just after the cold front, but overall a bit windier in the days following in the cold front.

3. How does wind speed change as the front moves through?
   The daily pattern of rising and falling wind speed doesn't happen as the front moves through, and it is windier than before the front.

WEATHER REPORT

...bring your umbrellas for the morning of October 21. The chance of rain is high.

DISCUSS WITH YOUR CLASS:

Why do you think the chances are high for precipitation the morning of October 21?
Because the temperature decreases, and the humidity is high.

How is this storm similar to, or different from, the isolated storm that you investigated before?
The storm doesn't develop over just one day, but rather it develops over several days.

Students at a high school in Virginia collected the weather data that's in this lesson's graphs.
If you collected weather data at your school, what types of weather events would you likely observe?
Answers will vary. Look for an understanding of typical weather patterns specific to your location.

Name Period Date

LESSON 9 What causes precipitation along a cold front?

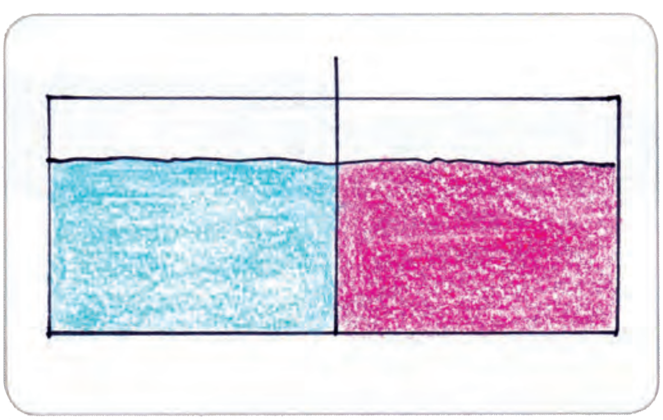
STEP 1: How does the air change as a front moves through a place?
Illustrate the weather conditions (temperature, humidity, and wind) you might see a day before the front, during the front, and a day after the front arrived at Freedom High School, South Riding, Virginia. Use color and symbols to show changes in temperature, humidity, and wind.

CREATE A KEY: Warm air Cool air humidity wind

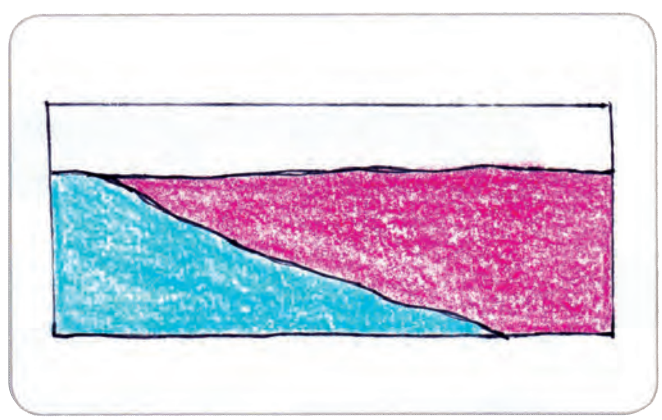
(choose a color) *(choose symbols to show changes in humidity and wind)*

STEP 2: Make observations of what happens to the warm and cool fluids in the tank.
Record your observations of the water tank in the space below. The tank is a model that uses warm and cool water to simulate warm and cool air in the atmosphere. With it, we can see what happens when warm air and cool air meet.

Make a cross section that shows what the tank looks like **BEFORE** the partition is removed.



Make a cross section that shows what the tank looks like right **AFTER** the partition is removed.

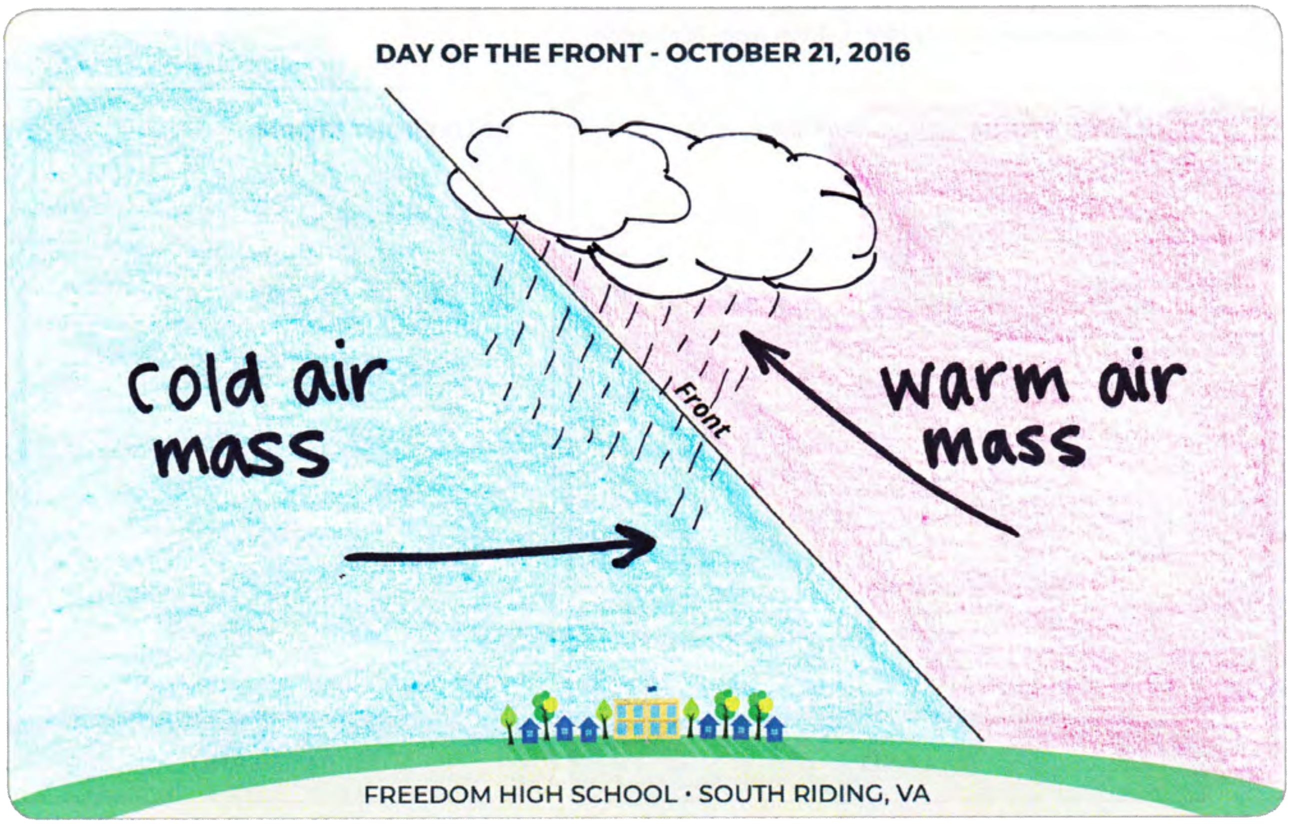


DISCUSS AS A CLASS:
What happened when the cold and warm fluids met?
The cold, dense fluid pushes into the warm, less dense fluid and forces it upwards.

What causes precipitation along a cold front?

STEP 3: Develop a model for explaining precipitation during the cold front.
This model is a cross section of the atmosphere, just like the water tank that showed a cold front. Draw on the model to explain:

1. The location of the cold air mass.
2. The location of the warm air mass.
3. The direction that each air mass is moving.
4. Where you'd expect clouds to form.



EXPLANATION: Write a caption for your model to explain why Freedom High School had precipitation on October 21, 2016.

The cold, dense air mass forced the warm, humid air mass up into the atmosphere, where the air cooled and condensed to form clouds and rain. The cold air mass caused a sharp drop in the air temperature at Freedom High School.

What causes precipitation along a cold front?

STEP 4: Investigate air masses and fronts.

Over large areas, air can have similar temperature and moisture. Air with similar characteristics is called an **air mass**. For example, air over northern North America can form a cold, dry air mass. It is cold because it forms at high latitude, near the Arctic. It is dry because it forms over land, and there is little moisture evaporating from the land as compared with the ocean. Air over the Gulf of Mexico and the southern United States can form a warm, moist air mass. It is warm because it forms at a lower latitude, closer to the equator. Water evaporating from the Gulf of Mexico makes the air mass moist. The two kinds of air masses often "bump" into each other as they move, forming fronts.

STOP AND THINK

What type of air mass was over Freedom High School before the front moved through the area?

WARM

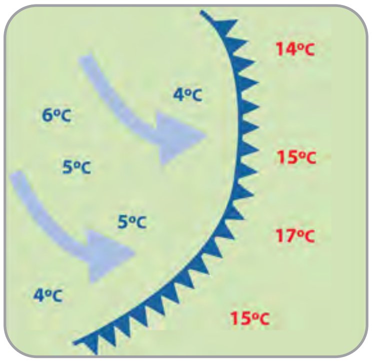
What type of air mass was over Freedom High School after the front moved through the area?

COLD

(Students might also note that the warm air mass was more moist than the cold air mass.)

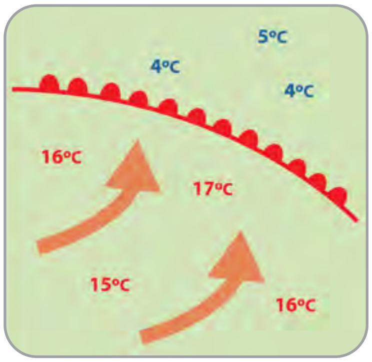
There are several different types of fronts. The type of front depends on how the air masses interact. The pictures below show how different types of fronts are shown on weather maps using symbols.

COLD FRONT



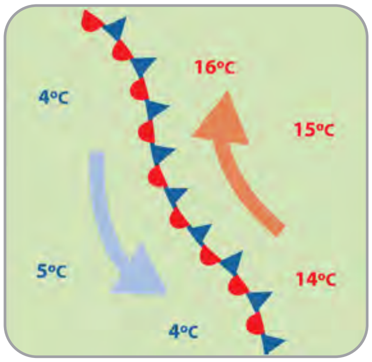
At a cold front, a colder air mass moves into a warmer air mass. A cold front is shown on a weather map as a blue line with triangles in the direction of movement.

WARM FRONT



At a warm front, a warmer air mass moves into a colder air mass. A warm front is shown on a weather map as a red line and half circles in the direction of movement.

STATIONARY FRONT



At a stationary front, a cold air mass and warm air mass are side by side. Both might be moving, but neither has enough force to move into the other's space. A stationary front is shown on a weather map with both red half circles and blue triangles.

What causes precipitation along a cold front?

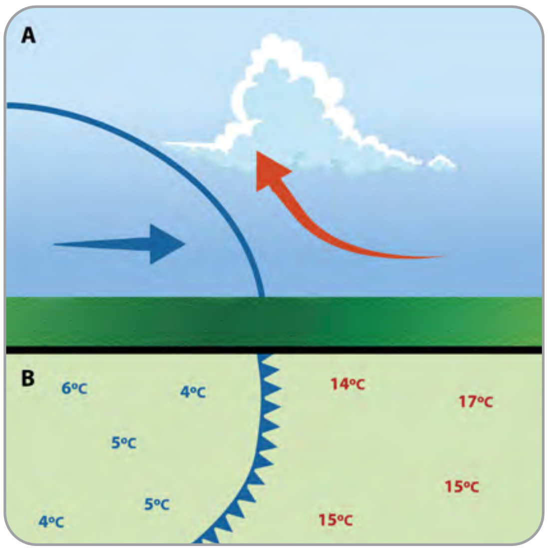
LESSON 9

In this investigation, we are focusing on cold fronts.

Cold fronts can produce dramatic storms. Winds become gusty, and there is a sudden drop in temperature. There can be heavy rain, hail, thunder, and lightning. As warm air is pushed up at a cold front, cumulus clouds form just as they did in the isolated storms you learned about before – as the air moves upward it cools, and water vapor becomes liquid water droplets that make up clouds. The clouds may grow into cumulonimbus clouds and cause rain, or snow if the temperature is below freezing. After a cold front moves through, you may notice that the temperature cools down, the rain stops, and clear skies or other types of clouds replace the cumulus clouds.

STOP AND THINK

What happened as the cold air mass moved into the warm air mass at Freedom High School?



(A) The upper part of this image shows a cross section of a cold front. This is 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) The lower part of this image shows a weather 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.

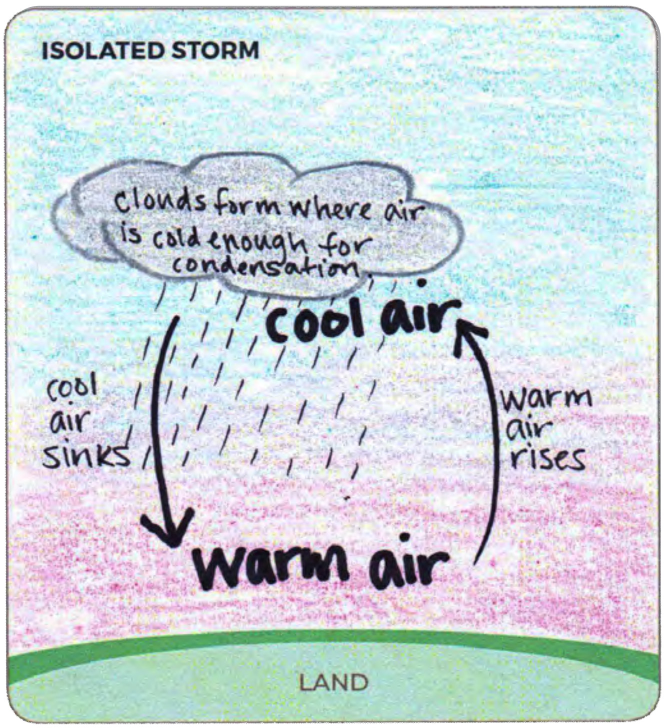
A cold front (and the cold air mass that moves in) may not be cold. During the summer, temperatures might be quite warm, but we can still have cold fronts. A cold front in the summer typically brings cooler weather compared with the previous days.

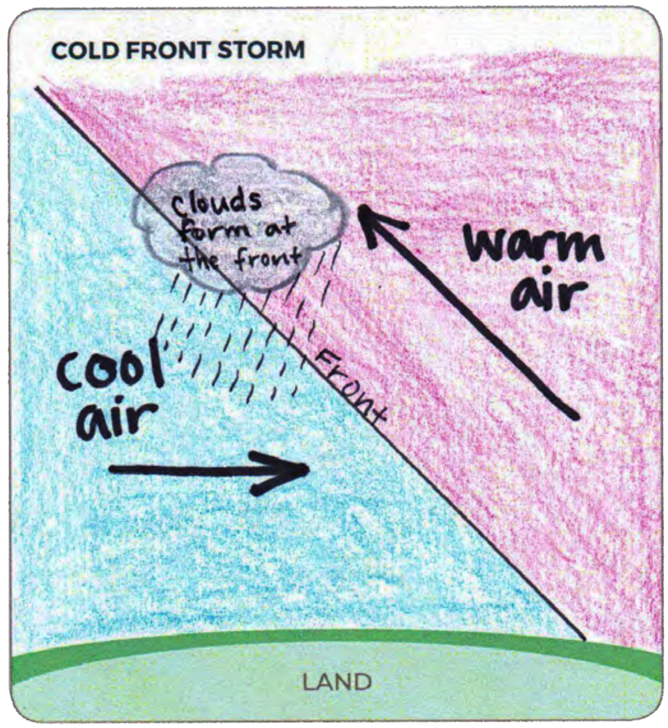
What causes precipitation along a cold front?

STEP 5: Let's compare our two types of storms: isolated storms and storms that form along a cold front.

Draw cross section models to explain how precipitation could happen in each kind of storm.

- Use the other models you've made and the reading in this lesson to help you decide what to draw.
- Indicate where air is warmer and where it is cooler.
- Use arrows to show how air moves.
- Show where clouds form in both types of storms.





1. How are isolated storms and cold front storms similar?

Both types of storm result from warm, humid air rising into the cooler upper troposphere where water vapor condenses to form cumulus clouds. In both types of storms, cumulus clouds can develop into cumulonimbus clouds that cause precipitation.

Both types of storms can result in severe weather.

2. How are they different?

An isolated storm typically develops over the course of one day and is short-lived, lasting only a few hours. A cold front lasts longer.

In an isolated storm, warm air rises due to convection as energy from the Sun warms the Earth's surface, which then warms the air near the surface. In a cold front, a warm air mass is forced to rise when it collides with a cold air mass. The cold air mass is more dense than the warm air mass, which causes the warm air to rise above the cold air.

What causes precipitation along a cold front?

STEP 6: Focus on the big picture using our cold front model.
Your teacher will assign you to a group. Each member of your group will map weather data for one day over a four-day time period on the map on the following page. Then you'll look at all four maps together to see what happened as a cold front moved through this area, the Midwest, and Northeast.

1. **Choose a day.** Each member in your group will choose one day of data to map. On the next page, circle your day on the Maximum Temperature and Precipitation Tables and write the date on your map.

2. **Color and label your map.**
   a. Color locations where the temperature is greater than 30°C RED.
   b. Color locations where the temperature is equal to, or less than, 30°C BLUE.
   c. Draw slanted rain lines near the location if it had precipitation.
   d. Add the red and blue colors to the key.

3. **Compare maps.** When your group completes all four maps, line them up in order beginning September 8 and ending with September 11.

4. **Determine where the cold front is located.** Draw the front on each map using the blue line/blue triangle symbol.

5. **Determine where the cold air mass is located.** Shade the cold air mass BLUE on each map.

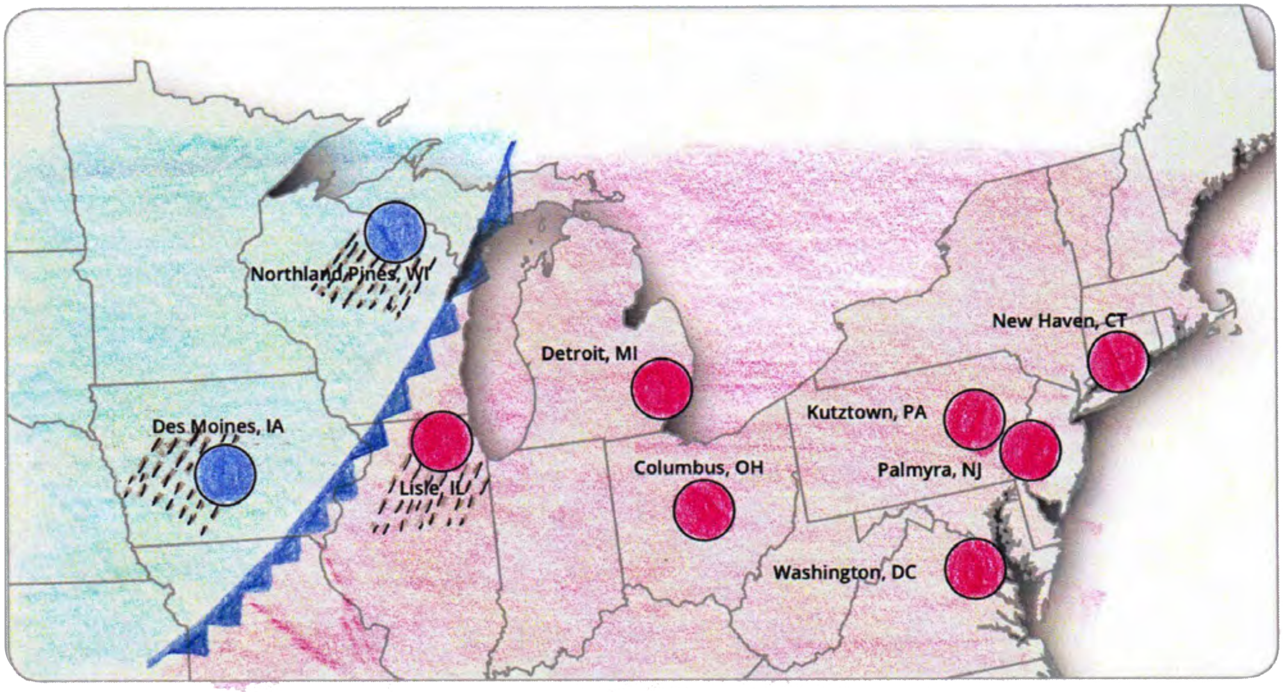
6. **Determine where the warm air mass is located.** Shade the warm air mass RED on each map.

7. **Make observations of how the front and air masses move over time.** Be prepared to discuss your ideas.

The front moves from the West towards the East (from left to right) over the course of the four days.

LESSON 9

What causes precipitation along a cold front?



DATE:

9/8/15

Max temperature above 30°C

Max temperature equal to or less than 30°C

Precipitation

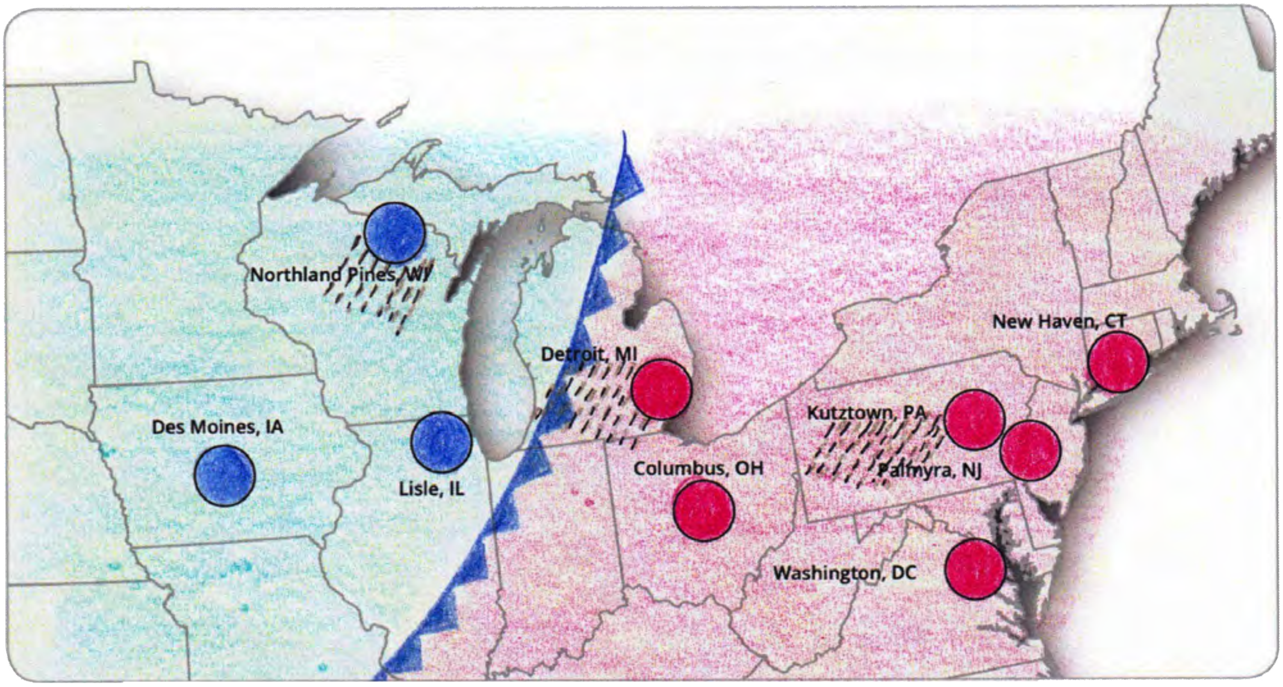
MAXIMUM TEMPERATURE (˚C)

	9/8/15	9/9/15	9/10/15	9/11/15
Des Moines, IA	27.8	27.8	28.9	21.1
Northland Pines, WI	25.4	22.7	19.6	16.9
Lisle, IL	31.7	23.3	25.6	19.6
Detroit, MI	31.2	30.1	24.7	25.8
Columbus, OH	32.7	30.9	26.1	28.2
Washington, DC	33.3	34.4	28.9	30.5
Palmyra, NJ	32.2	32.7	33.9	26
Kutztown, PA	31.2	32.5	32.7	22
New Haven, CT	32.8	30	25	26.7

PRECIPITATION (cm)

	9/8/15	9/9/15	9/10/15	9/11/15
Des Moines, IA	0.3	0	0	0
Northland Pines, WI	0.5	0.1	0	0.1
Lisle, IL	2.2	0	0.9	1.5
Detroit, MI	0	0.1	0	0.6
Columbus, OH	0	0	0	1.6
Washington, DC	0	0	0.3	0
Palmyra, NJ	0	0	3.6	0.1
Kutztown, PA	0	0.6	3.6	0
New Haven, CT	0	0	0	0

What causes precipitation along a cold front?



DATE:

9/9/15

Max temperature above 30ºC

Max temperature equal to or less than 30ºC

Precipitation

MAXIMUM TEMPERATURE (˚C)

	9/8/15	9/9/15	9/10/15	9/11/15
Des Moines, IA	27.8	27.8	28.9	21.1
Northland Pines, WI	25.4	22.7	19.6	16.9
Lisle, IL	31.7	23.3	25.6	19.6
Detroit, MI	31.2	30.1	24.7	25.8
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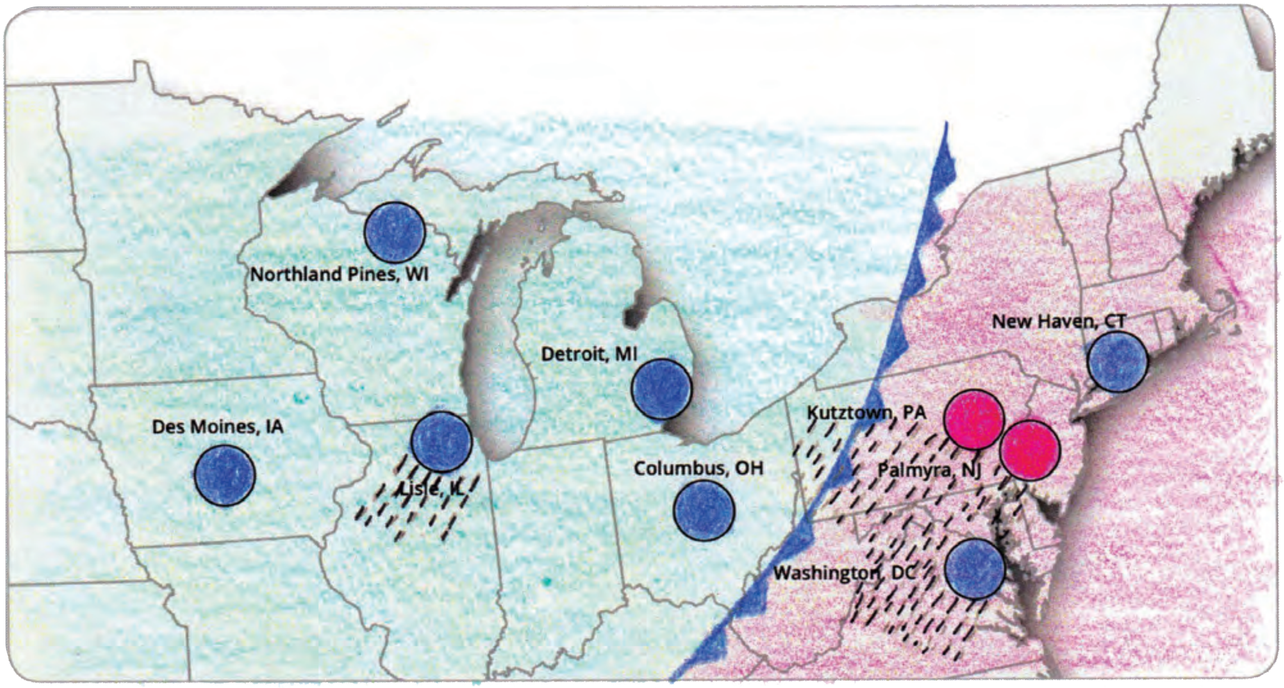
Palmyra, NJ	32.2	32.7	33.9	26
Kutztown, PA	31.2	32.5	32.7	22
New Haven, CT	32.8	30	25	26.7

PRECIPITATION (cm)

	9/8/15	9/9/15	9/10/15	9/11/15
Des Moines, IA	0.3	0	0	0
Northland Pines, WI	0.5	0.1	0	0.1
Lisle, IL	2.2	0	0.9	1.5
Detroit, MI	0	0.1	0	0.6
Columbus, OH	0	0	0	1.6
Washington, DC	0	0	0.3	0
Palmyra, NJ	0	0	3.6	0.1
Kutztown, PA	0	0.6	3.6	0
New Haven, CT	0	0	0	0

9 What causes precipitation along a cold front?



DATE:

9/10/15

Max temperature above 30°C

Max temperature equal to or less than 30°C

Precipitation

MAXIMUM TEMPERATURE (˚C)

	9/8/15	9/9/15	9/10/15	9/11/15
Des Moines, IA	27.8	27.8	28.9	21.1
Northland Pines, WI	25.4	22.7	19.6	16.9
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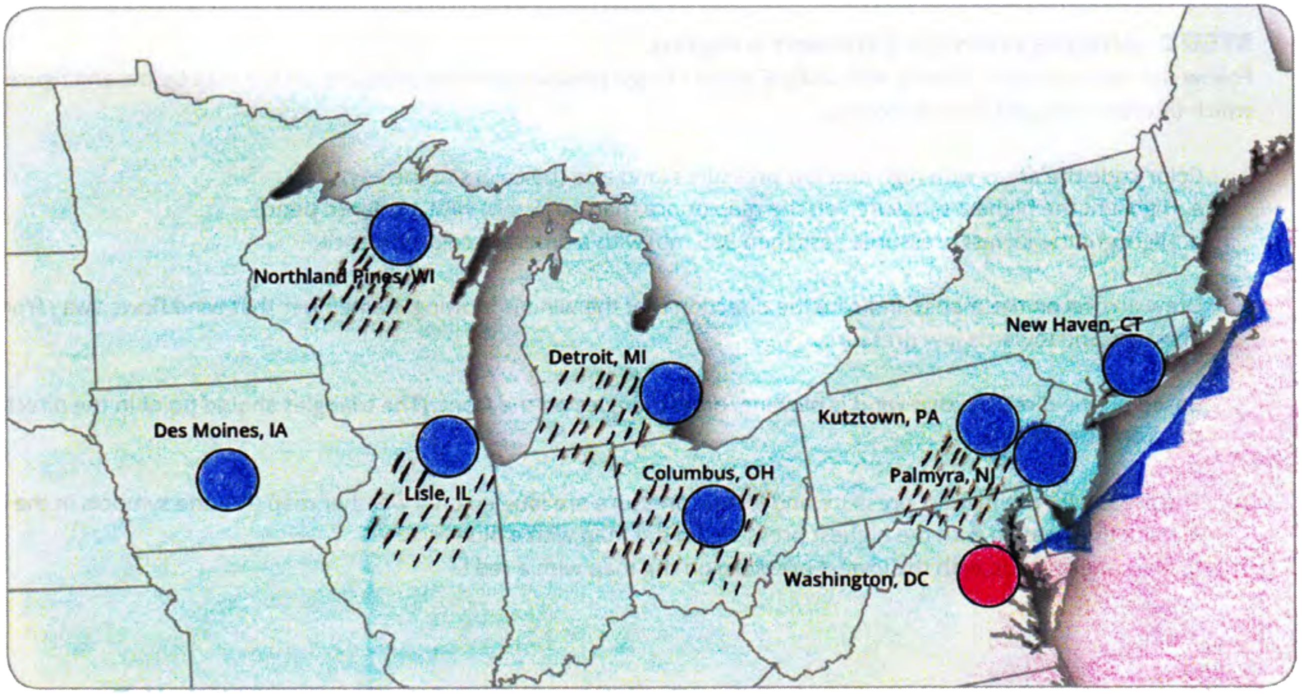
	9/8/15	9/9/15	9/10/15	9/11/15
Des Moines, IA	0.3	0	0	0
Northland Pines, WI	0.5	0.1	0	0.1
Lisle, IL	2.2	0	0.9	1.5
Detroit, MI	0	0.1	0	0.6
Columbus, OH	0	0	0	1.6
Washington, DC	0	0	0.3	0
Palmyra, NJ	0	0	3.6	0.1
Kutztown, PA	0	0.6	3.6	0
New Haven, CT	0	0	0	0

9 What causes precipitation along a cold front?



DATE:

9/11/15

Max temperature above 30ºC

Max temperature equal to or less than 30ºC

Precipitation

MAXIMUM TEMPERATURE (˚C)

	9/8/15	9/9/15	9/10/15	9/11/15
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Columbus, OH	0	0	0	1.6
Washington, DC	0	0	0.3	0
Palmyra, NJ	0	0	3.6	0.1
Kutztown, PA	0	0.6	3.6	0
New Haven, CT	0	0	0	0

LESSON 10 What causes fronts to move?

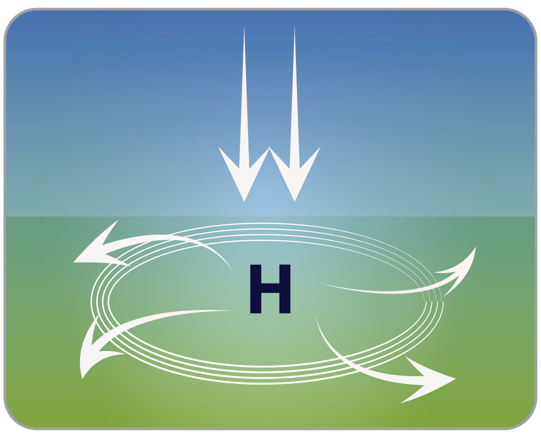
STEP 1: Remember air pressure? There's more to it.

In Lesson 5 you learned that air pressure causes air to move.

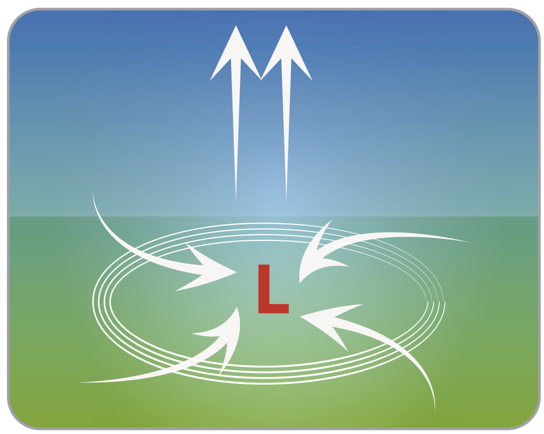
- Air rises in the atmosphere when it has lower pressure.
- Air sinks in the atmosphere when it has higher pressure.

You learned how air moving up and down is able to cause a small isolated storm. It turns out the same thing can happen over vast areas (the size of large US states), and this creates winds that can move fronts.

Air pressure isn't always the same from place to place. In one location, air might have somewhat lower pressure, which causes it to move upward. In another location, air might have somewhat higher pressure, which causes it to move downward.



In areas with high pressure, air moves downward and spreads outward once it gets to the land. High pressure is marked with a blue H on weather maps.



In areas with low pressure, air moves upward, so nearby air rushes in to fill the space. Low pressure is marked with a red L on weather maps.

The air rushing into low pressure and away from high pressure is wind.

Measurements of air pressure are made using an instrument called a barometer. Barometers used for weather measurements record the pressure in units called millibars (mb). The average air pressure at ground level is 1013.3 mb.

LESSON 10

What causes fronts to move?

STEP 2: Analyze pressure data over a region.

Follow the instructions to identify and analyze areas of high pressure and low pressure on the map below and figure out which direction the cold front is moving.

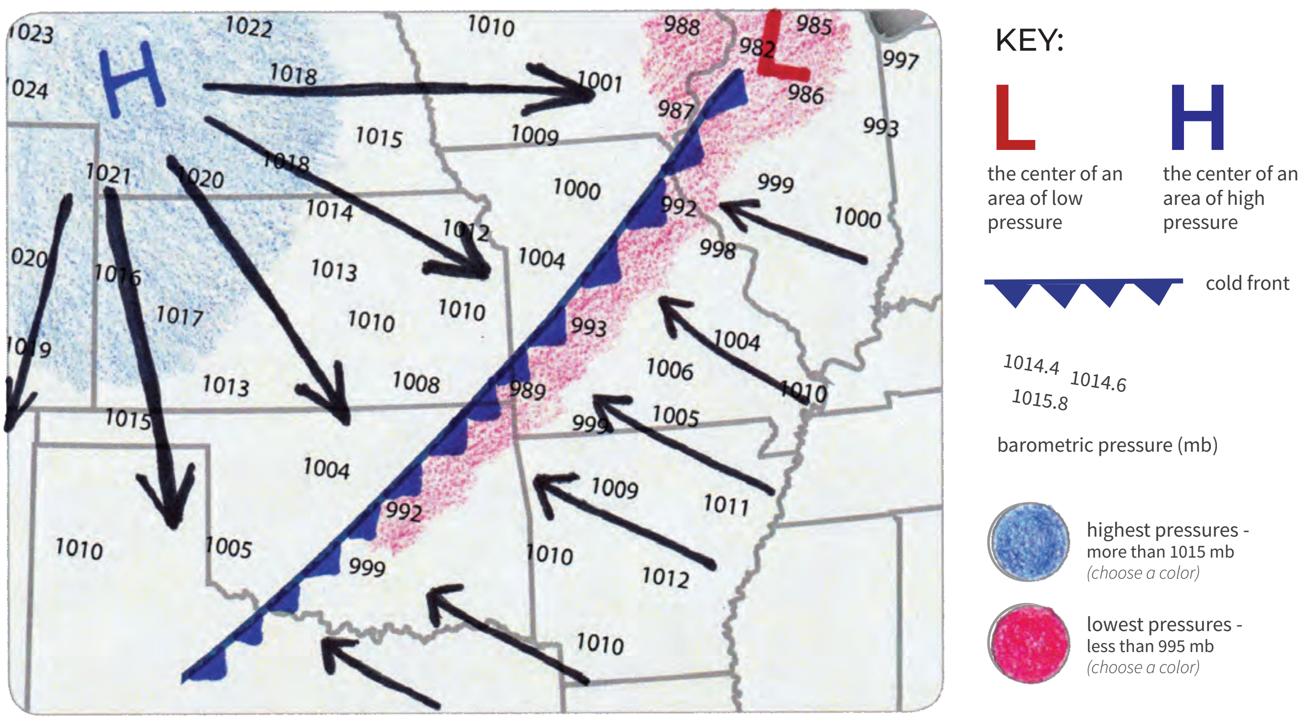
1. Color code the areas with high and low pressures (and add the colors to the key).
   a. Highlight the highest pressures on the map (more than 1015 mb) with a colored pencil.
   b. Highlight the lowest pressures (less than 995 mb) with a different colored pencil.

2. Draw arrows on the map to indicate the direction that the wind is blowing. Remember that wind flows away from high pressure and towards low pressure.

3. Based on the direction that wind is blowing, draw triangles on the front. (The triangles should point in the direction that the front is moving.)

4. The areas with the highest pressure and lowest pressure are labeled on a weather map (like the symbols in the key).
   a. Mark the location with the highest pressure on the map with a blue H.
   b. Mark the location with the lowest pressure on the map with a red L.

PRESSURE MEASURED IN MILLIBARS (mb)



DISCUSS AS A CLASS:

Which way did the wind blow? What evidence do you have to support your claim?

The wind blew east, or from the upper left of the map towards the front. Air always moves from an area of higher pressure towards an area of lower pressure. In this example, the highest pressures are in the upper left corner of the map.

LESSON 10

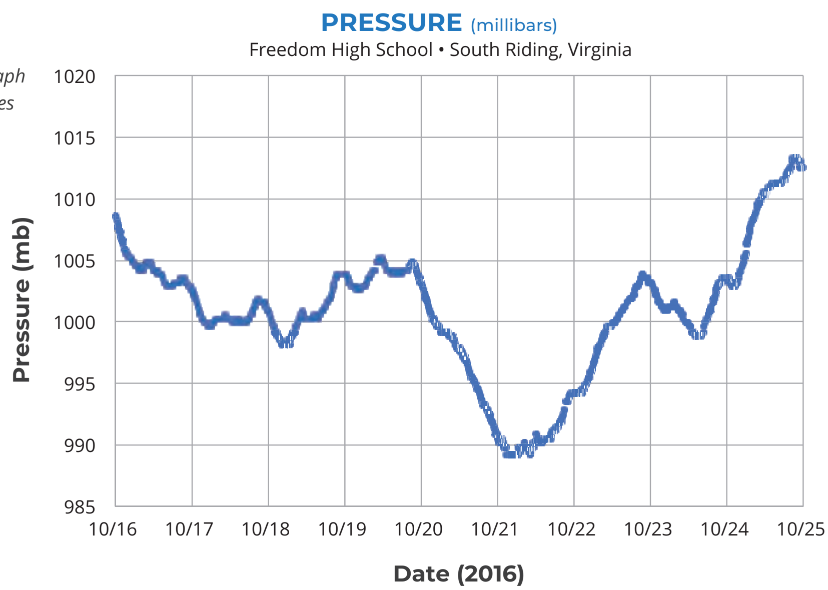
What causes fronts to move?

STEP 3: Analyze pressure data in one location.

In Lesson 8 you looked at weather data from Freedom High School in South Riding, Virginia, over a 10-day period, when a cold front passed through the area. The pressure data below was collected at Freedom High School during that same 10-day period. Remember that the cold front arrived at Freedom High School early on October 21.

How did the pressure change over time? Add **What I See** and **What It Means** statements to describe the pressure before, during, and after the cold front.

Note: The vertical lines on the graph indicate noon on each of the dates listed on the x-axis.



WIS: On 10/20 the pressure begins to drop rapidly.
WIM: A cold front reaches South Riding, VA

WIS: After reaching a low of 989, pressure begins rising again.
WIM: The cold front moves through South Riding, VA. The lowest pressure measurements are along the cold front.

1. When was barometric pressure the lowest? When was it the highest?

   Lowest pressure: 10/21 (989 mb)
   Highest pressure: 10/25 (1013 mb)

2. Write a sentence to describe where pressure is lowest and highest around a cold front.

   Pressure begins dropping when a cold front arrives and is lowest during the front, but begins rising again as the front moves through and is highest after the front has passed.

3. Take a look at the wind data in Lesson 8. The windiest time during this storm was when the pressure was lowest. Write a sentence to explain why winds happen when air pressure is low.

   Air is rising when the pressure is low. In addition to rising air, air along the surface is pulled towards the area of low pressure. This movement of air creates windy conditions. There was more air movement, or wind, when the pressure was lowest.

Name Period Date

LESSON 11

What could cause a front to stall?

Even though Colorado is far from the ocean and other large bodies of water, there was an unusually high amount of moisture in the air above Colorado, and the storm didn't move for days, which led to the flooding event in September 2013. In this activity, you'll examine information about the storm. Your goal is to figure out what led to so much moisture in the atmosphere and to develop a model to show why this precipitation event lasted so long over Colorado.

STEP 1: Analyze data for the Colorado storm.

Using the table of daily rainfall totals collected during the storm at Centennial Middle School in Boulder, Colorado, choose which of the claims below you believe is true about the Colorado storm in September 2013.

DATE	RAINFALL* (mm)
9/10/2013	23.9
9/11/2013	35.1
9/12/2013	214.1
9/13/2013	84.1
9/14/2013	0.8
9/15/2013	4.8
9/16/2013	36.8

**Rainfall totals are for the same Colorado storm, which lasted for seven days.*

- ○ The Colorado Storm in September 2013 was an isolated storm.
- ○ The Colorado Storm in September 2013 was a cold front.
- ● The Colorado Storm in September 2013 was unlike either an isolated storm or a cold front

1. Explain why the claim you chose is true. Use evidence to support your claim.

The storm lasted for several days, which makes it different than an isolated storm. The enormous amount of rainfall, resulting in severe flooding, is unlike a cold front.

LESSON 11

What could cause a front to stall?

STEP 2: Interpret the storm report.
Read the storm report below to collect information about how the air was moving, how moisture was moving, and where rain was falling during the storm.

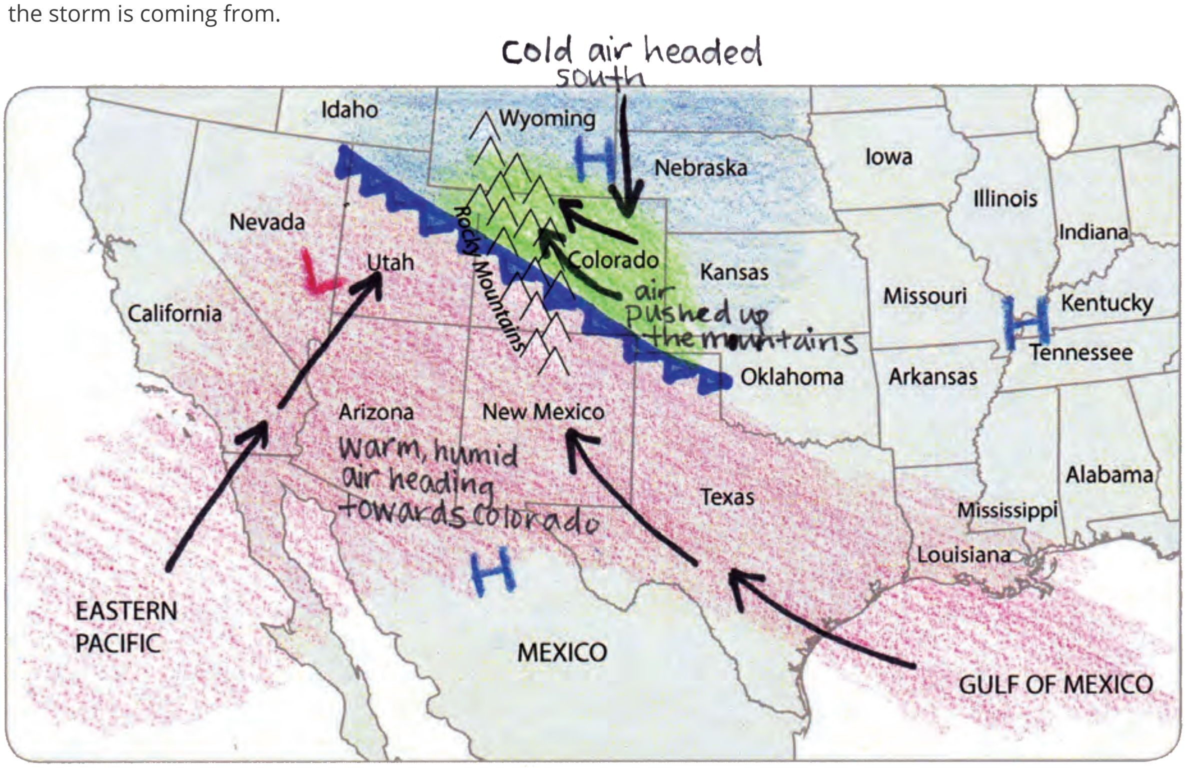
STORM REPORT

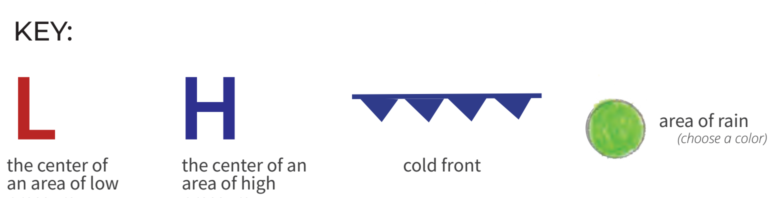
High Pressure: There was high pressure to the north, over Wyoming, which was pushing a cold air mass south and there was a high pressure area to the south, over Mexico, and high pressure to the east over Tennessee and the surrounding area. This caused the front to stall over Colorado.

Low Pressure and Moisture: Low pressure over Utah and Nevada pulled warm, humid air from the Gulf of Mexico and eastern Pacific into the storm.

The Effect of Mountains: As the air traveled up the eastern side of the Rocky Mountains, it formed clouds and then rain, and remained in place for days.

Create a model for the storm: Use the symbols from the key and the information in the storm report to develop a model. Indicate on the model the direction air is moving based on the highs and lows, and where the humid air that caused the storm is coming from.





LESSON 11

What could cause a front to stall?

STEP 3: Use your model to explain what happened in Colorado.

Use your model of the Colorado storm to answer the questions below.

1. Where did the moisture come from for the storm?

   Low pressure over Utah and Nevada pulled moisture from the Gulf of Mexico and the Eastern Pacific Ocean into the storm.

2. What kinds of air masses interacted in the storm? Which air mass had the moisture for the storm?

   - *Cold/dry (continental-polar) air mass from the north*
   - *Warm/moist (maritime-tropical) air mass from the south-west. *This air mass had the moisture for the storm*

3. What caused the precipitation at the front?

   Warm, moist air pushed up into the troposphere by cold, dense air at the cold front, and also by the mountains. As the rising moist air cooled, condensation caused clouds to form and eventually precipitation to occur.

4. Why did the front stall, causing days of drenching rain in parts of Colorado?

   Three areas of high pressure surrounded the storm front, causing it to be stuck over Colorado for days.

UCAR CENTER FOR SCIENCE EDUCATION

TEACHER ANSWER KEY

LEARNING SEQUENCE 3

LESSON 12 How do storms move around the world?

LESSON 13 Why is it hotter at the equator than other places on Earth?

LESSON 14 How and why does air move in the tropics?

LESSON 15 When air and storms move, why do they curve?

BSCS SCIENCE LEARNING

NASA

THE GLOBE PROGRAM

Name Period Date

LESSON 12

How do storms move around the world?

STEP 1: How do storms move across North America?

Watch the video of storms moving across North America and draw arrows on the map below to record the patterns of storms you observe.

Draw arrows to indicate the direction that each storm moves through this region.

Storms have a general pattern of arriving from the west and moving across the continent towards the east.

STEP 2: Why is this pattern important?

Explain below why it would it be helpful to understand the patterns of storm movement.

Understanding patterns of storm movement is useful for predicting the weather in your area. People who live in the central or eastern US states can monitor weather in the western states to prepare for storm systems that may be heading their way.

How do storms move around the world?

STEP 3: Observe precipitation movement around the world.
Watch a video of storms as they move around the world. How do storms move near the equator? In the tropics? In the midlatitudes?

Draw arrows on and write on the map below to record your observations of moving storms from the video.

STEP 4: Discuss your observations.
Discuss the following questions with your peers and record your answers below. Be ready to share your ideas in a whole class discussion.

1. What patterns did you notice about how precipitation moves around the world?

   Storms appear to move in predictable patterns around the world. In the mid-latitudes, storms move from the west to the east across the Earth's surface. In the tropics, storms form from the east to the west across the Earth's surface.

   Though it wasn't specifically asked for in this question, students might also notice that storms in the tropics are smaller than storms in the mid-latitudes. Mid-latitude storms appear to elongate or stretch out. There are also more storms in the tropics than in the midlatitudes. Though it is hard to see in the video, storms swirl counterclockwise in the Northern Hemisphere, and clockwise in the Southern Hemisphere.

2. What questions do you have about these patterns?

   Answers will vary. Students may wonder what causes these patterns of movement, or why the storms move in different directions at certain places on the Earth. They might also wonder how convection, which they learned about in Learning Sequence 1, influences these patterns.

How do storms move around the world?

STEP 5: Form an initial explanation.
What do you think could be causing these patterns of global storm movement? Draw on your knowledge from Learning Sequences 1 and 2 to answer the questions below.

1. What do you know about what causes rain?

    - *In Learning Sequence 1, students learned that convection causes air and water vapor to rise in the troposphere, and that high altitude air is cooler than air at the surface, which leads to condensation/cloud formation and can lead to precipitation.*

    - *In Learning Sequence 2, students learned that rain happens along a cold front due to the collision of a cold air mass and a warm air mass. The cold, dense air mass forces the warm, moist air mass upwards, which leads to cloud formation and storms.*

2. What do you know about what causes air to move?

    - *In Learning Sequence 1, students learned that as air is heated, the molecules spread further apart, becoming less dense, and rise. When air cools, the molecules move closer together, becoming more dense, and sink.*

    - *In Learning Sequence 2, students learned that air moves from high pressure areas to low pressure areas.*

    - *In Learning Sequence 2, students learned that low pressure air rises and high pressure air sinks.*

3. How could the same processes affect the whole world?

    - *Students may note that some regions of the Earth are warmer or colder than others and connect what they have learned about air movement to how storms move around the world. For example, students may predict that air from warm places on the Earth will rise while air from cold places on Earth will sink. They may predict that warm places on Earth will have lower air pressure, and cold places will have high air pressure.*

    - *In Learning Sequence 2, students learned that rain happens along a cold front when a cold air mass meets a warm air mass. Students may connect this learning to storms across the whole world and predict that the interaction of air masses with different temperatures on a global scale is driving the storm patterns.*

Name Period Date

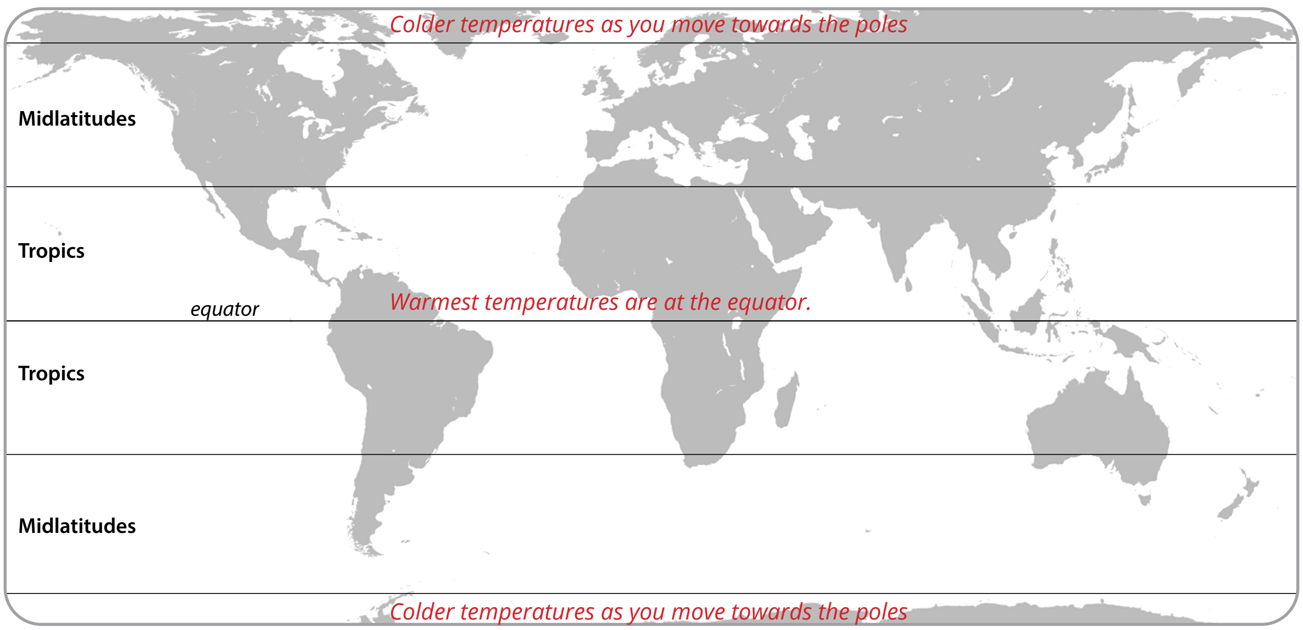
LESSON 13 Why is it hotter at the equator than other places on Earth?

STEP 1: Observe patterns in average annual temperatures.
Look closely at the World Average Temperatures slide.

1. Where are temperatures cooler?
2. Where are they warmer?
3. What patterns do you notice?

Draw and write your answers to the questions above on the map below.

Students should draw or write on the map to show the pattern of decreasing temperatures as the distance from the equator increases.



Record your ideas about why it's hotter at the equator than other places on Earth.

Answers will vary. Use student responses to pre-assess their understanding of the uneven heating of the Earth. Look for answers that explain the connection between the amount of sunlight received and temperature. The equator is hotter than other places because it receives more direct sunlight than other places on the Earth.

Why is it hotter at the equator than other places on Earth?

LESSON 13

STEP 2: Observe energy angles.
Work in groups of three to investigate what happens to light when it shines on graph paper at different angles. Be prepared to share your ideas.

Materials: A clipboard or flat surface, flashlight, ruler, one sheet of graph paper, pencil

What does the flashlight represent in this investigation?

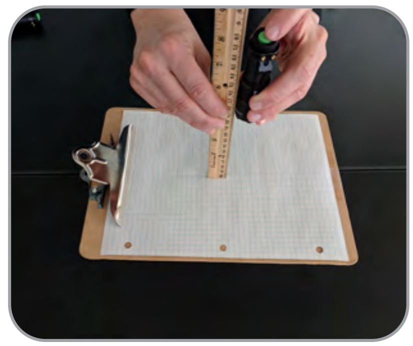
sunlight

What does the clipboard represent in this investigation?

the surface of the Earth

INSTRUCTIONS:

1. Decide who will hold the flashlight and ruler, who will hold the clipboard, and who will record.
2. Put a piece of graph paper on your clipboard and lay it flat on the table.
3. To investigate what happens to light that shines at different angles onto a surface, follow these steps:
   a. Turn on the flashlight and hold it directly above the clipboard.
   b. Adjust the distance between the flashlight and the clipboard so that the light shines entirely on the graph paper, with lots of space around the edges. Use your ruler to measure the distance. *Note: This distance will vary depending on how bright your flashlight is, but try about 4-5 cm and move closer or further away as needed.*
   c. The recorder will trace the edges of the light pattern onto the graph paper. Be sure that the flashlight is pointed straight down when you take this measurement!
   d. Label this image "straight on."
   e. Next, tip the clipboard so that the light shines on graph paper at an angle, as shown in the picture at the right. Remember to hold the flashlight the same distance from the clipboard as you did when taking the "straight on" measurement (Use your ruler!). Again, be sure that the flashlight is pointing straight down towards the table like it was when you made the "straight on" measurement.
   f. The recorder should trace the new pattern of light on the graph paper.
   g. Label the new image "tilted."
   h. Now, tip the clipboard at different angles and observe what happens to the light. You do not need to record these images. Just notice what happens to the light when you have less of a slant (less of an angle) versus more of a slant (a greater angle).



STRAIGHT ON

TILTED

DISCUSS WITH YOUR GROUP:

- Describe how the pattern of light changes when the clipboard changes from flat to angled. *The area of illumination increases as the angle increases.*
- Do you observe any difference in the brightness of the light? *Brightness might decrease as the light spreads out, depending on the flashlight and lighting conditions in your room.*
- Think about the amount of light energy from the flashlight that reaches any particular square on the graph paper. How does this change when you change the angle of the clipboard? *Light energy is most concentrated when the clipboard is flat. As you change the angle, the light energy is more spread out, and less energy reaches each square on the graph paper.*

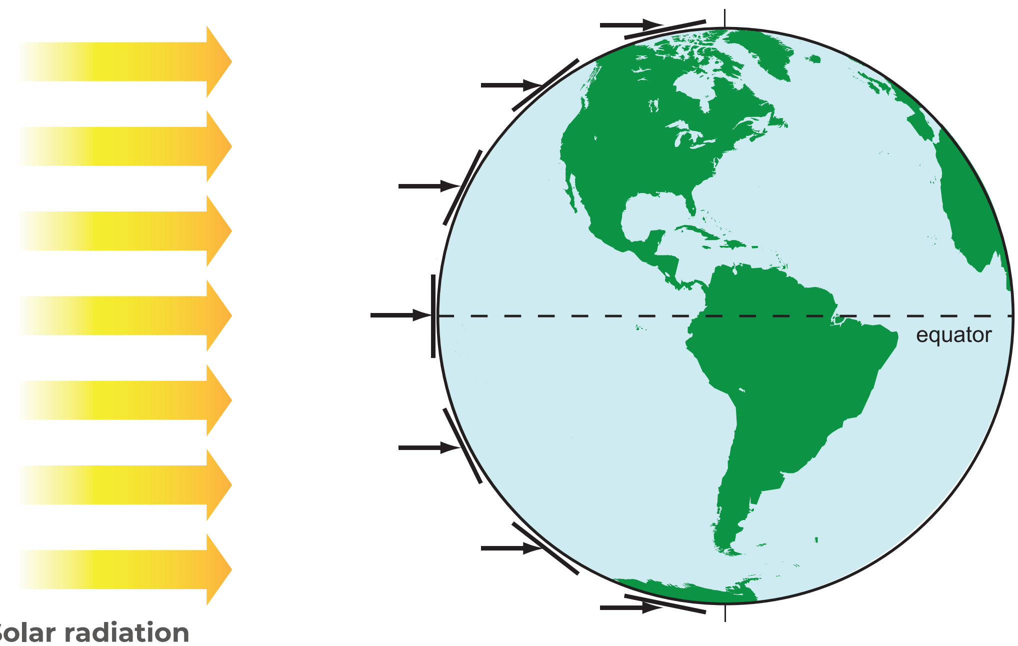
LESSON 13

Why is it hotter at the equator than other places on Earth?

STEP 3: Think about the Sun's incoming energy.

Use the image below to think about where solar radiation (sunlight) is more direct and where it is more spread out on Earth's surface. Then answer the questions below.

THE SUN'S INCOMING ENERGY - ANGLE RELATED TO LATITUDE



1. Which area receives more concentrated sunlight? What is your evidence?

   The equator receives more concentrated sunlight. The Sun is directly overhead at the equator, which means that energy from the Sun strikes the surface with the smallest angle (about 90 degrees). Sunlight is most concentrated here, just as it was in the energy angle experiment when the clipboard was flat.

2. Which area receives less concentrated sunlight? What is your evidence?

   All locations as you move north or south from the equator receive less concentrated sunlight than at the equator itself. The poles receive the least concentrated sunlight. Energy from the Sun strikes the surface with increasingly larger angles the further you move from the equator. Sunlight is less concentrated as the angle increases, just as it was in the energy angle experiment when the clipboard was held at an angle.

3. How does the concentration of sunlight affect temperatures? Which areas are hotter? Which areas are colder?

   There is a direct relationship between temperature and concentration of sunlight: temperature increases as the concentration of sunlight increases. Hotter areas have more concentrated sunlight (the tropics, which is the region surrounding the equator). Colder areas have less concentrated sunlight (the polar regions; the Arctic in the north and the Antarctic in the south). The temperate zone inbetween experiences more moderate temperatures but also significant seasonal variation.

Why is it hotter at the equator than other places on Earth?

LESSON 13

STEP 4: Analyze temperature and latitude.

Your teacher will provide you with graphs of daily maximum temperature. Students at schools in Finland, Vermont (US), Arizona (US), Saudi Arabia, and Sri Lanka collected these data. Work with your group to match the graphs with the location where you think that data was collected. Use the clues below to help you decide how graphs and locations match:

CLUE 1: Seasonal differences are stronger at higher latitude (further from the equator). At or near the equator there is usually no seasonal difference in temperature.

CLUE 2: Temperatures are warmer at low latitude (close to the equator) than at high latitude (far from the equator).

	GRAPH (letter)	LOWEST MAXIMUM TEMPERATURE	HIGHEST MAXIMUM TEMPERATURE	DIFFERENCE IN TEMPERATURE (highest minus lowest)
Finland	*B*	*-30° C*	*30° C*	*60° C*
This is why I think Finland matches this graph:	*Answers will vary. Graph B shows the lowest maximum temperature and the greatest difference in temperature throughout the year, which matches with Finland's location, which is the furthest from the equator.*			
Vermont, US	*E*	*-22° C*	*35° C*	*57° C*
This is why I think Vermont matches this graph:	*Answers will vary. Graph E also shows a lot of difference in temperature throughout the year, but doesn't get quite as cold as Finland (Graph B), which matches with Vermont's location, which is the second furthest from the equator.*			
Arizona, US	*A*	*-7 °C*	*44° C*	*51° C*
This is why I think Arizona matches this graph:	*Answers will vary. Graph A is similar to Graph E, both have over 50° C of difference in temperature throughout the year, but overall temperatures are warmer in Arizona than in Vermont because Arizona is closer to the equator.*			
Saudi Arabia	*C*	*24° C*	*49° C*	*25° C*
This is why I think Saudi Arabia matches this graph:	*Answers will vary. Graph C shows considerably less difference in temperature throughout the year but does still show some seasonal fluctuation. Temperatures are overall quite warm, which matches with Saudi Arabia's location, which is the second closest to the equator.*			
Sri Lanka	*D*	*27° C*	*41° C*	*14° C*
This is why I think Sri Lanka matches this graph:	*Answers will vary. Graph D shows very little difference in temperature throughout the year, with overall warm temperatures, which matches with Sri Lanka's location, which is the closest to the equator.*			

Name Period Date

LESSON 14 How and why does air move in the tropics?

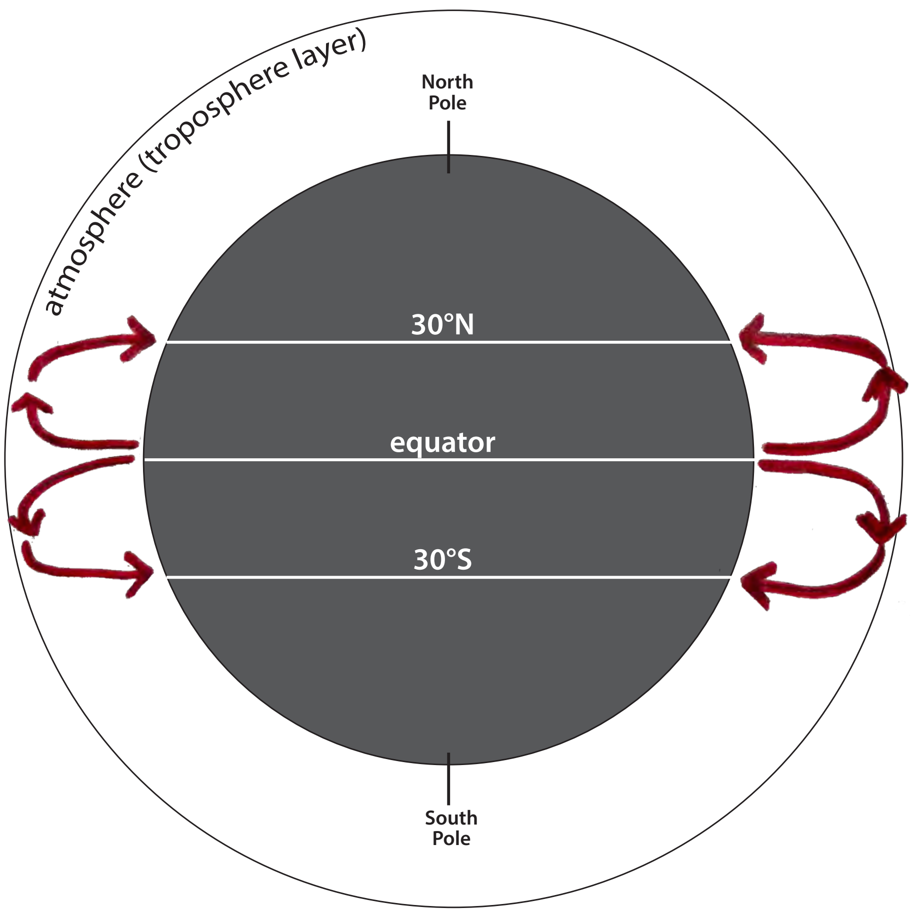
STEP 1: Develop a model.
How do you think air is moving in the tropics between 30°N and 30°S? Why? Record your initial ideas on the image below.

Temperature differences cause air to move around the world.

- In some places, warm temperatures cause air to rise from the Earth's surface to higher in the atmosphere.
- In other places, cooler temperatures cause air to sink from higher in the atmosphere to the Earth's surface.

Translate those ideas to the illustration of Earth's atmosphere below. In the illustration, the atmosphere is exaggerated.

1. **Draw arrows in the troposphere layer of the atmosphere** to indicate where air is rising. Remember that warm air rises.
2. Air can't rise forever. **Draw arrows** to indicate where you think the rising air goes when it gets to the top of the troposphere.
3. At 30°N and 30°S latitude, air is cooler than it is at the equator. **Draw arrows** in the atmosphere to indicate what happens to the cooler air.



LESSON 14

How and why does air move in the tropics?

STEP 2: Investigate air movement across Earth's surface.

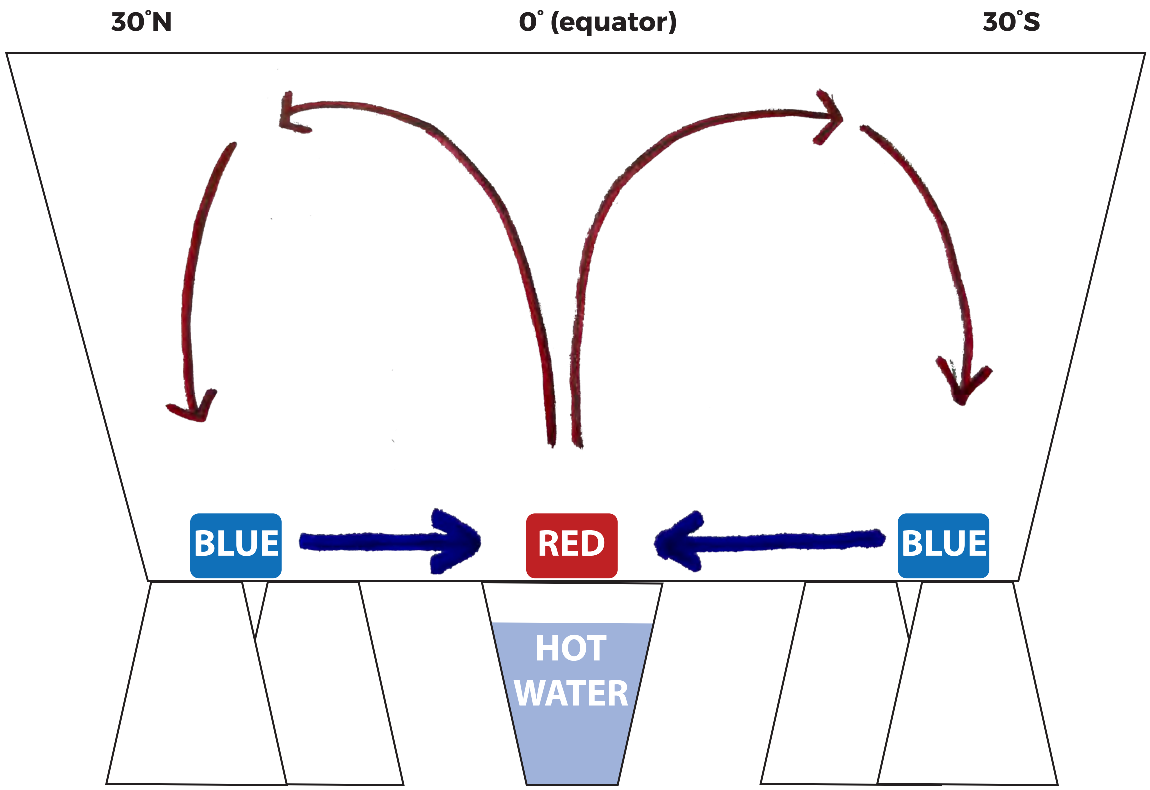
With a partner, write a statement that connects the water tank demonstration to the real world and explains why they are alike. The first part of the model is completed for you as an example.

PART OF THE MODEL		PART OF THE REAL WORLD		WHY ARE THEY ALIKE?
The water in the tank	*is like*	*the atmosphere*	*because*	*the water in the clear plastic tub represents the air in the tropics (between 30°N and 30°S latitude). Air and water are both fluids, so they behave similarly.*
Red food coloring	*is like*	*warmed air*	*because*	*warm air rises up into the atmosphere. The air is heated because the surface has absorbed energy from the Sun, creating low pressure.*
Blue food coloring	*is like*	*cool air*	*because*	*it is located further from the equator and is pulled towards an area of low pressure, rushing in to fill the space left by rising warm air.*
The cup of boiling hot water	*is like*	*solar energy/sunlight*	*because*	*it is the source of heat.*
The bottom of the clear plastic water tub	*is like*	*the Earth's surface*	*because*	*the surface absorbs energy from the Sun, and then transfers heat to the air, causing it to rise. The bottom of the tub is warmed by the cup of boiling hot water (sunlight), which transfers heat to the red food coloring (air) and causes it to rise.*

How and why does air move in the tropics?

STEP 3: **Record observations of the water movement.**

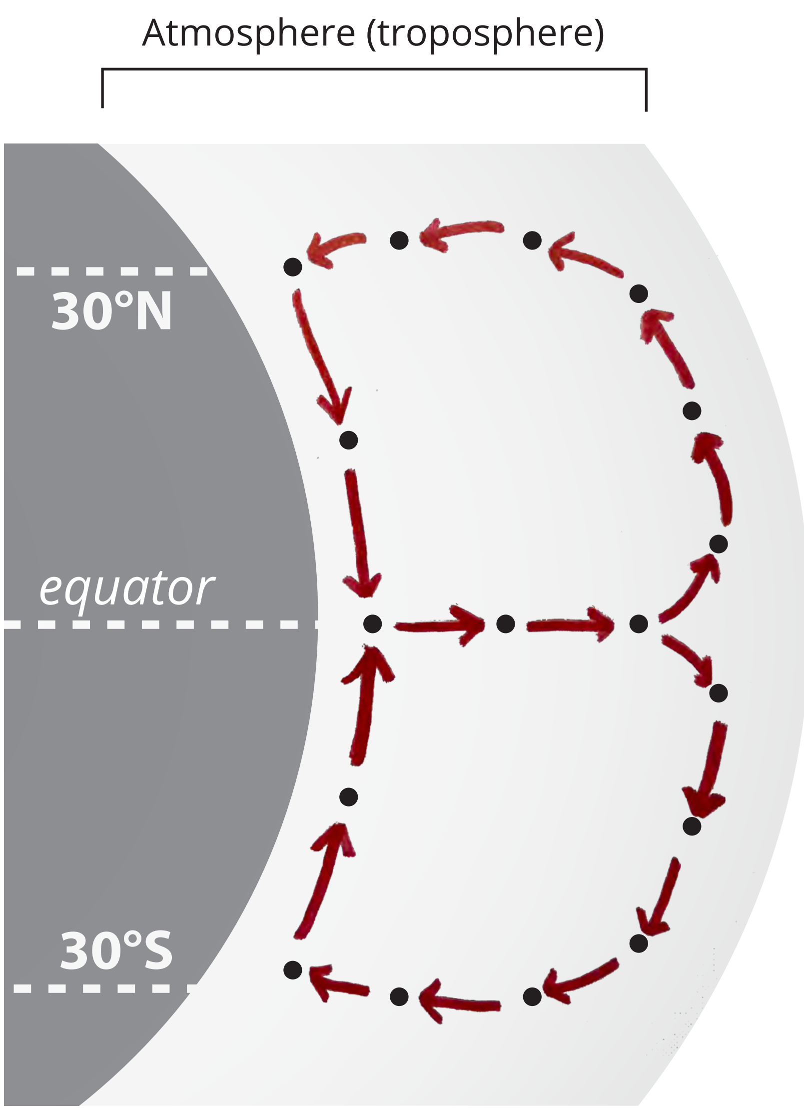
Draw how the water moves through the tank.



RECORD YOUR OBSERVATIONS *I notice...*	RECORD IDEAS FOR WHY *I think...*	RECORD YOUR QUESTIONS *I wonder...*
Observations will vary, but may include: • *The red food coloring rises until it reaches a certain height, and then it spreads out and sinks back down.* • *The blue food coloring is pulled along the bottom of the tub towards the heated area (where the cup of hot water is).* • *After a while, the rising and sinking seem to stop, and the colors mix within the water.*	*Ideas will vary, but look for an understanding of convection:* • *Warmed (red) water becomes less dense and rises until it cools and becomes more dense, and sinks.* • *Cooler water from along the surface (blue) is pulled towards the heat to replace the rising warm (red) water.* • *There is not enough heat to continue convection, the water temperature is equalizing, and the food coloring is diluted by the water.*	*Questions will vary. Look for students wondering about the processes involved, and how they relate to weather.*

How and why does air move in the tropics?

STEP 4: Describe how and why air moves in the tropics.
Focus on how air is moving in the tropics (between 30°N and 30°S of the equator). Draw arrows to connect the dots and show how air is moving in the atmosphere, just as the water moved in the water tank model.



Write a caption to describe air movement in the model above.

Warmed air at the equator rises and then cools and sinks back towards 30°N and 30°S latitude. Cool air along the surface is pulled towards the warm, rising air at the equator.

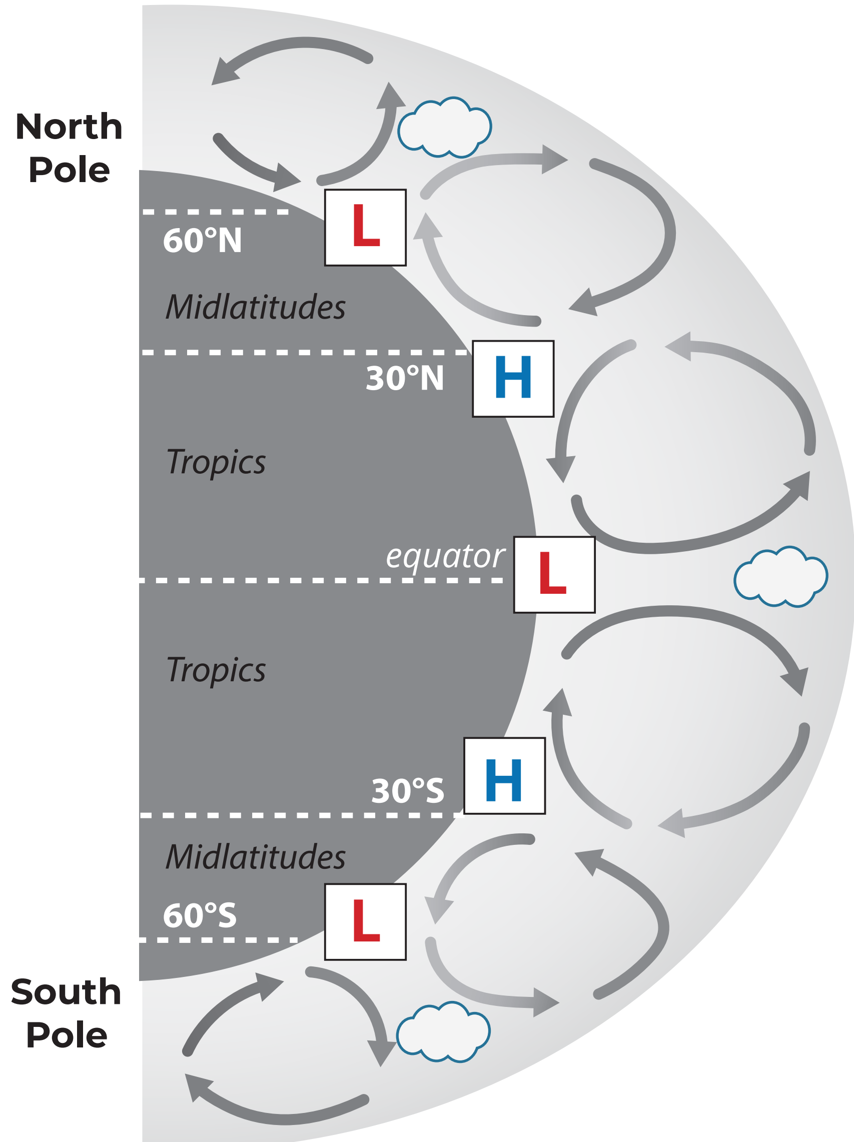
LESSON 14 How and why does air move in the tropics?

STEP 5: Create a model to describe air pressure and clouds at different latitudes.
Review the following diagram of how air moves around the world.

L **Put an "L"** in the white boxes where there would be low pressure.

H **Put an "H"** in the white boxes where there would be high pressure.

Draw in clouds at locations of low pressure, where they are likely to form.



Name Period Date

LESSON 15

When air and storms move, why do they curve?

STEP 1: Compare storm movement with your model.

Watch the *Global Rainfall and Snowfall* video from Lesson 12 again, this time focusing your observations on the movement of storms in the tropics. Below, compare the movement you see in the video to how you might predict storms to move based on your model about air movement in the tropics (from the end of Lesson 14).

1. What kind of movement did you observe in the video that isn't explained by your model?

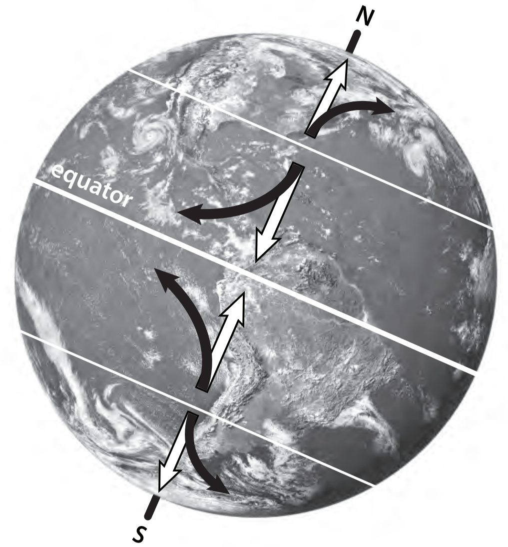
In the video, all of the storms appear to move either from west to east or from east to west. According to our model, warm air should be rising from the equator towards the midlatitudes, and then sinking back down towards the equator as it cools, which would cause air at the Earth's surface to move either from north to south or from south to north.

LESSON 15

When air and storms move, why do they curve?

STEP 2: Learn about the Coriolis effect.

Because Earth is spinning, air does not travel in a straight line above the surface (like the white arrows on the picture to the right). Instead, air has a curved path (like the black arrows). Air north of the equator turns to the right as it moves. Air south of the equator turns to the left as it moves. This is called the **Coriolis effect.**



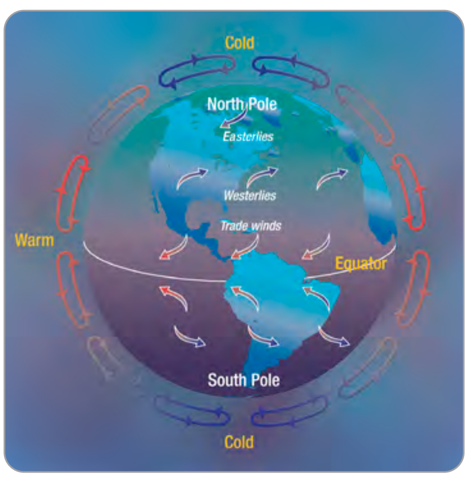
STOP AND DO

Make a model of the Coriolis effect.

1. Make a model of the Earth.
    - **Inflate** the balloon.
    - **Draw** an equator around the widest point.
    - **Draw** lines around the balloon where 30˚N latitude and 30˚S latitude lines would be.

2. Simulate how air in the tropics would move if the Earth didn't spin.
    - *Student 1:* **hold the balloon** in front of you so that the equator and latitude lines are parallel to the floor.
    - *Student 2:* **draw an arrow** starting at 30˚N latitude going toward the equator.

3. Simulate how air moves with Earth's spin.
    - *Student 1:* **slowly rotate** the balloon counterclockwise to model the Earth spinning on its axis. (Look at the balloon from above to determine which direction is counterclockwise.)
    - *Student 2:* **draw another arrow**, starting from the same point as before and trying to get to the equator.



Why does air move in different directions in the tropics and in the midlatitudes?

Earth is always on the move. Earth rotates, or spins, making one full turn every 24 hours. If Earth did not spin, air would rise at the equator and sink at the poles. But because Earth spins, there are three areas of convection north of the equator and three south of the equator. Convection causes winds to move across Earth's surface toward the equator in the tropics, away from the equator in the mid-latitudes, and toward the equator around each pole. These winds are called **prevailing winds**. Prevailing winds curve because of the Coriolis effect. Winds in the midlatitudes curve, moving west to east. Winds in the tropics generally move from east to west.

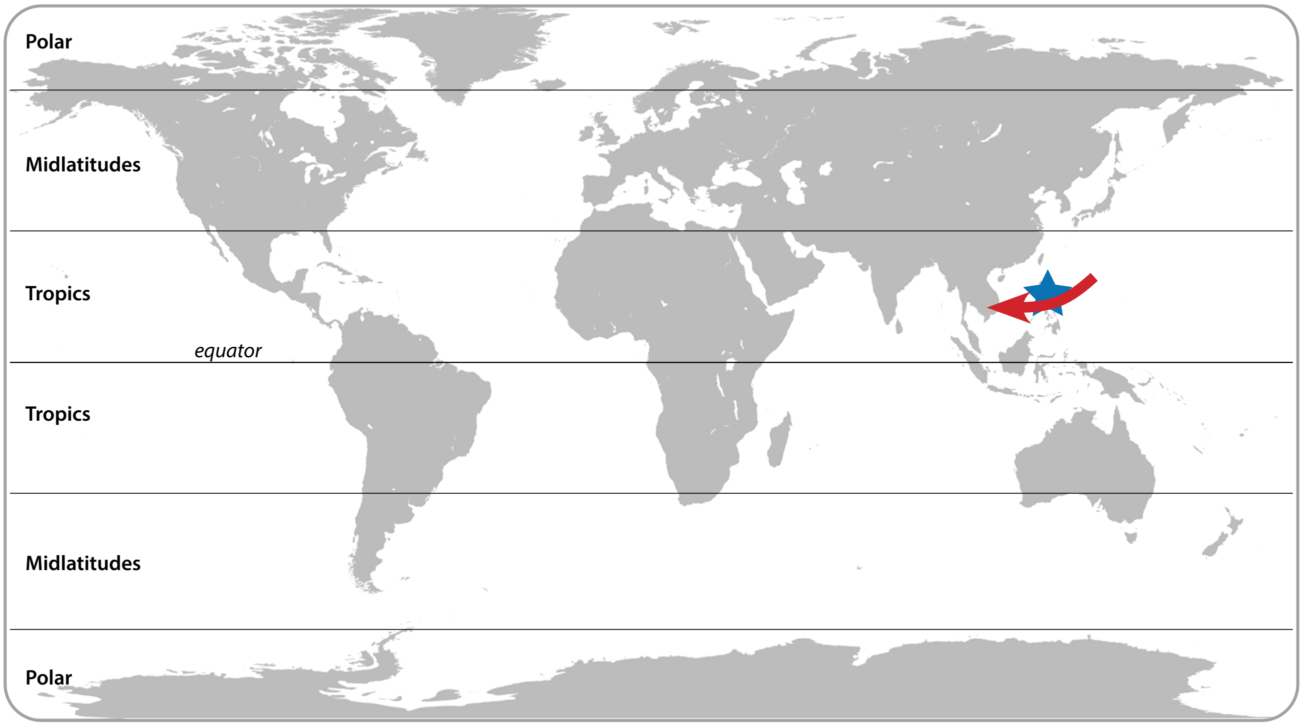
When air and storms move, why do they curve?

STEP 3: Record an explanation.

Use the model of air movement in the tropics you developed and what you learned about the Coriolis effect to explain the direction that storms will likely move through the Philippines (indicated with a star below) and where you live.

- **Draw an arrow** on the map to indicate the direction that storms in the Philippines (starred location) usually travel.
- **Draw a different symbol** on the map that shows where you live. Then, **draw an arrow** to indicate the direction that storms usually travel where you live.

Answers will vary. Look for a correct understanding of which direction storms should travel from your location according to global circulation and the Coriolis effect.



1. Explain why you think storms move through the Philippines in a particular direction.

   Storms in the Philippines usually move from east to west because this location is in the tropics, where air moving towards the equator is deflected to the right (in the Northern Hemisphere) due to the Coriolis effect.

2. Explain why you think storms will come from a particular direction where you live.

   Answers will vary. Look for a correct understanding of which direction storms should travel from your location according to the Coriolis effect and global circulation patterns learned in lesson 14.

UCAR CENTER FOR SCIENCE EDUCATION

TEACHER ANSWER KEY

CULMINATING TASK

CULMINATING TASK: **Challenge 1**	California Storm
CULMINATING TASK: **Challenge 2**	Where's the Snow?
CULMINATING TASK: **Challenge 3**	We're Warning You

BSCS SCIENCE LEARNING

NASA

THE GLOBE PROGRAM

Name Period Date

CULMINATING TASK: **Challenge 1**

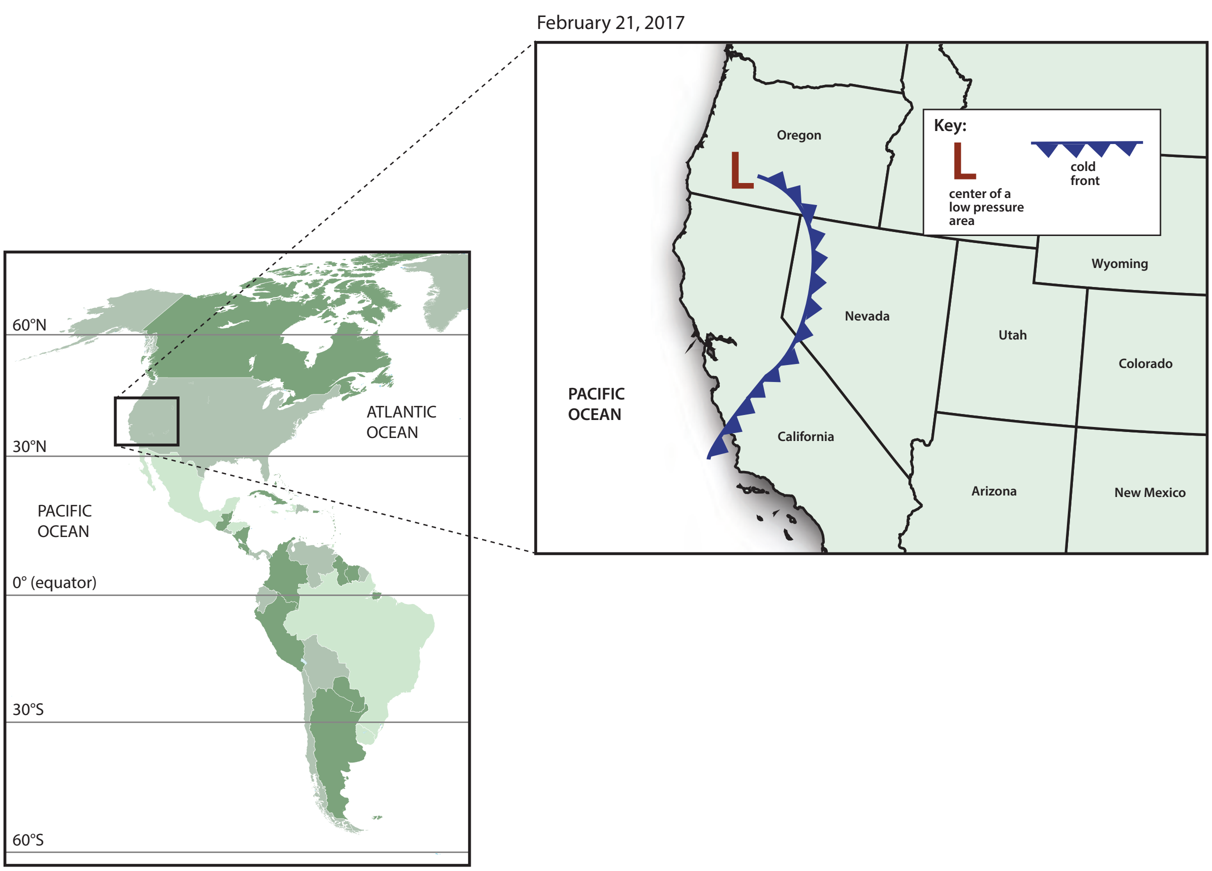
Why did the storm cause rain in some places and snow in other places in California?

On February 20, 2017, a storm passed through California on the West Coast of the United States. The storm brought extreme rainfall which caused flooding and mudslides in some places. The storm brought deep snow to mountainous areas of California.

USA TODAY:

Battered Northern California blasted by new storm

"The National Weather Service was calling for up to eight inches of rain over parts of the region Monday and Tuesday. Wind gusts in some areas could reach 65 mph. Flood warnings for a handful of rivers could last until week's end — this for a state that two months ago was mired in severe drought. Heavy snow was forecast to pound the Sierra Nevada Mountains, where totals will be measured in feet, not inches."



Why did the storm cause rain in some places and snow in other places in California?

STEP 1: Analyzing the California storm.

Use the maps on the previous page and what you have learned about storms to answer the questions below.

1. Based on what you learned about global winds, where do you think the cold front was located before it passed over California?

   The front likely came from over the Pacific, moving east towards California. We learned in Lesson 12: Step 1 that storms in North America typically move from west to east.

2. For a storm to cause rain and snow, there must be moisture in the air (humidity). Where do you think the moisture in this storm came from before it was in the atmosphere? Consider what you know about the water cycle as you answer.

   Moisture came from the Pacific Ocean. Solar radiation caused evaporation over the ocean. That moisture rose and then condensed into clouds as air temperature cooled at higher altitudes. When the air became saturated with moisture, precipitation (rain and snow) fell to the ground.

3. Based on what you learned about cold fronts and the symbols on the weather map on the previous page, where do you think the storm will go next? How do you know?

   The cold front should move east, towards Nevada. The triangle symbols on the front line point in the direction that the storm is moving. In this example, the triangles are pointed towards the east.

Why did the storm cause rain in some places and snow in other places in California?

STEP 2: More details about the California storm: On February 21, 2017, the town of South Lake Tahoe, California, had 6.1 cm (2.4 inches) of rain. Meanwhile, the nearby summit of Heavenly Mountain had 61 cm (24 inches) of snow.

1. What information would you need to decide whether rain or snow will fall during a storm? Explain your answer.

   Temperature data would be needed. Air temperature below freezing would result in snow. We know that air temperature decreases with elevation, so we could expect that at a higher elevation, there would be a greater chance of snow.

2. Look below at the cross section showing the town of South Lake Tahoe and Heavenly Mountain. Use what you know about the atmosphere to explain why it snowed on Heavenly Mountain, but rained in the town of South Lake Tahoe.

   Heavenly Mountain is at a higher elevation than South Lake Tahoe. At higher elevations, there are lower temperatures. At higher elevations, precipitation will happen in the form of snow rather than rain if the temperature is below freezing.

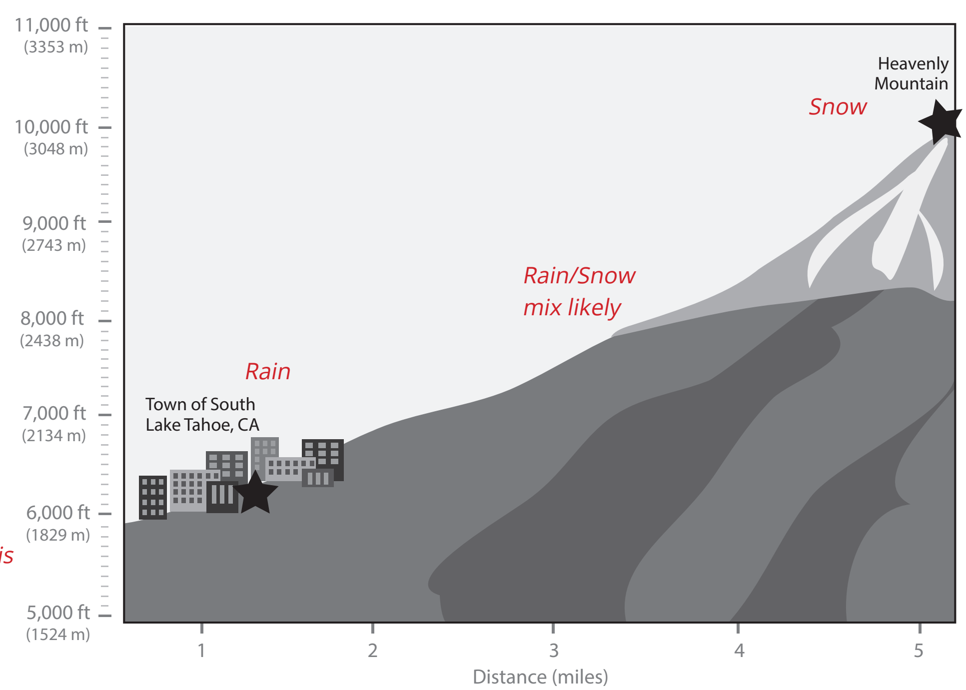
3. **Draw on the cross section below.**

   a. Indicate where the atmosphere is colder and where the atmosphere is warmer.

   b. Indicate the location where it rained and the location where it snowed. Also indicate where along the ground you think a rain/snow mix may have fallen.

   c. Indicate if there are places where you would like more information to know whether rain, snow, or a rain/snow mixture fell.

The atmosphere is colder at higher altitudes.



The atmosphere is warmer at lower altitudes.

**In order to know precisely where precipitation changed from rain to snow, or where there was a rain/snow mix, we would need to know the air temperature at different locations.*

Name Period Date

CULMINATING TASK: **Challenge 2**

As the storm moved east, why did it snow in some areas but not others?

Over a few days, the cold front and the low pressure center moved. From February 20 to 22, the storm moved gradually from California to Nevada. Then, on February 23, the storm moved more quickly to the east and south. In the middle of the country, temperatures were cold enough for snow.

CULMINATING TASK: **Challenge 2**

As the storm moved east, why did it snow in some areas but not others?

STEP 1: Map the snowfall data.

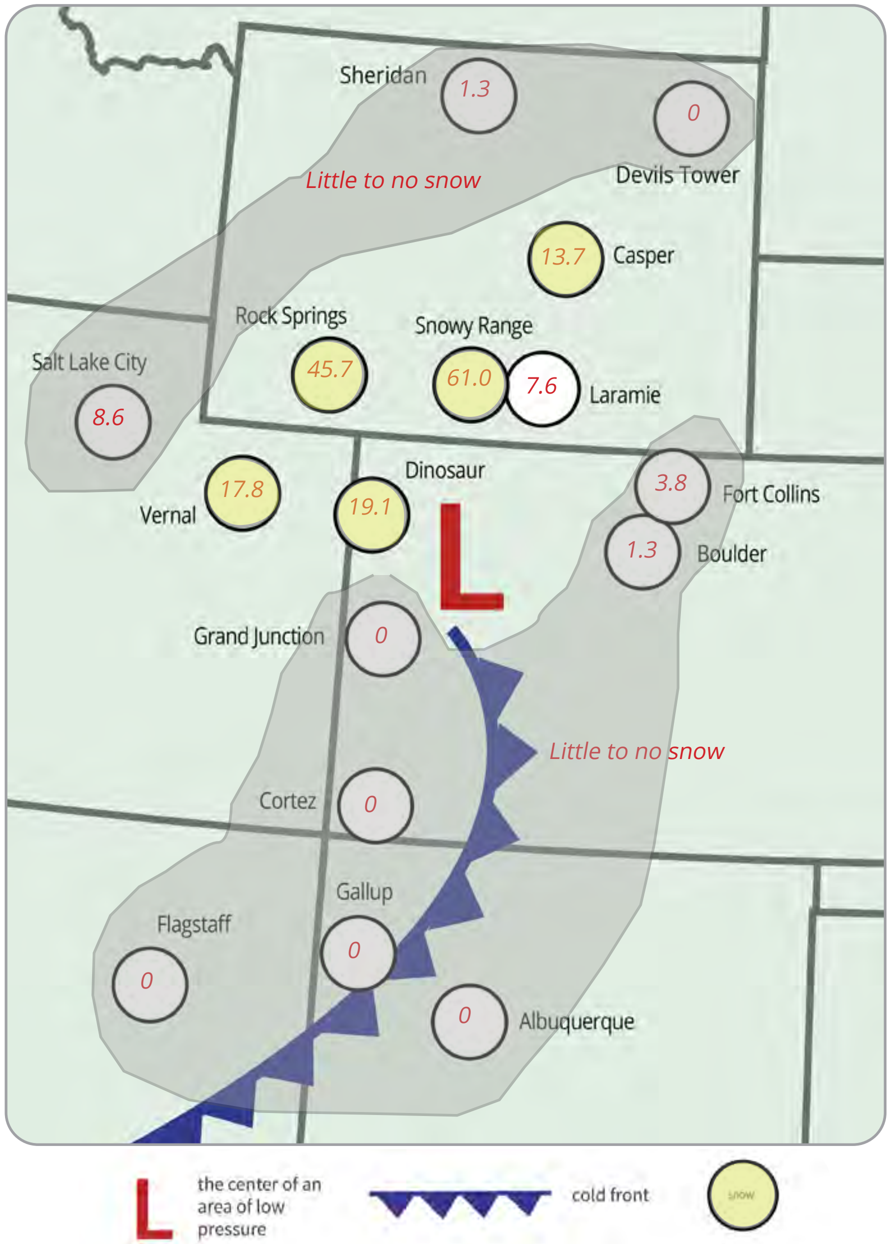
Below is the snowfall report for the communities shown on the map.

1. Locate the communities on the map and **write the snowfall** in the circles.

**Areas shown in gray on the snowfall map below refer to Step 4 on the following page. These are locations with little or no snowfall.*

LOCATION	SNOW (cm)
Rock Springs, WY	45.7
Laramie, WY	7.6
Snowy Range, WY	61.0
Sheridan, WY	1.3
Devils Tower, WY	0
Casper, WY	13.7
Dinosaur, CO	19.1
Grand Junction, CO	0
Fort Collins, CO	3.8
Boulder, CO	1.3
Cortez, CO	0
Flagstaff, AZ	0
Salt Lake City, UT	8.6
Vernal, UT	17.8
Gallup, NM	0
Albuquerque, NM	0

SNOWFALL: FEBRUARY 23, 2017



STEP 2: Where might schools close?

Schools may close if there is heavy snowfall.

Locate where you think schools closed because of snow. **Color these locations with a bright color** on the map so you can easily see where the most snow occurred.

Note: Students' answers about where schools may have closed will vary depending on what they think qualifies as "heavy" snowfall. Look for reasonable selections, and perhaps ask students to justify their choices.

As the storm moved east, why did it snow in some areas but not others?

STEP 3: Look for a trend in the snowfall.

Refer to the map of snowfall on the previous page to answer the questions below.

1. What do you notice about the location of communities with the most snowfall? Where did the most snow fall with respect to the front and area of low pressure?

   The areas with the most snowfall (Rock Springs, Snowy Range, Casper, Dinosaur, and Vernal) are all located to the north of the front and near the low pressure area.

2. Why do you think this area received more snow?

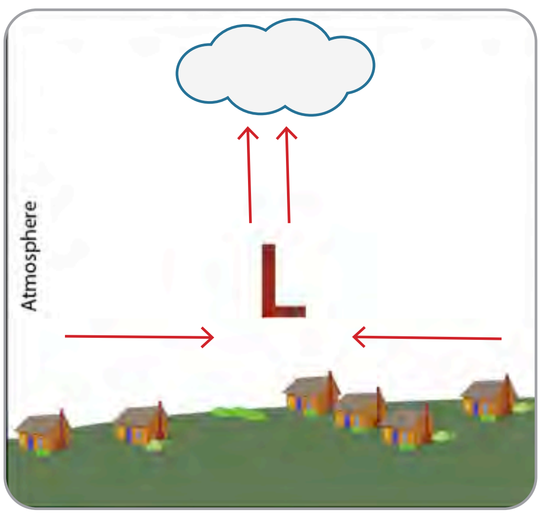
   At a low pressure area, warmer air is rising. Warmer air can have higher humidity, so that might be why there was more precipitation.

STEP 4: Why didn't it snow everywhere?

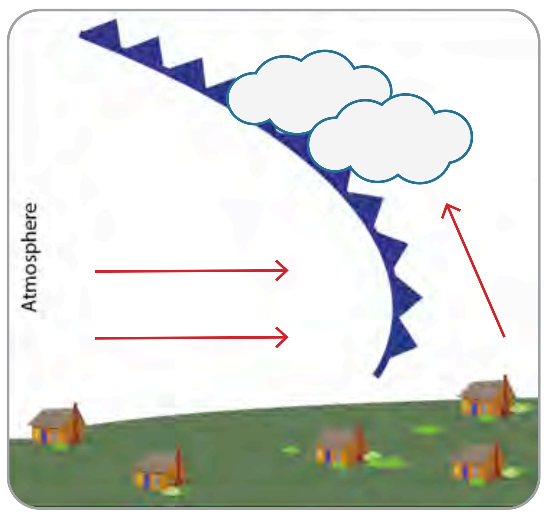
There are two things that a storm needs to cause precipitation:

1. Air that is rising and cooling and
2. Enough moisture in the air to create clouds and precipitation.

1. **Draw a cross section** that shows how air is moving and where clouds are forming at an area of low pressure and at a cold front using models you developed as a class.



How air is moving and where clouds are forming **at an area of low pressure**



How air is moving and where clouds are forming **at a cold front**

2. Notice where there is low pressure and where the front is on the snowfall map. Remember that the storm came from the west, so it moved over the areas on the west side of the map before it got to this location.
   - **Circle locations on the snowfall map** where there was little or no snow. **shown in gray on the snowfall map*
   - Why do you think these locations didn't get much/any snow?

     They are too far away from the area of low pressure.

3. **Name the locations** that you think are too far from the storm to get much snow.

   Flagstaff, Gallup, Alberquerque, Cortex, Grand Junction, Boulder, Fort Collins, Sheridan, and Devil's Tower

Moisture: When it was on the West Coast, this storm was full of moisture, which is what caused so much rain and snow. Is it still full of moisture? The amount of moisture in the air is measured as humidity. On the following page is the average humidity data for the communities shown on the map.

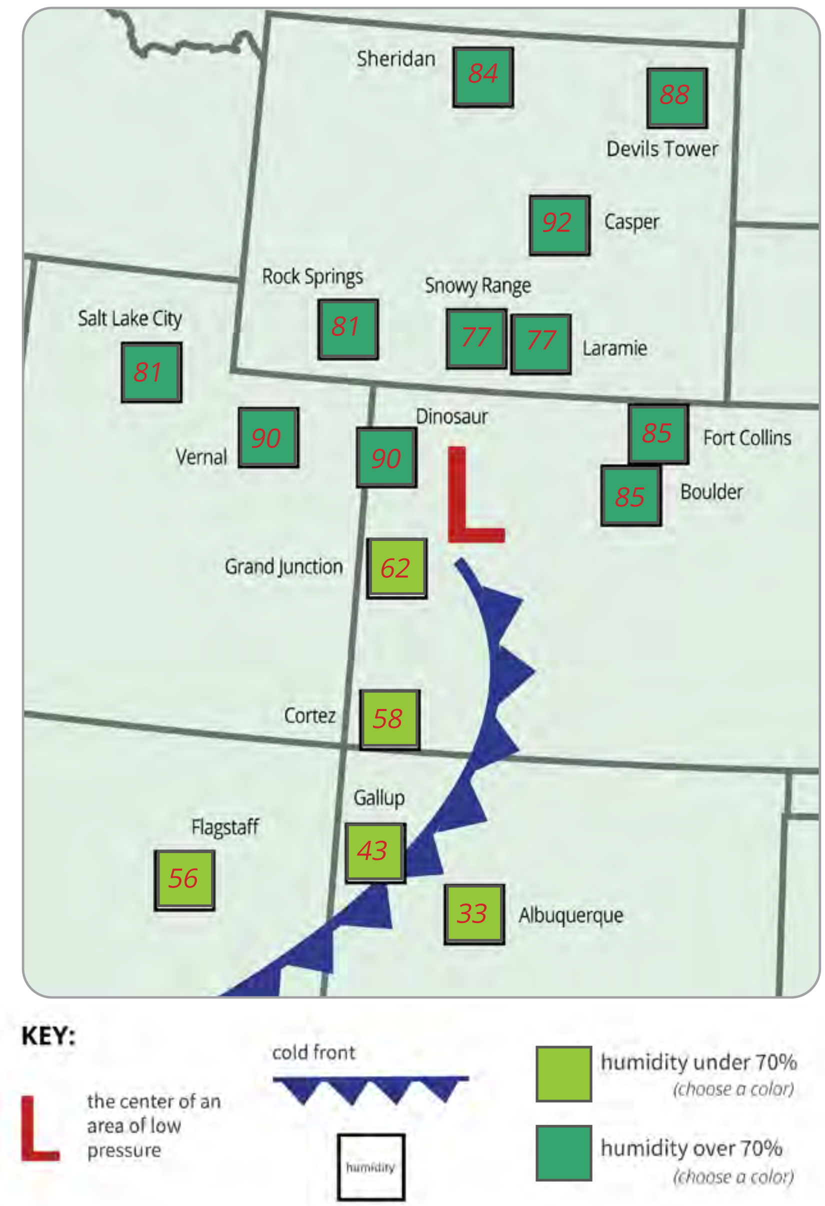
As the storm moved east, why did it snow in some areas but not others?

Use these directions below to create the humidity map.

1. The humidity measurements in the table are from near the ground, not up in the clouds, but they can help us estimate how much moisture is in the air. Locate the communities on the map and **write the humidity** in the squares using a different color than the snowfall measurements.
2. **Color code** the locations that had an average humidity under 70%. These locations are less likely to get precipitation. **Choose another color** for the locations with humidity over 70%. These locations are more likely to get precipitation.
3. Name the locations that you think didn't get much precipitation because the air didn't have enough moisture.
   Flagstaff, Gallup, Alburquerque, Cortez, Grand Junction

LOCATION	AVERAGE HUMIDITY (%)
Rock Springs, WY	81
Laramie, WY	77
Snowy Range, WY	77
Sheridan, WY	84
Devils Tower, WY	88
Casper, WY	92
Dinosaur, CO	90
Grand Junction, CO	62
Fort Collins, CO	85
Boulder, CO	85
Cortez, CO	58
Flagstaff, AZ	56
Salt Lake City, UT	81
Vernal, UT	90
Gallup, NM	43
Albuquerque, NM	33

HUMIDITY: FEBRUARY 23, 2017



Discuss with your class.

How does the humidity data help you understand why it snowed in some places and not others?

Where the humidity is less than 70%, there is less or no snow. There is more snow in places where the humidity is higher than 70%, and they are near the area of low pressure.

Name Period Date

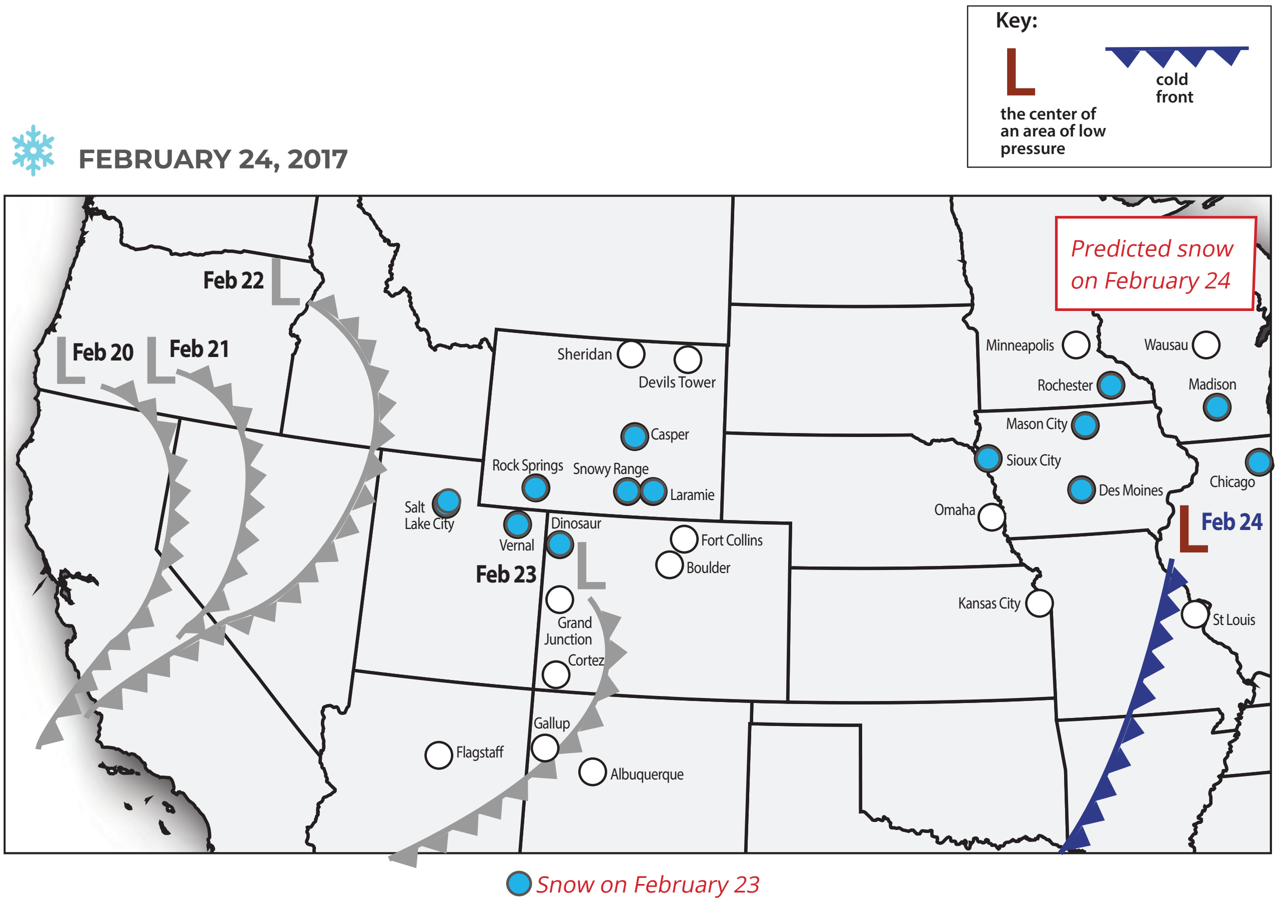
CULMINATING TASK: **Challenge 3**

Where will schools have a snow day on February 24?

STEP 1: Consider where it snowed on February 23.

To predict the weather, meteorologists take into account what the weather was like the day before. In this case, you are the meteorologist. To predict where snow is likely to fall on February 24, you must take into account where this storm caused snow the day before (February 23).

Choose a color and fill in the circles where it snowed more than 5 cm on February 23 using the snowfall map from Challenge 2: Step 1. Leave circles without a color where little snow (5 cm or less) or no snow fell on February 23.



Snow on February 23

Where will schools have a snow day on February 24?

STEP 2: Where's the snow compared to the cold front and low pressure area?

Over North America, it's common for an area of low pressure to be located at the north end of a cold front. Looking at the map on the previous page, what do you notice about the location of the snow on February 23?

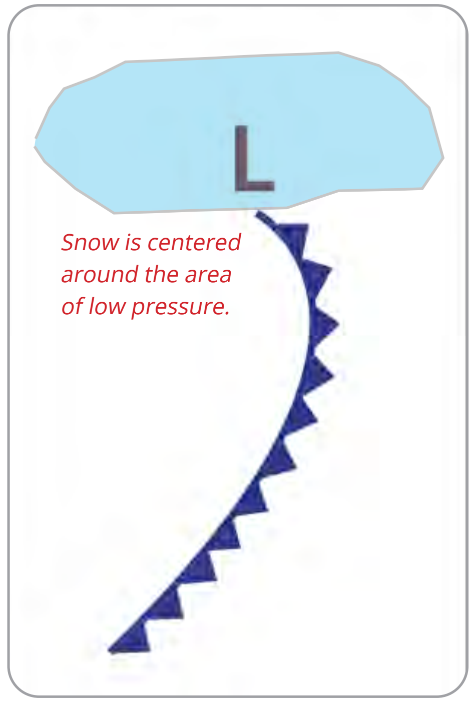
Draw the approximate location of snow in relationship to the location of the cold front and the area of low pressure on the diagram on the right.

1. How is the winter storm in this example similar to the cold front model that you developed? How is it different?

   Similar: The winter storm is caused by a cold front, so it has cold air pushing warm, moist air up into the atmosphere with a low pressure system to the north of the front, just like in the cold front model.

   Different: Unlike the cold front model we developed, the precipitation in the windier storm is centered around the low pressure area and not along the front. Also, lower temperatures mean that the storm is bringing snow instead of rain.

WHERE SNOW IS LIKELY:



STEP 3: Make a prediction for where it will snow on February 24.

Based on where the snow fell during this storm on February 23, where do you think snow will fall on February 24?

1. **Color in the circles** for towns on the February 24th weather map where you think it will snow more than 5 cm.
2. **Write the names** of the locations below and explain why the locations would receive precipitation.

   Predict snow on February 24th in Sioux City, Mason City, Rochester, Madison, and Chicago.

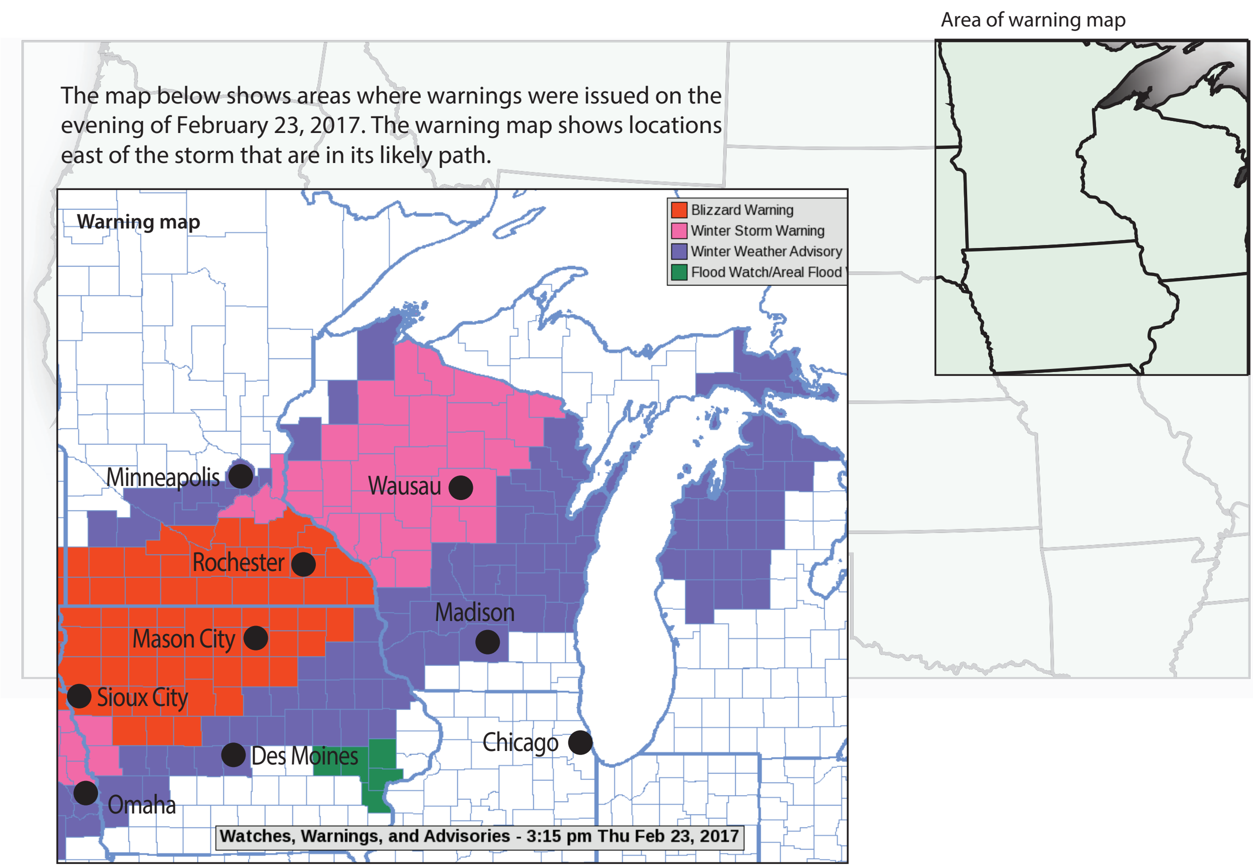
   Places that are just north of the low pressure area and near the cold front will have snow, based on snowfall from the previous day.

Where will schools have a snow day on February 24?

STEP 4: Warning Map.

The map below shows areas where warnings were issued on the evening of February 23, 2017. The warning map shows locations east of the storm that are in its likely path.

- **A Blizzard Warning** is issued for winter storms with winds of 35 mph or higher and heavy, blowing snow.
- **A Winter Storm Warning** is issued when a winter storm is expected within 36 hours with at least 4 inches (10 cm) of snow or at least 3 inches (7.6 cm) of snow and large amounts of ice.
- **A Winter Weather Advisory** is issued when a low pressure system produces a combination of winter weather (snow, freezing rain, or sleet) that presents a hazard.
- **A Flood Watch** is issued when conditions are favorable for flooding.



Where will schools have a snow day on February 24?

Is it a snow day?

Depending on where you live, you might have felt the excitement when snow is in the forecast. Sure, snow is fun no matter when it happens, but when it happens on a school day and school is canceled, that's particularly exciting.

School officials must decide if they're going to cancel school or delay classes. Their job is to keep people safe. How do they make that decision?

In places where snow is rare, like the southeast U.S., a weather forecast that includes any snow and ice might be enough to cause schools to close. These places often don't have snow plows or trucks that add salt or sand to the roads to melt ice. This means that it doesn't take much to make the roads and sidewalks unsafe.

In places where snowy weather is common, towns and cities usually have plans for dealing with it. Schools often do not close for snow if the roads and sidewalks can be cleared. However, schools do close for extreme cold temperatures so that students are not waiting for the bus or walking to school when the temperature is below freezing. Schools might also close if snow is blowing, which reduces visibility.

Many types of weather information are important for school officials to decide whether to cancel school including the timing of the storm, the temperature, the amount of snow, and the amount of wind. School officials take into account whether the National Weather Service has issued weather watches, warnings, or advisories.

1. What locations should cancel school based on the reading above and your predictions of snowfall from Step 3?

   Schools in Sioux City, Mason City, Rochester, and Wausau should cancel.

   These places are within the Blizzard Warning or the Winter Storm Warning, and also are located just north of the cold front and within the low pressure area. Students might also suggest that places within the Winter Weather Advisory (purple) could also be at risk for lots of snow.

STEP 5: Discuss with the class.

Talk with your classmates. Does everyone have the same hypothesis about where it will snow on February 24? Look at where the most snow (more than 15 cm) fell on February 23 and decide which locations might close schools and work-places on February 24. Take the warning map into account.

School cancellations could also be possible in Madison, Des Moines, and Omaha. Students should support their choices by comparing the amount of snowfall on previous days to the location of cities relative to the storm front and low pressure area.