UCAR | CENTER FOR SCIENCE EDUCATION

TEACHER GUIDE

LEARNING SEQUENCE 1

BSCS SCIENCE LEARNING

NASA

THE GLOBE PROGRAM

From Cloud to Storm
What causes an isolated storm?

Precipitation is a regular phenomenon in our lives. Every morning, as the Sun peaks over the horizon, the sunlight we receive begins a chain of events that often leads to cloud formation across the day. If the conditions are just right, the clouds turn into thunderstorms. In this learning sequence, students begin their investigations of storms and precipitation looking closely at small-scale convective storms that happen within an air mass. These small-scale convective storms serve as an investigative phenomenon for this learning sequence. These storms are called "isolated storms" or "afternoon thunderstorms" because they often happen in the afternoon. In this learning sequence, we use the term isolated storms because they do not always happen in the afternoon, and we focus on their formation rather than their location within air masses (since students will learn about air masses in the second learning sequence). Isolated thunderstorms are usually short-lived and small in scale. These storms can cause hazardous conditions, such as lightning and small tornadoes. They also cause precipitation, which can be a welcome respite from summer heat. In this learning sequence, students learn about important factors related to isolated storm formation, such as the temperature differential between the surface and the clouds and the availability of moisture. Students also learn about convection as a lifting mechanism that moves warm, moist air vertically, allowing storm clouds to form.

SCIENCE IDEAS

Sunlight heats Earth's surface and evaporates water in a location. As surface temperatures rise, so does air temperature. The rising temperatures near the surface coupled with rising relative humidity from evaporating water lead to good conditions for storms to form. Warm air, which can hold more water, rises through the atmosphere. As it cools, the air can no longer hold as much moisture. The cool temperatures lead to condensation and precipitation.

Background Science Content

HOW DO CLOUDS FORM?

Clouds are made of small water droplets or ice crystals depending on the air temperature. These water droplets and ice crystals form from water vapor. The water in the atmosphere can be a solid (ice and snow), a liquid (rain), or a gas (water vapor). These three different phases depend on temperature and pressure. Water vapor gets into air mainly by evaporation of liquid water from the surface of ocean, lakes, and rivers. Air that is cool and under less pressure can evaporate less water vapor than air that is warm and under higher pressure.

Variations in the air temperature and pressure allow clouds to form. For example, as temperature and humidity rise throughout the day, cumulus clouds can build, leading to isolated afternoon storms, the main phenomenon that students explore in this learning sequence. The Earth's surface is heated by sunshine, which then heats the air above it. That warmed air starts to rise because, when warm, it is lighter and less dense than the air around it. As it rises, its pressure and temperature drop resulting in water vapor becoming small water droplets or ice crystals. It's easier for water vapor to condense into water droplets when it has a particle to condense upon. These particles, called condensation nuclei, can be dust, pollen, or air pollution that is suspended in the atmosphere. Eventually, enough water vapor condenses upon condensation nuclei to form a cloud.

For additional information on the water cycle:

- https://scied.ucar.edu/shortcontent/water-cycle

PRESSURE AND TEMPERATURE DECREASE WITH ALTITUDE IN THE TROPOSPHERE, ALLOWING CLOUDS TO FORM.

In the first part of Lesson 3, students explore temperature change between 0-12 km in the atmosphere using the Virtual Ballooning simulation; however, they may see other patterns in the data if they choose to toggle between temperature and pressure or if they get data that goes beyond 12 km.

The troposphere is the lowest layer of the atmosphere found from ground level up to about 10 km (33,000 feet) above sea level on average. We live in the troposphere, and nearly all weather occurs in this lowest layer. Almost all clouds are in the troposphere along with 99% of the water vapor in the atmosphere. The online Virtual Ballooning simulation illustrates how air temperature and pressure change with altitude. This curriculum uses the Virtual Ballooning activity to focus on the troposphere. Weather balloons that carry instruments are one way that scientists explore what's happening higher up in the sky to help them better understand what might be happening where clouds form.

Energy from the Sun that penetrates the Earth system is mostly absorbed by the ground and then released as heat in infrared wavelengths of light. Both air pressure and temperature decrease as you climb higher in the troposphere. Air pressure, a measure of the weight of the molecules above you, decreases with altitude because air molecules higher up in the atmosphere have fewer molecules above them, so less weight. Lower air pressure allows air molecules higher in altitude to move apart from each other, which causes the air temperature to decrease.

For more information, visit:

- https://scied.ucar.edu/webweather/weather-ingredients/change-atmosphere-altitude
- https://scied.ucar.edu/virtual-ballooning
- https://scied.ucar.edu/shortcontent/troposphere-overview

THERE ARE MANY TYPES OF CLOUDS.

By observing clouds and identifying cloud types we can learn about the temperature, moisture (humidity), and wind conditions at different heights in the atmosphere, which helps in predicting the weather. Clouds can indicate that moist air is moving upward. This can lead to precipitation. However, many cloud types do not cause precipitation. The GLOBE cloud chart below indicates cloud types and the altitude (low, mid, high) at which they are found. Observations of clouds also help us to know how much sunlight is reaching the ground and how easily heat from the ground and lower atmosphere can escape to space. Clouds play a central role in controlling the exchange of heat in the atmosphere, and changes in clouds over time can have significant climate impacts with some types of clouds trapping heat in the atmosphere and others blocking solar energy from getting to Earth.

Cloud Identification Chart

THE **GLOBE** PROGRAM

Altitude of Cloud Base

Contrails

| Short-Lived | Persistent Non-Spreading | Persistent Spreading |

HIGH

| Cirrostratus | Cirrus | Cirrocumulus |

6 km
5 km

Clouds are categorized by height and shape.

Stratus	Cumulus
Looks like a sheet or blanket.	Looks like cotton or cauliflower.

Stratocumulus clouds look like a lumpy blanket.

MID

4 km
3 km

| Altostratus | | Altocumulus |

2 km

LOW

| Fog/Stratus | Stratocumulus | Cumulus |

1 km

Nimbostratus clouds produce light rain or a steady drizzle, while **cumulonimbus** clouds produce intense storms.

Precipitating

| Nimbostratus | | Cumulonimbus |

2019

The types of clouds you see in the sky depend on weather conditions in the area. Some clouds form only in fair weather, while others bring rain showers or thunderstorms. Specific cloud types can indicate a trend in the weather. Convective clouds associated with thunderstorms and precipitation include cumulus and cumulonimbus clouds. For example, in middle latitudes, before a cold front, you can observe cirrus clouds and then cumulonimbus clouds as the cold front passes through.

HEAT FROM THE SUN CAUSES CONVECTION IN THE ATMOSPHERE.

Energy from the Sun leads to heating of the Earth's surface and evapotranspiration as shown in the image below. The incoming solar radiation is affected by cloud cover, cloud type, and albedo (reflectance) of the surface of the Earth. Overall, about half of all incoming solar radiation is absorbed by the land surface and oceans. Surfaces that absorb sunlight warm up. The air above the Earth's surface is warmed through sensible heat. In addition, while evaporation is the movement of water to the air from different sources, such as bodies of water, evapotranspiration is the sum of evaporation and transpiration from plants.
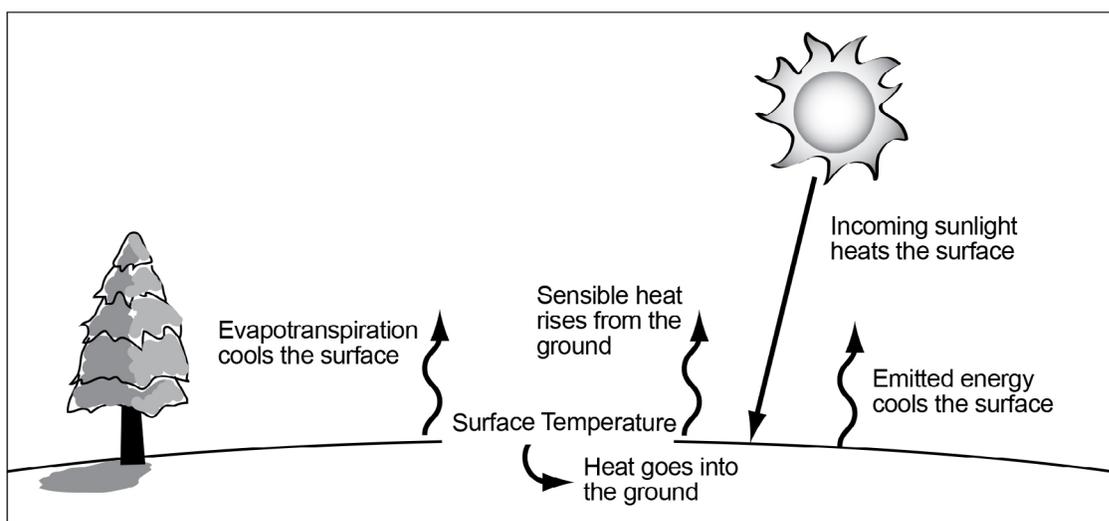
Partitioning of the Sun's Energy as Related to the Earth's Surface Temperature. Found in GLOBE Surface Temperature Protocol Reading (Courtesy: GLOBE).

There are many different materials covering the Earth's surface, such as soil, rocks, water, forests, snow, and sand. Materials like these have different ways of dealing with the solar energy that gets to our planet, which affects surface temperature. During the infrared thermometer activity in this learning sequence, students look closer at surface temperatures and whether temperatures vary depending on land cover. The amount of energy reflected by a surface is called albedo. Dark colored surfaces, such as asphalt, concrete, or vegetation have low albedo and reflect very little of the solar energy that gets to them and therefore have higher surface temperatures. In contrast, light-colored surfaces, such as snow, ice, water, and bare soil, reflect almost all of the solar energy that gets to them resulting in lower surface temperatures.

For more information, visit:
- https://www.globe.gov/documents/348614/7537c1bd-ce82-4279-8cc6-4dbe1f2cc5b5
- https://scied.ucar.edu/longcontent/energy-budget

CONVECTION IN THE ATMOSPHERE CAUSES ISOLATED STORMS.

Air near the ground, warmed by the Earth's surface, rises because it is less dense. This air cools and expands as it rises and can cause cumulus clouds to form. When water vapor condenses, heat (latent heat/energy) is released. This energy can help a thunderstorm grow via convection, the transfer of energy and mass in motion in a liquid or a gas. In the atmosphere, convection usually refers to the vertical movement of air. Cold air sinks from the upper levels of the atmosphere.

Convection is the primary mechanism driving cumulus cloud formation. Meteorologists usually use convection to refer to the upward motion as updrafts and the downward motion as downdrafts. Convection forms clouds as heat is transferred in the air as warm air rises to condensation level. Supercell thunderstorms occur when very strong updrafts are balanced by downdrafts, which can allow the storm's cumulonimbus clouds to persist for many hours. The three main stages of thunderstorm development are developing (cumulus) stage, mature stage, and dissipation stage. The developing and mature stages are the focus of the phenomenon that students are investigating in this learning sequence. Updrafts occur in the developing stage, while there are both updrafts and downdrafts in the mature (maximum growth) stage of the thunderstorm.

ⓘ **For more information, visit:**   https://scied.ucar.edu/shortcontent/how-thunderstorms-form
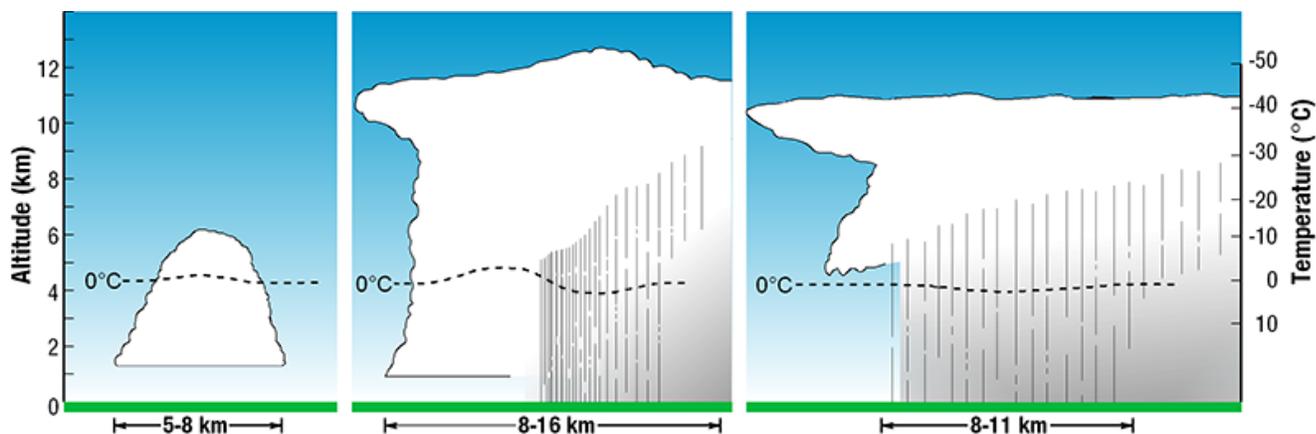
Three Stages of a Thunderstorm (Courtesy: NOAA).

PRECIPITATION DEPENDS ON WATER VAPOR IN THE ATMOSPHERE.

If there is enough moisture (water vapor) in the air, clouds can form and precipitation is possible. Water vapor gets into the air by evaporation, transpiration, and respiration.

Relative humidity (RH) is the percent of water vapor in the air compared to the maximum amount of water vapor that the air can hold. It's measured with a digital hygrometer or a sling psychrometer. When air is saturated with water vapor, the relative humidity is 100%. Because cool air has less energy, water is less likely to evaporate, so it can hold less water vapor than warm air. Warm air has more energy and, thus, has the ability to evaporate more water so it can hold more water. The same amount of water vapor may cause 100% relative humidity in cool weather and only 50% relative humidity in warm weather. In GLOBE Weather, relative humidity is referred to as "humidity."

On a clear, sunny day, the relative humidity is higher in the morning than in the afternoon because cooler morning air is closer to saturation than hot afternoon air with the same amount of water vapor. In contrast, on days with precipitation or significant cloud cover, relative humidity often increases during the day as clouds grow and the temperature is not as warm. Note that the relative humidity in a cloud is 100% as precipitation is falling, but relative humidity at the ground level, where it is typically measured, will often be lower.

Both low and high humidity can be hazardous. Low humidity can lead to dehydration, fatigue, and dry, cracked skin. High humidity can lead to heat strokes and heat exhaustion because sweat does not evaporate off the skin.

ⓘ **For more information, visit:**   https://scied.ucar.edu/shortcontent/humidity

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

MISCONCEPTION	CORRECT EXPLANATION
Air is warmed directly by the Sun.	Energy from the Sun is absorbed by the Earth's surface, which causes the surface temperature to rise. Air that comes in contact with the surface is heated by conduction. Thus, it is the Sun's warming of the Earth's surface that affects air temperatures in the lower troposphere and not the Sun warming the air directly.
Air that is higher in the sky is warmer because it is closer to the Sun.	In the troposphere, air temperature decreases as altitude increases. This is because the troposphere is heated from below (as described in the previous misconception above) and also because at higher altitudes there is less air pressure, which causes air molecules to spread out. With more space between each air molecule, they are less able to retain heat (there are fewer heat transferring collisions between molecules).
Peak air temperature happens when the Sun is highest in the sky.	Even though the Sun is highest in the sky around midday, air temperature continues to rise later in the day because the air above Earth's surface is warmed from the ground up. The air temperature is often warmest a couple hours after the Sun has reached its peak in the sky.
Clouds are made of water vapor.	Liquid water turns into water vapor when it evaporates and rises up into the sky; however, clouds form at the point where the air is cold enough for the water vapor to condense back into liquid water or even frozen water crystals. This condensation happens around small particles called condensation nuclei. Thus, clouds are made of either liquid water droplets and/or frozen ice crystals but not water vapor. Probe students with questions to identify whether they understand the reason that water changes phase within the weather side of the water cycle. For example, water vapor will condense into liquid water when air cools, forming clouds. Help students make connections between the water cycle and the formation of clouds and rain.
Confusion about how air temperature and humidity relate to isolated storms.	On a day with afternoon rain showers, air temperature would likely rise during the day and drop before it rains. As air temperature rises, air molecules are farther apart and humidity increases because the warmer air can hold more water vapor. Humidity would be high during the day leading up to the storm because you need moisture for a storm to form. Students should recognize that air temperature and humidity are important for storm formation.
It only rains when the humidity is 100%.	For the rain to fall, the humidity in the atmosphere, where the clouds have formed, must be 100%. But the relative humidity at the surface can be less. If the air at the surface is very dry, rain that is falling could evaporate before it even hits the ground, which is called virga.

2 WATCHING THE SKY
What causes storms to form?

LESSON

ENGAGE · EXPLORE · EXPLAIN · ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes, plus time for sky watching)	
Making Observations: Sunny Day / Stormy Day Students brainstorm how observations can help them make sense of weather. Students watch time-lapse videos, which are one way to see what's happening in the sky over time. The time-lapse videos show the sky on a sunny day and a stormy day from sunrise to sunset. As students watch each video, they make visual observations to compare the conditions and movement of clouds in the sky over time.	**Lesson 2: Student Activity Sheet** 2 Whiteboard, smart board, or chart paper and markers (to make the Driving Question Board and Model Idea Tracker) Sunny day time-lapse video (2 min.) Stormy day time-lapse video (2 min.)
Diagram of a Storm Forming Students go further with the stormy day time-lapse video and model how the storm began, grew, and dissipated. Students draw a model of each of these stages of a storm. Students compare their diagrams to those of their peers.	
Sky Watching Option 1: Cloud Observations Students are encouraged to make observations of clouds over a few days, recording observations in their notebooks or using a data sheet. Students can also make time-lapse videos of clouds and use those videos as evidence of how clouds change over time.	Device with time-lapse capabilities GLOBE Cloud Chart (https://bit.ly/2019globecloudchart) Science notebook to record cloud observations
Sky Watching Option 2: GLOBE Cloud Protocol Students are introduced to the GLOBE Cloud Protocol and use the protocol to make observations. Students record their data on GLOBE protocol observation sheets and enter their data into the GLOBE website or via the GLOBE Observer app.	GLOBE Cloud Protocol (globe.gov/do-globe/globe-teachers-guide/atmosphere) • Data sheet or GLOBE Observer app • GLOBE cloud chart • Data entry options • UCAR Field Guide to Clouds app (scied.ucar.edu/apps/cloud-guide)

2 WATCHING THE SKY
What causes storms to form?

NGSS Sensemaking

Students engage in developing initial explanations and diagrammatic models to explain isolated storm formation. During their discussion of the growing thunderstorm, students are expected to use what they know about the water cycle and phase changes of water and the heating of Earth and transfer of energy to help explain the storm. The purpose of this lesson is to elicit students' prior knowledge about water cycle processes and the water cycle's connection to weather. Additionally, the lesson should create a heightened awareness that something interesting is happening on days when there is a thunderstorm compared to a sunny day, and that they need to collect more data and gather additional information to help them explain storms. Cloud observations are one source of data they can collect as they investigate this phenomenon.

PERFORMANCE OUTCOME
Develop a model to describe how clouds form during a stormy day and build until they form a rainstorm.

NGSS DIMENSIONS (GRADES 6-8)
- Water continually cycles among land, ocean, and atmosphere via evaporation, condensation, and precipitation. Global movement of water and its changes are propelled by sunlight.
- Develop a model to describe unobservable mechanisms.
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)
- Identify limitations of models.

Teacher Procedures

Making Observations: Sunny Day / Stormy Day

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1. **Navigate from the previous lesson.** Give students an opportunity to discuss where they left off in the Anchoring Phenomenon (Lesson 1). Remind students of their questions on the Driving Question Board and the need for further investigation of their questions.

2. **Assess students' prior knowledge about water cycling and phase changes during cloud formation.** In pairs, have students explain to each other how water on the Earth's surface might end up as a cloud in the atmosphere. Students may want to sketch a diagram on scratch paper or in their science notebook to help explain their thinking. Instruct students to focus on anywhere water is changing phase (e.g., from liquid to gas and back to a liquid). After explaining in pairs, hold a whole class share out to assess understanding. Provide direct instruction and vocabulary (e.g., water vapor, condensation) as needed.

LESSON 2 STEP 1

3. **Transition to the importance of making observations of the sky, specifically clouds.** Direct students to the *Lesson 2: Student Activity Sheet*. Have students complete *Lesson 2: Step 1* on the activity sheet with partners or in small groups. Students are prompted to think about the purpose for observing clouds and how observations are beneficial for understanding weather. Allow time for students to share why cloud observations, or other observations of the weather/ sky, can be useful.

    Suggested prompts for discussion:

    *   *What can we learn about the weather by observing the sky over time?*
    *   *What would we see if we watched the sky on a day when a storm was forming?*
    *   *How could viewing a time-lapse video of the sky help us figure out more about clouds and storms?*

LESSON 2 STEP 2

4. **Make observations of sunny day and stormy day time-lapse videos.** Introduce students to the time-lapse video context (see below). Play the sunny day time-lapse video. Have students make observations in *Lesson 2: Step 2* of their activity sheets. As students observe, help them identify evidence from the video that indicates time of day. Next, play the stormy day time-lapse video and have students make observations on their activity sheets. Identify indicators for time of day—this is important for establishing that the morning begins clear, clouds appear, and the storm occurs in the afternoon.

Cause-Effect
As students discuss differences between the two days, elicit their ideas about what is causing the storm to form.

SUNNY DAY AND STORMY DAY TIME-LAPSE VIDEOS
These videos were captured on Eagle Ridge above Lyons, Colorado near the Front Range of the Rockies by David Niels as part of his research for the Colorado Climate Center. The sunny day video was filmed on April 6, 2017. The stormy day video was filmed on July 4, 2017. Each video is two minutes in length.

Sunny Day Video: https://scied.ucar.edu/sunny-day-2017-04-06
Stormy Day Video: https://scied.ucar.edu/stormy-day-2017-07-04

5. **Have students write their ideas and discuss the guiding question: "Why do you think that the storm formed on one day and not the other?"** (*Lesson 2: Step 2*, continued) Prompt students to generate their initial ideas about what is different between the two days and if there is something causing the storm to form on the stormy day that is not present on the sunny day. (Note: While there are several factors related to the difference, the available moisture in the atmosphere is an important one.) Give students an opportunity to discuss their ideas in small groups, followed by whole group discussion.

This is your opportunity to informally assess what students already know about the relationship between storms and the water cycle. Below are examples of beginning and developing student ideas:

- **Beginning:** *The water vapor goes up in the air. There is more evaporation.*
- **Developing:** *Evaporation was caused by heat. The heat and evaporation traveled up from the ground. The Sun's energy warms the water and it evaporates and goes up to the clouds.*

6. **Record ideas to the Model Idea Tracker.** Find a visible place in the classroom that will be used to record student ideas about how storms form (e.g., chart paper, PowerPoint, smart board, or whiteboard). This is the Model Idea Tracker, and it will be used repeatedly through GLOBE Weather. The tracker is a place to record consensus ideas that are helpful for explaining moisture in the atmosphere and precipitation. At this point in the lesson sequence, students may have inaccurate or incomplete ideas, which is important to be aware of moving forward. Do not record ideas to the Model Idea Tracker if the idea is not agreed upon.

Model Ideas:

- Evaporation of water at the surface is important for clouds/storms.
- Evaporation happens because of heating from sunlight.
- Clouds form when water condenses.

Assessment
Listen closely to how students discuss evaporation, heating, and how water gets up to the clouds. These science concepts will be developed throughout this learning sequence.

Developing & Using Models
The Model Idea Tracker is used to record consensus ideas that help explain a phenomenon. These ideas are generated by students and agreed upon as a class.

Students develop a diagrammatic model as part of their Working Model for an Isolated Storm. Working Models capture important pieces of the system but are not comprehensive.

Diagram of a Storm Forming

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1. **Tell the story of a thunderstorm forming throughout the school day.** *"Let's imagine together a storm that might form throughout the day. You wake up to a blue sky. During the morning, a few small clouds appear. By lunch, there are more clouds, and they are much larger. By the end of the school day, it's raining! The rain does not last all night, and by the time you go to sleep, stars are visible because the clouds are gone."*

LESSON 2
STEP 3

2. **Direct students to construct a time series diagram using *Lesson 2: Step 3* on their activity sheets.** The purpose of the time series diagram is to focus students on how storms change over time and what might be different at various moments over the course of a storm. The time series diagram is the first part of their Working Model for an Isolated Storm. They can revisit their diagrams throughout the learning sequence and especially as they work toward a Consensus Model later in this sequence. (Note: Students will not yet know the term "isolated storm" since this is the first type of storm that they are investigating in depth. The term is first used with students in *Lesson 5*, although you may wish to modify and add it earlier.)

3. **Share and discuss the diagrams.** Prompt students to explain what is different in each stage of the storm and why they think there is a difference. As students share, use the following prompts to get them to think about measurements they may want to see to better understand the storms:

   - *In the diagrams, we can see that the clouds are high above the ground. If you could somehow investigate the air up high compared to the air near the ground, what do you think you would see?*
   - *What are some measurements you would want to take of the air from different altitudes? How might those measurements help us figure out how clouds start to form on a sunny day?*

Storyline Link
This question set is a critical link to maintain coherence as students move between Lesson 2 and Lesson 3 to motivate analysis of weather data.

FORMATIVE ASSESSMENT

One way to assess your students' learning in an Engage lesson is to ask students to comment on important ideas they learned in the lesson. Consider using an Exit Ticket or home learning assignment to do this. For the Exit Ticket, have students write down their ideas to the questions below on an index card and hand it to you as they leave the classroom. For a home learning activity, have students respond to the questions in their science notebooks and be prepared to share their ideas in the following class.

- **What?** Write one idea or concept that you found particularly interesting.
- **So what?** Write why that concept or idea is important.
- **Now what?** Think about how your thinking changed based on that new idea.

👥 *Have students share their responses with a partner or with the rest of the class.*

Assessment
This assessment can give you insight as to what students understood as important ideas from the lesson and whether these are similar to the Model Ideas generated by the class.

Sky Watching

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2 LESSON
STEP 4

Up until now, students have mostly discussed clouds and storms using video and images made by other people. Nothing can match the real experience of making observations outdoors. For *Lesson 2: Step 4* choose either Option 1 or Option 2 below.

OPTION 1: Cloud Observations
Consider doing an outdoor cloud observation together as a class, identifying cloud types using the GLOBE Cloud Chart (https://bit.ly/2019globecloudchart). Then assign a project or home learning activity where students make a time-lapse video of clouds using their device and then make observations from their videos. Time-lapse videos are particularly powerful to see change over time and can be an engaging project for your students. The following example questions can guide discussion around their videos and observations:

- *What did you notice happening to the clouds over time?*
- *Did the clouds change shape or color?*
- *Did you notice patterns in clouds at certain times of day?*

OPTION 2: GLOBE Cloud Protocol
The GLOBE Cloud Protocol, in which students either use the GLOBE Observer Cloud app (observer. globe.gov) or the GLOBE Cloud Chart (https://bit.ly/2019globecloudchart) with the GLOBE Cloud Protocol (https://www.globe.gov/web/s-cool), are excellent ways to help students make in-depth observations of their environment. The required materials and time will vary depending on how you collect your observational data and use the data entry system. The Cloud Protocol is part of the Atmosphere Protocols (https://www.globe.gov/do-globe/globe-teachers-guide/atmosphere).

Planning & Carrying Out Investigations
Making time-lapse videos supports students in conducting investigations to produce data. Students can make observations from their videos to answer questions or explain phenomena.

The GLOBE Cloud Protocol takes student-driven investigations to a deeper level. The process of collecting and entering cloud data as part of the GLOBE community supports students in authentic science investigations where their ground observations contribute to a joint effort with NASA scientists.

LESSON 3 TEMPERATURE CLUES
How does temperature relate to cloud formation?

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(90 minutes, plus optional activity)	
Temperature: Ground to Clouds Students collect simulated air temperature data from near the ground to an altitude of about 10 kilometers. Students identify a pattern in the data that temperatures are warmer near the surface and cooler as altitude increases in the troposphere.	**Lesson 3: Student Activity Sheet** LESSON 3 Weather video https://scied.ucar.edu/weather-bal-loon-launch-video Virtual Ballooning simulation https://scied.ucar.edu/virtual-ballooning
Surface Temperature and Air Temperature Students look closer at temperatures near the surface to make sense of why air temperatures near the ground are warmer than air temperatures higher in the troposphere. They analyze surface temperature and air temperature data that show surface temperatures are warmer than air temperatures.	
Option: GLOBE Air and Surface Temperature Students collect their own air temperature and surface temperature data for analysis using the GLOBE Air Temperature and Surface Temperature protocols. Students also collect data from a variety of surfaces to see how the kind of surface influences temperature.	GLOBE Air Temperature and Surface Temperature protocols (globe.gov/do-globe/globe-teachers-guide/atmosphere), a thermometer, and an infrared (IR) thermometer
Model: Heating Earth's Atmosphere Students use their temperature data to develop a Working Model explaining how Earth's atmosphere is heated from the surface below and not directly from the Sun above.	Colored pencils

LESSON 3 — TEMPERATURE CLUES
How does temperature relate to cloud formation?

NGSS Sensemaking

The purpose of this series of activities is to see temperature as a potential factor in storm formation. The temperature gradient from the surface to the clouds is an important one, and students will cycle back to the temperature pattern throughout this sequence. This series of activities also helps students make sense of the underlying mechanisms that cause the observed pattern and focuses students on explaining why the surface is warmer than the air above it. A common misconception is that air in the atmosphere is heated directly from sunlight above and not from the surface below. Understanding heating of Earth's surface is an important piece of a convective model of storm formation.

PERFORMANCE OUTCOME

- Collect and analyze data to identify patterns that describe the relationship between temperature and altitude.
- Analyze and interpret data to describe differences in surface temperature and air temperature during a day.

NGSS DIMENSIONS (GRADES 6-8)

- Weather is influenced by interactions involving sunlight, the atmosphere, and land.
- Collect data to produce data to serve as the basis of evidence to answer scientific questions.
- Analyze and interpret data to provide evidence of phenomena and to identify temporal relationships.
- Develop a model to describe unobservable mechanisms.
- Ask questions to clarify and/or refine a model.
- Use graphs to identify patterns in data.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

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

Teacher Procedures

Collect Temperature Data

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1. **Navigate from the previous lesson.** During the previous lesson, the following questions were posted and can be used to introduce this lesson:

   - *In the diagrams (Lesson 2: Step 3) we can see that the clouds are 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 see?*
   - *What are some measurements you would want to take of the air from different altitudes?*
   - *How might those measurements help us figure out how these clouds form?*

2. **Show a video of a weather balloon launch.** The video shows how weather balloons are launched to take measurements in the atmosphere, and temperature is one of those important measurements.

   UCAR WEATHER BALLOON VIDEO
   This video shows scientists launching a weather balloon (2 minutes).
   Video Link: https://scied.ucar.edu/weather-balloon-launch-video

3. **Make predictions of how temperature changes from the surface to altitudes where clouds form.** Direct students to the *Lesson 3: Student Activity Sheet*. Read the instructions together. Tell students to imagine a weather balloon collecting temperature data as it goes up in the atmosphere. Ask students to make predictions about temperature from the ground to the height of clouds in *Lesson 3: Step 1* and to share those predictions in small groups.

   LESSON 3 STEP 1

4. **Arrange students in groups with computers or tablets for the Virtual Ballooning simulation.** Explain to students that they will collect data from a simulation of weather balloon data. Orient students to the Virtual Ballooning simulation and discuss how they should collect and record temperature data in *Lesson 3: Step 2*, which prepares students for the simulation.
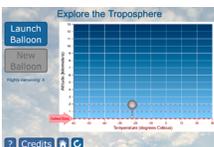
   LESSON 3 STEP 2

   UCAR VIRTUAL BALLOONING SIMULATION
   Simulation Link: https://scied.ucar.edu/virtual-ballooning
   (Note: Students should choose "Explore the Troposphere" within the interactive.)

5. **Students collect temperature data and record it on their activity sheet in *Lesson 3: Step 2*.**

   LESSON 3 STEP 2

Storyline Link
This question set is a critical link to maintain coherence as students move between Lesson 2 and Lesson 3 to motivate analysis of weather data.

3 **LESSON** **STEP 3**

6. **Students work with peers to analyze the data (*Lesson 3: Step 3*, Questions 1 and 2) and interpret the data (*Lesson 3: Step 3*, Questions 3 and 4).** Conduct a class discussion focusing on students' ideas about these questions and working toward the key pattern:

    KEY PATTERN: Temperature is warmer near Earth's surface and temperature decreases as the weather balloon moves higher into the atmosphere where clouds/storms form. *(Note: This pattern holds true in the troposphere.)*

    As students discuss this pattern, elicit other first-hand or second-hand experiences they've had related to Earth's warmer air temperatures at lower altitudes and the air being cooler higher in altitude/elevation. Probe students' initial ideas about why this pattern might occur.

7. **Discuss the final question: How does temperature relate to clouds as an isolated storm forms?** Encourage students to use what they figured out about temperature and altitude to reconsider what might be happening in the Anchoring Phenomenon or storm formation in general. Students can discuss specific storms at this time or more general patterns they notice about temperature and storms.

8. **Transition to the next activity.** Use the following questions to get students thinking more about temperatures near the surface of Earth:

    •   *If we were able to look closely at different altitudes, from near the surface to high in the sky, what temperature pattern would you expect to see?*
    •   *How do you think the results would compare if we measured temperature throughout a school day?*

Patterns in Data
Students identify a temperature pattern related to the heating of Earth and storm formation.

Comparing Surface Temperature and Air Temperature Data

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3 **LESSON** **STEP 4**

Planning note: If you want students to focus only on data analysis, you can use the data set provided in the activity below. If you'd like students to collect their own data, have students collect air temperature and surface temperature data following GLOBE Atmosphere protocols (globe.gov/do-globe/ globe-teachers-guide/atmosphere) and replace Lesson 3: Step 4 on the activity sheets with your students' data.

DATA ANALYSIS ONLY OPTION

1. **Navigate from the previous activity.** Have students explain the temperature patterns they observed in the Virtual Ballooning investigation. Remind students of questions at the end of the last activity in order to set a purpose for analysis of the next data set:

    •   *If we zoomed in to this part of the altitude where we live, what temperature pattern would you expect to see?*
    •   *How do you think the results would compare if we measured temperature throughout a school day?*

    ** If doing the GLOBE Surface Temperature and Air Temperature protocols, introduce the protocols here. Students do not need to complete the data analysis on the Longmont Data Set below because they can analyze their own data set.**

Storyline Link
Use these two questions to review where students ended up in the previous activity.

2. **Introduce students to the data set.** Describe where the air temperature and surface temperature data was collected, over what time period, and how it was collected. (See description below.)

WESTVIEW MIDDLE SCHOOL DATA SET

Middle school students in Longmont, Colorado wanted to know how the ground temperature (surface temperature) compared to air temperature. They measured both temperatures over a school day. Their surface temperature data were measured on their school track and their air temperature thermometer was located on the school roof. The students agreed these two surfaces were the most similar, which is why they selected the school track for their surface temperature location. They measured both temperatures every hour during the school day. They also made observations of cloud cover.

3. **Use the Identify and Interpret (I²) Sensemaking Strategy to analyze and interpret the graphed data.** Orient students to the graph in terms of the axes, the data lines showing surface and air temperature data, and the cloud cover notes at the top of the graph.

   a. **Write "What I See" statements.** To do this, students write observations of the data in the graph. Students draw the "What I See" icon followed by their observation (e.g., "The surface temp line on the graph is always above the air temp line"). Students also draw an arrow to the part of the graph that corresponds to their observation. Remind students to avoid "because" statements and focus on observations only. Conduct a short discussion highlighting where students have similar or different observations.

   b. **Write "What It Means" statements.** To the side of each "What I See" statement (observation) students draw the "What it Means" icon and then an explanation (e.g., "The surface is warmer than the air"). Each What I See statement should have a What it Means statement next to it. These statements are students' interpretations of what is happening in each part of the graph. Conduct a discussion about students' ideas. Because students are still exploring, it is okay for them to have incomplete explanations. Focus on accurate observations and logical, even if incomplete, explanations.

Option: GLOBE Air and Surface Temperature Data Collection

Collecting surface temperature data is a highly engaging activity for students. They enjoy exploring how surface temperature varies across the day and across different kinds of surfaces. Use the GLOBE Air Temperature and GLOBE Surface Temperature protocols to conduct this investigation. There are several options for how to gather the data, but if time and equipment permit, students should collect surface and air temperatures over a variety of surfaces to compare their relationships and whether they change depending on the surface. See the GLOBE Connections section of the GLOBE Weather website if you/your students are interested in using these observations as a starting point to a GLOBE Investigation.

Data Analysis & Interpretation
The I² Sensemaking Strategy is an instructional strategy to frame the process of data interpretation. When used with graphical data, students make observations and interpret parts of a graph before looking at the graph as a whole.

Model: Heating Earth's Atmosphere

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1. **Ask students to share what they learned from the surface temperature and air temperature analysis.** Have students reflect on how the Virtual Ballooning data and the Longmont Data Set have informed their thinking. One important finding is that the surface is warmer than the air above it but that the two temperatures mirror each other as the Sun heats the Earth. Add this idea to the Model Idea Tracker.

   Model Ideas:

   • The surface is warmer than the air above it.

   • The air near the ground is warmer than air closer to where clouds form.

LESSON 3 STEP 5

2. **Introduce the Working Model for explaining temperature patterns.** In *Lesson 3: Step 5,* students will develop a Working Model of surface heating to explain temperature patterns, with the ground surface having the warmest temperatures and temperature decreasing with altitude. This is a Working Model because it's a work in progress and does not capture a complete representation of the system, only part of the system.

3. **Draw and label a Working Model individually.** Before students begin their model, preview the items listed on *Lesson 3: Step 5* of their student activity sheets to provide guidance about what their models need to explain and the question their models are trying to answer: *"Why does the surface temperature warm over the day, and why is the surface warmer than the air above it?"* Their models should describe connections between sunlight heating Earth's surface and the temperature pattern they've observed, particularly why the surface is warmer than the air above it, which leads into the next lesson on warm air rising. These models will vary in sophistication based on prior learning of particle models, temperature, and thermal energy transfer.

4. **Share and revise Working Models in small groups.** Arrange students in small groups to share their models. Students should revise their models based on feedback from their group.

5. **Discuss Working Models in whole group discussion.** Have students share how they represented different parts of the model and allow the students time to debate how they want to represent those parts as a class. Students can make edits to their models as the class discusses these models. As students discuss their thinking, check the Model Idea Tracker to add to the tracker or update the Model Ideas.

   Suggested prompts for discussion:

   • *Why do we think surface temperature is warmer than the air temperature above it?*

   • *How is the warm air moving? Does this match our temperature pattern?*

   • *More advanced question for students with prior knowledge on particles and temperature: What's happening to the air molecules when they are heated near the surface?*

LESSON 3 STEP 6

6. **Connect the Working Model to an isolated storm.** In *Lesson 3: Step 6*, have students discuss their ideas about how the temperature patterns relate to the formation of clouds and storms. In particular, have students think about why these types of storms tend to happen in the afternoon, after the Sun has been up for hours.

Developing & Using Models

In this activity students use temperature data patterns to generate more Model Ideas for their Model Idea Tracker. Then they develop a Working Model to explain the heating of the atmosphere from below, as opposed to heating from above directly by the Sun. This is an important mechanism in the system.

4 FUEL FOR STORMS
What is different about a sunny day and a stormy day?

LESSON

ENGAGE · **EXPLORE** · EXPLAIN · ELABORATE

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(80 minutes)	
Data Analysis: Sunny and Stormy Day Students analyze temperature and humidity data on a sunny day and a stormy day. They find different patterns in both. On a sunny day, temperature increases, while relative humidity decreases. On a stormy day, this normal pattern begins, but then changes, as humidity rises. This leads students to think about humidity as a critical variable in storm formation to add to their Model Idea Tracker.	**Lesson 4: Student Activity Sheet**
Bottle Model Lab / Demonstration Students create models using soda bottles to simulate what happens when temperature increases when there is moisture present and when no moisture is present. Large bodies of water can be a source of moisture, but there is also moisture present in the ground as demonstrated in the bottle model systems.	Three bottles, water, sand/dirt, thermometers, lamp, funnels, rubber stoppers, clock/timer

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

NGSS Sensemaking

The purpose of this series of activities is to see moisture as a key factor in storm formation. Students learn that warm temperatures coupled with a lot of moisture are good conditions for storms. The measurement used for moisture is humidity. If either warm temperatures or humidity are missing from the system—for example cool temperatures or not enough moisture—then there is less chance for a storm.

PERFORMANCE OUTCOME

- Analyze and interpret data to identify differences in patterns in air temperature and humidity during stormy days and sunny days.

- Conduct an experiment and collect and analyze data to compare changes in humidity in sunny and in stormy conditions.

NGSS DIMENSIONS (GRADES 6-8)

- Water continually cycles among land, ocean, and atmosphere via evaporation, condensation, and precipitation. Global movement of water and its changes are propelled by sunlight. Weather is influenced by interactions involving sunlight, the atmosphere, and land.

- Analyze and interpret data to provide evidence of a phenomenon.

- Collect data to produce data to serve as the basis of evidence to answer scientific questions.

- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.

- Use graphs to identify patterns in data.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

- Patterns of change can be used to make predictions.

Teacher Procedures

Data Analysis: Sunny and Stormy Day

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1. **Navigate from the previous activity.** At the end of the previous activity, students discussed how temperature could be related to storms forming. Have students review their ideas before beginning the next activity.

2. **Brainstorm ideas about a sunny day vs. a stormy day.** Get students thinking about data comparisons between a sunny day and a stormy day.

   Pose the following questions:
   - *How can one day be warm and sunny, while the next day is still warm but with an isolated storm? What is different about the two days?*
   - *What weather measurements might help to answer these questions?*

3. **Orient students to the sunny day and stormy day data.** Direct students' attention to *Lesson 4: Step 1* of their student activity sheets. Students will compare air temperature on a stormy day and a sunny day. You can use the I² Sensemaking Strategy, or another graph interpretation strategy, for this activity.

LESSON 4 STEP 1

SUNNY DAY AND STORMY DAY DATA

The temperature and (relative) humidity data set comes from a local automated weather station in Albuquerque, New Mexico. The data can be found online through Weather Underground and the U.S. National Weather Service. The July 29, 2017 plot is from a sunny day, while it was a stormy day on July 31, 2017.

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4. **Analyze the sunny day and stormy day data.** Give students time to analyze and interpret the graphs in partners or small groups. Encourage students to write on the graphs using WIS and WIM statements if using the I² Sensemaking Strategy.

5. **Identify air temperature patterns.** Ask students to describe the sunny day and stormy day temperature patterns. Ask students to share and compare the patterns they observed in the air temperature graphs. The following two patterns should emerge from these discussions:

   - **Sunny pattern:** Temperature gradually warms and then gradually cools on a sunny day
   - **Stormy pattern:** Temperature gradually warms but then quickly cools in the afternoon

   Have students circle on their stormy day graph when they think it rained. Ask students to write an explanation about their choice and share their ideas with their group. Prompt several students to share their ideas aloud during whole group discussion. Encourage students to explain what they see in the temperature data that indicates a storm.

6. **Identify humidity patterns.** Direct students to *Lesson 4: Step 2*, which is the second set of graphs showing humidity over the same times. Tell students that humidity is a way to measure the amount of water vapor, or moisture, in the air. Use the I² Sensemaking Strategy to help students analyze and interpret the humidity graphs. Ask students to describe the sunny day

LESSON 4 STEP 2

Storyline Link
Link back to the stormy and sunny day time-lapse videos to get students wondering about other factors related to storms.

Data Analysis & Interpretation
Students analyze temperature and relative humidity data on a sunny day and a stormy day.

Patterns in Data
Students identify important temperature and humidity patterns that are different between a sunny day and a stormy day.

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and stormy day humidity patterns. Ask students to share and compare the patterns they observed in the humidity graphs. The following two patterns should emerge from these discussions:

- **Sunny pattern:** Humidity begins high but goes down during the day
- **Stormy pattern:** Humidity begins high and starts to go down, then it climbs really high, really quickly in the afternoon/early evening

Have students circle when it rained on their stormy day humidity graph. Ask students to write an explanation about their choices and share their ideas with their group.

7. **Compare air temperature and humidity for a stormy day.** Using both data sets, when does the class think it rained? What were the temperature and humidity conditions that led to this event? Have students articulate what the temperature and humidity was like before, during, and after the storm through a whole class discussion.

8. **Add new ideas to the Model Idea Tracker.** Have students generate new ideas about the stormy day using the air temperature and humidity patterns. Record these on the Model Idea Tracker.

   Model Ideas:
   - Rising temperature and humidity are good conditions for an isolated storm.
   - Rising temperature and low humidity are not good conditions for an isolated storm.

9. **End the discussion transitioning to the next activity on bottle models:** *"If we created a system with warm temperatures and lots of moisture, it would rain. But if we didn't have warm temperatures or enough moisture, do you think it would rain or not? Let's see if we can try this out."*

Bottle Model Lab / Demonstration

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Planning note: The Bottle Model activity can be completed as a lab or a demonstration. There is also a time-lapse video that can be used if time and materials do not allow for a lab or demonstration. Make the necessary modifications to meet your students' needs based on your available equipment. The purpose of this demonstration is to help students connect the data measurements they just analyzed with visual evidence they can see. The instructions below are written for a class demonstration. See the following page for a description of the demonstration set-up.

1. **Navigate from the previous lesson.** In pairs, have students describe the temperature and humidity patterns for a sunny day and a stormy day. Introduce that we are going to test these conditions to see if they can create "storms" and "no storms" in a small system.

2. **Use temperature and humidity patterns to brainstorm how to build a storm in a bottle.** Ask students to use what they have learned about temperature and humidity to make a storm in a bottle. Provide students with a general idea of how to set-up the experiment and a list of possible materials, but allow students to brainstorm what they would add to a bottle to form a storm versus what they would add so as not to form a storm.

3. **As a class, decide on two systems, one "sunny day" (no storm) bottle; one "stormy day" (storm) bottle, to test.** Ask student volunteers to help insert the necessary materials into the bottles using a funnel. For wet sand/dirt, insert the dry sand or dirt first, then add water.

4. **Diagram the lab set-up.** Direct students to *Lesson 4: Step 3* to draw the lab set-up and to label the parts of each system and what those parts represent.

Developing & Using Models
Using patterns in temperature and humidity data, students add to their Model Idea Tracker.

Storyline Link
This closing sets the stage for the bottle model lab/demonstration and a need to test out students' initial ideas about temperature and humidity.

Storyline Link
Setting the stage for the bottle model lab/demonstration is important so that students connect the data they analyze to the observation they make of the bottles.

LESSON 4 STEP 3

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LESSON

STEP 3

5. **Discuss, as a whole group, students' predictions about which conditions will lead to the best storm and why (and vice versa).** Specifically, talk about what we expect to see if we have created conditions for a storm to form (e.g., *Will it actually "rain" inside the bottle? What might we see?*). Remind students that water vapor isn't visible and review the parts of the water cycle this activity will demonstrate (focus on evaporation and condensation). Look at the data table (*Lesson 4: Step 3*) and point out that temperature should be measured every 2 minutes. Decide as a class what will be recorded in the humidity column of that data table (e.g., Will students record when condensation is visible vs. not visible?).

6. **Turn on the lamp and let the demonstration run for at least 15-20 minutes.** The higher the watt bulb used, the quicker your students will see results. You can run this lab as long as you need to see a temperature change and condensation.

Planning & Carrying Out Investigations
Include students in the planning of the bottle model lab/demonstration. Prompt students to articulate why certain conditions should be tested to help them figure out the best conditions for storms.

BOTTLE MODEL DEMONSTRATION

TIME:
- Set-up will take approximately 10 minutes depending on how many bottles you want to test.
- Results appear within 20 minutes of turning on the lamp.

MATERIALS:
- 100-watt incandescent bulb and lamp (e.g., clamp lamp)
- Two or more clear plastic soda bottles or transparent containers
- Two or more thermometers
- Rubber stoppers with a hole (optional)
- Funnel
- Dried sand or soil
- Water

TIPS AND ADVANCE PREP:
- If not using rubber stoppers, punch a hole in the bottle lid to insert the thermometers.
- Thermometers may become difficult to read with condensation.
- Insert dried sand/soil into the bottle before making it damp. It will be easier and cleaner to pour to avoid getting sand on the side of the bottle. Be careful to minimize the material that gets on the inside of the bottles. You want the sides of the bottles to remain as clear as possible so students can measure temperature and observe condensation.

Dry sand or soil | Wet sand or soil

VIRTUAL RESOURCES:
Bottle Model time-lapse video: https://scied.ucar.edu/bottle-model-timelapse
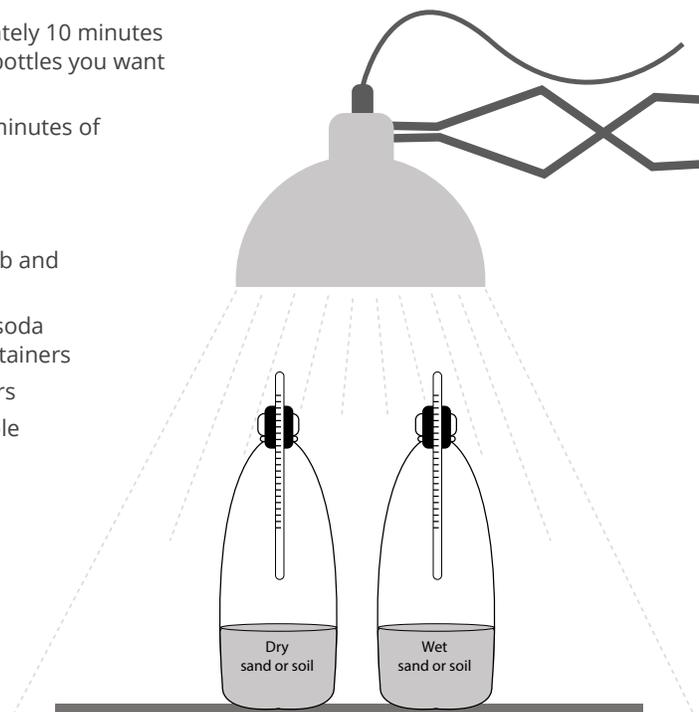
4 LESSON
STEP 3

7. **Make observations of the bottles.** Have students make observations of the bottles and record temperature measurements in a data table (*Lesson 4: Step 3*). Use a clock or timer to keep track of the time and have students record observations every 2 minutes.

8. **Discuss and compare results.** Give students an opportunity to discuss the questions on their activity sheets in small groups or using a collaborative group strategy.

   Discussion questions:
   - *How did the sunny day bottle match/not match what you expected?*
   - *How did the stormy day bottle match/not match what you expected?*
   - *Changing the amount of water in the system (humidity/moisture) was important. If a town is located far from an ocean or large body of water, where does the water come from?*
   - *Using evidence from the bottle models and the temperature and humidity data in Lesson 4: Step 1 and Step 2, what conditions are best for storms?*

9. **Transition to whole group discussion.** Specifically focus on the importance of the source of water and the best conditions for a storm. In the water only condition, the source of water might represent large bodies of water or the ocean. In the damp soil/sand condition, the source of water represents groundwater and smaller surface water sources. Prompt students to connect their observations back to the temperature and humidity patterns observed for a sunny and stormy day. Add to the Model Idea Tracker as students come to agree upon the role of moisture.

   Model Idea:
   - A source of moisture is important to get water into the atmosphere for storms.

10. **Look ahead to the next lesson.** End the discussion, posing the question: *"How did the water from the bottom of the bottle get up on the sides of the bottle?"* Have students share their initial ideas to this question.

Developing & Using Models
Add to the Model Idea Tracker the critical role of a water source for storm formation.

Storyline Link
Students will be investigating convection next, so they need to start thinking about how water at the surface moves up in the atmosphere.

5 AIR ON THE MOVE
How does air move and change when a storm is forming?

LESSON 5

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(100 minutes)	
Demonstration: Warm and Cool Air Students watch a demonstration of warming up and cooling down air inside a Mylar balloon that has been partially deflated. Students discuss what they think happens to cause the balloon to go up or down.	**Lesson 5: Student Activity Sheet** LESSON 5 Mylar balloon with helium Hair dryer
Interactive Reading: Air on the Move Students read about the warming of air and evaporation of water at the surface and how this air moves during convection. Students make illustrations of concepts throughout the reading and connect back to previous evidence they have collected.	Colored pencils
Consensus Model: Isolated Storm The class works together to construct a class Consensus Model for explaining the best atmospheric conditions for storms. Students pull together ideas from their previous Working Models to create a comprehensive model to show how moisture becomes available in a location, increasing the chance of an isolated storm.	Whiteboard, smart board, or chart paper and markers (for the Driving Question Board and Model Idea Tracker) Whiteboard or chart paper and markers (to make the Consensus Model)

5 AIR ON THE MOVE
How does air move and change when a storm is forming?

NGSS Sensemaking

This series of activities will help students to piece together different parts of a model they've been working toward in previous lessons. The goal is for students to identify important underlying mechanisms and processes that explain how moisture becomes available over a location in an isolated storm. Students use evidence from their investigations to vet the emerging model against their Model Ideas, or the rules of the system.

PERFORMANCE OUTCOME

- Conduct an experiment and analyze and interpret data to describe how changes in temperature in a body of air cause the air to change and move.
- Develop and use a model to explain how energy from the Sun, convection, water on the surface and in the air, and variations in temperature and humidity create conditions/cause the formation of isolated storms.

NGSS DIMENSIONS (GRADES 6-8)

- Global movement of water and its changes are propelled by sunlight. Weather is influenced by interactions involving sunlight, the atmosphere, and land.
- Analyze and interpret data to provide evidence of a phenomenon.
- Collect data to produce data to serve as the basis of evidence to answer scientific questions.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Cause and effect relationships may be used to predict phenomena in natural systems.

NGSS DIMENSIONS (GRADES 3-5) (REINFORCING)

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

Teacher Procedures

Demonstration: Warm and Cool Air

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1. **Navigate from the previous lesson.** At the end of the previous lesson, students shared their ideas about how water at the surface (near the bottom) of their bottles got onto the upper parts of the bottles.

   Review this discussion using the following question prompts:
   - *What happened to the water at the surface before it traveled to the top of the bottle?*
   - *What happened to the water at the top of the bottle?*
   - *How did that water get up there? Why would it go up?*

2. **Motivate the need to investigate vertical movement of air.** Students may say evaporation is how water at the surface gets higher in the atmosphere. Remind students about the water cycle. Talk about what evaporation means and how it explains the change of liquid water to gas but not how it travels upward. (Consider whether students need additional support to understand processes of the water cycle.)
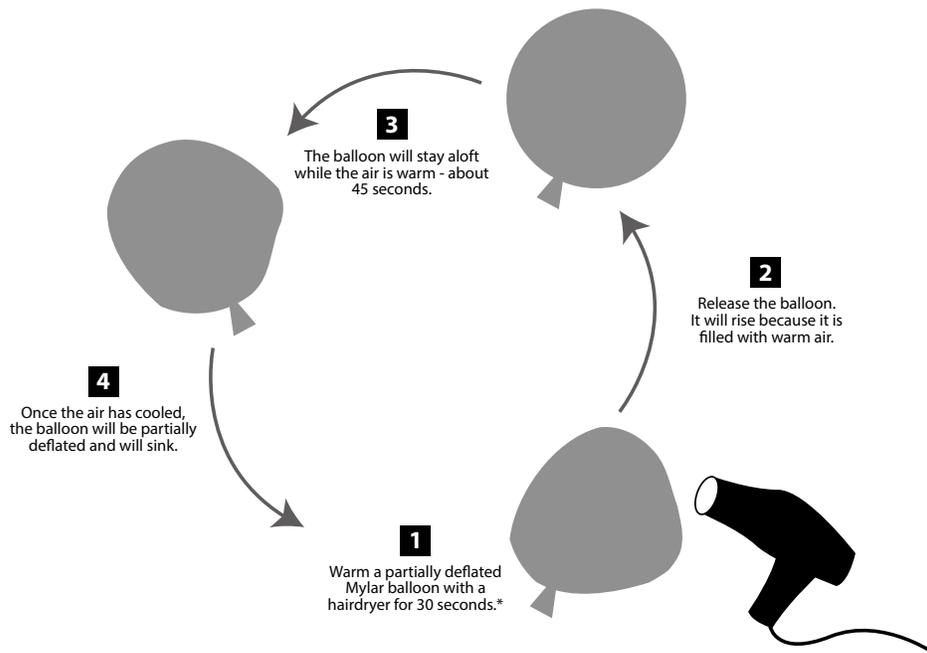
   Suggested transition:
   - *"So we know the surface is warmed here and water evaporates, and we know water condenses up here because it's cooler, but how and why does the water vapor travel up? We need to figure this out. If we add heat to air down here, can we get the balloon to travel up?"*

3. **Elicit student experiences of warmed air and steam.** Ask students to think about why recently warmed water vapor would travel up. Broaden the discussion to elicit students' experiences of warmed water vapor (e.g., steam) and warmed air (e.g., "heat waves" off highways). Point out a pattern that this warm air seems to move up. Ask students why they think warm air moves upward.

4. **Introduce students to the Mylar balloon investigation.** The Mylar balloon contains helium gas, and students are going to heat the gas to see if they can get the balloon to move upward.

Storyline Link
This move establishes the need to explain air traveling upward. Students might think evaporation is sufficient. They need help seeing they are missing a piece to their models.

MYLAR BALLOON DEMONSTRATION

3 The balloon will stay aloft while the air is warm - about 45 seconds.

2 Release the balloon. It will rise because it is filled with warm air.

4 Once the air has cooled, the balloon will be partially deflated and will sink.

1 Warm a partially deflated Mylar balloon with a hairdryer for 30 seconds.*

TIME:
- Set-up is less than a minute
- *The time it takes for the balloon to visibly inflate will vary (typically 20-60 seconds)
- The balloon will stay aloft for about 45 seconds before deflating and sinking back to the floor

MATERIALS:
- Partially deflated Mylar balloon filled with helium. Needs to be lightly rested near the floor
- Hair dryer
- Straw

TIPS AND ADVANCE PREP:
- Deflate the balloon by inserting a drinking straw three-quarters of the way into the hole near the base of the balloon. Lightly squeeze some air from the balloon but avoid emptying the balloon too much. Prepare a few extra balloons in case a one or more don't function properly.
- If you have an IR thermometer, consider taking temperature measurements of the balloon just before, as it's being heated, and as it cools.

VIRTUAL RESOURCES:
- Demonstration video: https://scied.ucar.edu/warming-mylar-balloon

LESSON 5 STEP 1

5. **Draw the lab set-up.** Direct students to *Lesson 5: Step 1* of their student activity sheets. Ask students to draw the demonstration set-up on their activity sheets.

6. **Warm the Mylar balloon.** Have a student volunteer to warm the Mylar balloon using a hair dryer. It is important to represent the balloon as a pocket of air located at the surface of Earth. The hair dryer should represent thermal energy radiated from the ground and not light energy from the Sun above.

7. **Make observations of the balloon.** Students make observations of what they see and hear happening to the Mylar balloon as the air inside is warmed (e.g., crinkling as it expands and travels up to the ceiling). Prompt students to add these observations to their observation sheet in *Lesson 5: Step 1*. Continue observing the Mylar balloon as it cools (roughly one minute or less). Once the air inside the balloon cools, it begins to sink and visibly shrink. Prompt students to add observations to their observation sheets. Repeat the demonstration a second or third time with different student volunteers to make additional observations and to prompt students to start explaining what's happening in the balloon.

8. **Develop an initial explanation.** Direct students to the questions at the end of *Lesson 5: Step 1* on their activity sheets. Students are prompted to explain what is happening inside the Mylar balloon as it is heated and when the balloon sinks. If students are new to particle motion and thermal energy, they may be more uncertain about what's happening in the balloon. You are steering them toward a basic understanding that warmed air molecules move more and are more spread apart, and vice versa for air molecules that have cooled. Students will encounter these concepts in the reading that follows. Encourage students to think about the balloon having the same amount of air, whether warm or cool, but changing in terms of volume, which they see when the balloon expands and contracts.

Interactive Reading: Air on the Move

1. **Navigate from the Mylar balloon investigation.** Students have initial ideas explaining the warm air inside the balloon traveling up. They likely need more information to put together the pieces of a convection model. Explain to students that reading more about the molecules in the air can help them figure out more of what's going on. Direct students to *Lesson: 5, Step 2*, an interactive reading called Air on the Move. Students will interact with the new information by drawing diagrams and summarizing new information.

2. **Read the first two paragraphs and diagram warm and cool air.** The first part of the reading focuses on what happens when heat transfers to air molecules or when those molecules lose energy. Students draw diagrams to show warmed air molecules in a balloon moving faster and spread apart and cooler air molecules closer together and moving slower.

3. **Read about how gravity affects air molecules.** Students read and draw air molecules low in the atmosphere at higher pressure and high at lower pressure (more spread out), which will help them understand why warm air rises. Have students label where "low pressure" and "high pressure" are on their drawings.

4. **Read about convection.** Students read and look at a particle diagram showing how air molecules change during convection. After reading, pose the question: "How could convection be related to _____?" (e.g., the Mylar balloon, the bottle models, storms forming). Students are reminded about the relationship between water vapor and warm/cooled air (from *Lesson 4*). The vapor condenses from the air when the air reaches cooler temperatures.

5. **Revisit explanations of warm air rising and add to the Model Idea Tracker.** Conclude the reading, reflecting on the question: "Why does warm air go up and cool air go down?" Students write their ideas on the reading first. As students share their thinking with the class, prompt students to connect to the previous phenomenon or data patterns they have seen in the unit (e.g., Mylar balloon, bottle models, isolated storm time-lapse videos, temperature patterns from the surface to the clouds), and how the new concepts help them explain what they observed.

   Model Ideas:
   - Warm air rises and cooler air sinks.
   - Warm air is able to take in more water vapor compared to cool air.

Literacy Connection
Students interact with this reading by making connections and synthesizing new information with what they have learned previously.

Obtaining Information
Students read scientific text to determine critical concepts that help them explain phenomena.

Storyline Link
This is a critical moment in the Explain lesson where students start to use particle motion, convection, and humidity to explain phenomena.

Developing & Using Models
Add to the Model Idea Tracker new ideas about convection and humidity obtained from the reading and Mylar balloon investigation.

Consensus Model for an Isolated Storm

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1. **Devote time to "taking stock" by returning to the Driving Question Board.** As you navigate from the reading and students' recently developed ideas about air molecules, particle motion, and convection, have students reflect on what they have learned. Return to the Driving Question Board to see which questions students can now answer. As students review their questions and develop answers to some of those questions, use this information to inform how you approach the Consensus Model. It might be the case that students need to revisit a particular data set from earlier in the sequence to "refresh" their thinking and/or to make connections they have not made yet.

2. **Revisit the stormy day time-lapse video to motivate explanation of this phenomenon.** Replay the isolated storm time-lapse video, and have students work in small groups to discuss important things happening for the storm to form. Tell students they are going to develop a model to explain the isolated storm:

   • *"Let's see if we can put together all the things we've learned to create a model that explains what's happening for the storm to form."*

3. **Revisit the Model Idea Tracker.** Use the Model Idea Tracker to review important "rules of the system". These Model Ideas have evidence to support them and can help students make sense of how a system works. As students construct the Consensus Model for an Isolated Storm, they should pay attention that it is consistent with their Model Ideas.

4. **Prepare for the Consensus Model.** Direct students to *Lesson 5: Step 3* on their student activity sheets to record their ideas individually about how precipitation happens in an isolated storm. Tell students that after they develop their model, the class will construct a Consensus Model for an Isolated Storm that takes student model ideas into account.

5. **Develop a Consensus Model.** In a public space, draw the Consensus Model for an Isolated Storm as students share their thinking about important processes and conditions for storms. For each suggested addition, put the idea forth to the class for other students to clarify and add to before it is recorded on the class model. Specifically ask students to cite data or other evidence to support their ideas. A list of guiding questions is provided on the student activity sheet to help organize parts of the model.

6. **Record the Consensus Model.** After the class version of the Consensus Model for an Isolated Storm is complete, direct students to revise their models on their student activity sheets using a different color of pencil. Encourage students to represent their thinking in different ways if it helps them make sense of what's happening in the model. They do not need to record the exact model constructed by the class, but they do need to record one that is consistent with the Model Idea Tracker.

LESSON 5
STEP 3

Assessment
Returning to the Driving Question Board allows for you and your students to assess the progress on their questions. You can formalize this assessment as much as you prefer, for example, asking students to write explanations to their questions or simply discuss their new ideas aloud.

Developing & Using Models
Students develop a model to explain an isolated storm phenomenon. The model is vetted against their evidence.

6 MAKING A THUNDERSTORM
Can we identify the best conditions for storms?

ENGAGE ···· EXPLORE ···· EXPLAIN ···· **ELABORATE**

AT A GLANCE

ACTIVITY DESCRIPTION	MATERIALS
(50 minutes)	
Make a Thunderstorm Simulation Students test their models by manipulating parts of the models to see how changes to those parts influence storm potential. Students have the opportunity to confirm parts of their models and refine other parts based on this investigation.	**Lesson 6: Student Activity Sheet** 6 Computers Make a Thunderstorm simulation https://scied.ucar.edu/make-thunderstorm
When Did It Rain? Students are given a set of data recorded over a two-day period. During the two days, it rained only once. Using what students know about the best conditions for precipitation, students identify the time it rained and develop an evidence-based explanation supporting their choice. This activity can be adjusted to serve as a performance assessment.	
Return to Driving Question Board / Assessment The class works together to construct a class Consensus Model for explaining the best atmospheric conditions for storms. Students pull together ideas from their previous Working Models to create a comprehensive model to show how moisture becomes available in a location, increasing the chance of an isolated storm.	Driving Question Board (used in Lesson 5) Assessment item bank

LESSON 6 MAKING A THUNDERSTORM
Can we identify the best conditions for storms?

NGSS Sensemaking

This series of activities helps students piece together different parts of a model they've been working toward in previous lessons. The goal is for students to identify important underlying mechanisms and processes that explain how moisture becomes available over a location in an isolated storm. Students use evidence from their investigations to vet the emerging model against their Model Ideas, or the rules of the system.

PERFORMANCE OUTCOME

- Collect, analyze, and interpret data to describe temperature and humidity conditions on the ground and in the clouds that create conditions/cause the formation of a storm.
- Analyze and interpret patterns in data to explain how and why humidity and temperature change around an isolated storm.

NGSS DIMENSIONS (GRADES 6-8)

- Global movements of water and its changes are propelled by sunlight. Weather is influenced by interactions involving sunlight, the atmosphere, and land.
- Analyze and interpret data to provide evidence of a phenomenon.
- Develop and/or revise a model to show the relationship among variables including those that are not observable but predict observable phenomena.
- Use graphs to identify patterns in data.
- Cause and effect relationships may be used to predict phenomena in natural systems.

Teacher Procedures

Make a Thunderstorm Simulation

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1. **Navigate from the previous lesson.** Take a moment to review the Consensus Model for an Isolated Storm. Ask students if there are new questions from the Driving Question Board that they can now answer. Have students share these questions and answers with the class.

2. **Return to the Anchoring Phenomenon.** In small groups, prompt students to discuss what they now know about "causes" of precipitation and potential for precipitation. Have students share their thinking about the Anchoring Phenomenon and whether they believe the Consensus Model for an Isolated Storm is consistent with the Colorado storm. Discuss how the Colorado storm may fit or may not fit the Model Ideas. Note that students might also recognize that the length of the storm, which persisted for several days, does not fit the Consensus Model for an Isolated Storm.

   Model Ideas from Learning Sequence 1:
   - Evaporation of water at the surface is important for clouds/storms.
   - Evaporation happens because of heating from sunlight.
   - Clouds form when water condenses.
   - The surface is warmer than the air above it.
   - The air near the ground is warmer than air at higher altitudes, like where clouds form.
   - Rising temperature and humidity are good conditions for an isolated storm.
   - Rising temperature and low humidity are not good conditions for an isolated storm.
   - A source of moisture is important to get water into the atmosphere for storms.
   - Warm air rises and cooler air sinks.
   - Warm air is able to take in more water vapor compared to cool air.

3. **Motivate a reason to test their models.** Explain to students that it is important to test a model to make sure it is useful for figuring out a phenomenon and that it can become helpful for making predictions. If they can figure out the best conditions for strong storms with heavy precipitation compared to conditions for weaker or smaller storms with less precipitation, their models will do a better job explaining why certain storms bring more precipitation compared to other storms.

4. **Introduce the Make a Thunderstorm simulation.** Direct students to the *Lesson 6: Student Activity Sheet*. Introduce students to the Making a Thunderstorm simulation, which allows them to manipulate the temperature and humidity parts in their models to see how changing parts of the model affects storm potential. Emphasize to students that if one variable in their models changes, the outcome changes. They will need to explain why a strong storm forms and also why weaker storms form based on changes they made to parts of the model.

LESSON 6

MAKE A THUNDERSTORM SIMULATION

Simulation Link: https://scied.ucar.edu/make-thunderstorm

Storyline Link
Returning to the Driving Question Board can help to remind students of their initial questions at the start of the unit.

Developing & Using Models
Students use their models to predict storm potential and refine their models based on simulated data.

Systems and Systems Models
Students learn that changing one variable in the Systems Model can change the model entirely.

Developing & Using Models
Students use their models to make predictions and refine their models based on the evidence.

LESSON 6 STEP 1

5. **Use the Consensus Model to make predictions.** Have students use their models to make predictions about the best conditions for storms. Students record their predictions in *Lesson 6: Step 1* of their activity sheets.

LESSON 6 STEP 2

6. **Collect evidence from the simulation.** Arrange students in groups with a computer or tablet. Orient students to the simulation and give them instructions for recording data in *Lesson 6: Step 2*. Students collect data from the simulation. Walk around and monitor progress. Prompt students to explain the storm outcome in terms of conditions that helped a storm form and conditions that did not help a storm form.

    Important patterns to identify from the simulation:

    •   Warm temperatures near the surface and colder temperatures higher in the atmosphere with high humidity are ideal conditions for thunderstorms.
    •   If there is less of a temperature difference between the two altitudes, weaker storms may still form.
    •   If there is low humidity, regardless of temperature, thunderstorms will not form.

7. **Confirm and/or refine the Consensus Model.** As a whole group, return to the Consensus Model to confirm or refine the model. Prompt students to use data from the simulation to determine whether they can confirm the model or want to change part of the model.

When Did It Rain?

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1. **Navigate from the previous activity.** Students understand how to use temperature and humidity to make sense of storm potential in convective storms, specifically isolated storms. Students will use what they know to identify a rain event and to construct an explanation about what happened leading up to this event. Use the Model Idea Tracker to provide students with guidance to help them pull together what they know to make a claim about when this type of rainstorm happens:

    •   *If the air near the Earth's surface needs to be warm and rise for a storm to form and the Sun heats the ground surface, which heats the air near the ground, then at what time of day would you expect a thunderstorm?*

LESSON 6 STEP 3

2. **Orient students to the new data set.** Direct students to *Lesson 6: Step 3* on their activity sheets. Students examine historical temperature and humidity data to test whether their isolated storm models help them determine when a rain event occurred in Pompano, Florida.

POMPANO DATA SET

This data set comes from Pompano Beach High School (a GLOBE school) in Pompano, Florida. The temperature and (relative) humidity data from July 21-22, 2017, come from a WeatherBug automated weather station co-located with this GLOBE school. These automated stations record weather data daily every 15 minutes. These data can be found on the GLOBE Visualization Tool and the GLOBE Advanced Data Access Tool.

3. **Analyze the data.** Allow students time to work individually or in groups to analyze the data and determine the time of the rain event. If students disagree, they should use evidence to argue for their choices.

Assessment
This activity can be used as an individual performance assessment if you feel your students are ready to demonstrate what they know. If your students need more practice with the concepts they should work on this task in groups.

Data Analysis & Interpretation
Students analyze temperature and humidity data to determine the likely moment of a rain event.

Patterns in Data
Students use patterns in the data to construct an explanation for a rain event.

4. **Share the precipitation data with students.** Project the precipitation data so that students can identify if they were correct in their identifications. Through a whole class discussion, prompt students to explain whether their decisions were correct or incorrect and to share.

Driving Question Board / Assessment

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1. **Provide time for students to update the Driving Question Board.** Ask students to return to the board to answer questions, make changes to questions, and/or add new questions. Have students share aloud the new answers they have and/or new questions they want to add.

2. **Return to the Anchoring Phenomenon again.** Ask students: "Did the Colorado storm happen in the afternoon?" Students might remember that the video revealed that the storm lasted several days. Ask students what parts of their models might explain the event and what they think could be different. Since the Colorado event lasted much longer than the typical isolated storm, something else might be going on in that type of storm. Use this to initiate further investigations into different kinds of storms that students will explore in Learning Sequence 2.

    For example:

    *   *"Our model helps us explain some kinds of storms, but the storm in Colorado lasted a lot longer. The Colorado storm might be a different kind of storm, so we need to do some more investigating to figure it out."*

3. **Emphasize the power and limitation of models.** Have students talk about the kinds of storms that their models explain well, but also the types of storms that do not fit their models. Explain to students that models are tools to help us explain things happening in the world but that they are not always perfect and cannot capture everything. This is especially true for models of complex systems like weather, which is why weather is predicted probabilistically.

4. **Assess student learning with the Learning Sequence 1 assessment.** You can find the assessment item bank and rubric in the Assessments section of *GLOBE Weather*.

Home Learning
Ask students to start thinking about storms that fit their models and storms that do not fit their models. They should come prepared to share their ideas at the next class.