WHEN *is the* GRASS GREENER?

Climate Change and Phenology for 6th

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Seasonal SAWTOOTH PATTERNS *in the* CARBON CYCLE

A Phenology and Climate Lesson for 9th-12th Grade Students

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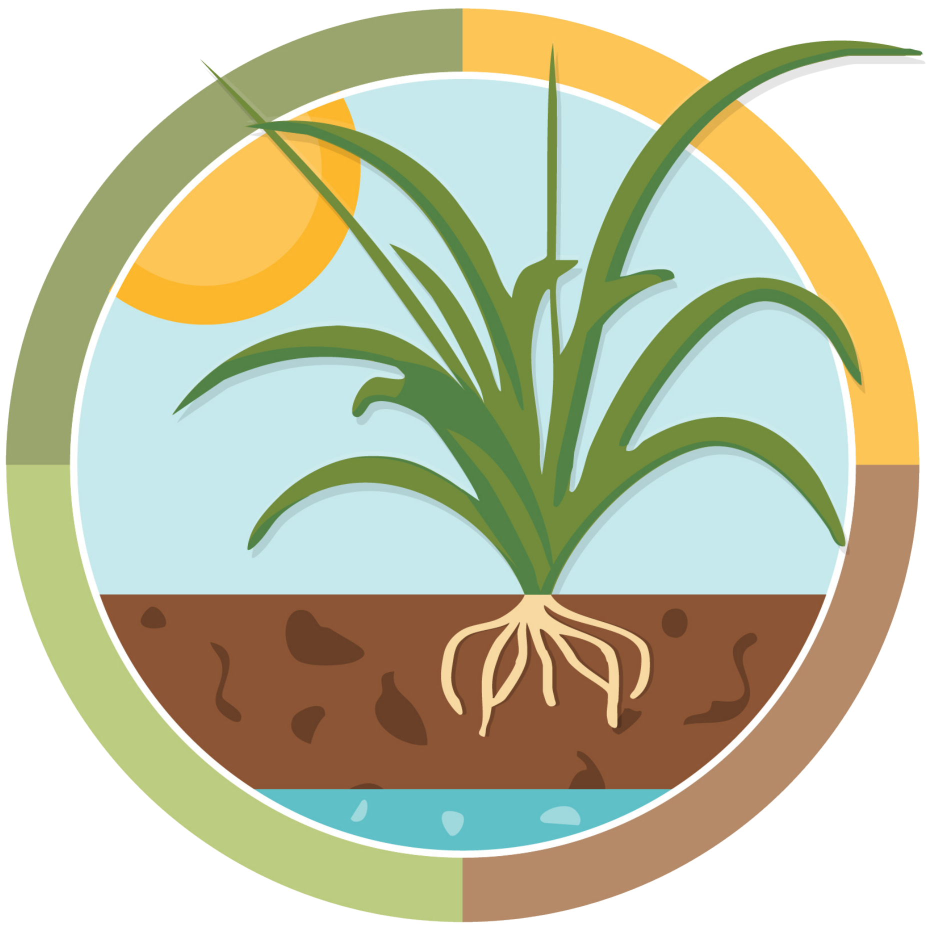
WHEN *is the* GRASS GREENER?



Climate Change and Phenology for 6th-8th Grade Students

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WHEN IS THE GRASS GREENER?

Climate Change and Phenology for 6th-8th Grade Students

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CURRICULUM DEVELOPMENT
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Abigail Miller

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A Desert Phenology Lesson

WHEN IS THE GRASS GREENER?

DESCRIPTION
Students will be introduced to phenology (cyclical, seasonal changes in plants) and use data to consider how climate change will impact the phenological cycles of desert grasses and shrubs.

PHENOMENON
Earth's changing climate will affect water availability, resulting in changes to plant phenology, including the green-up, of some plants.

GRADE LEVEL
6-8

OBJECTIVES
Students will:

- Learn how and why scientists monitor plant phenology
- Examine data on green-up dates of shrubs and grasses in the desert
- Model the effects of root length on accessing water
- Predict some impacts of climate change based on phenological patterns in plants

TIME
50 MINUTES

COMMON CORE STATE STANDARDS
English Language Arts

SL.1. Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade-level topics, texts, and issues, building on others' ideas and expressing their own clearly.

RST.3. Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

NEXT GENERATION SCIENCE STANDARDS
MS-LS2-1 Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. *(Clarification Statement: Emphasis is on cause-and-effect relationships between resources and the growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.)*

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data Engaging in Argument from Evidence Constructing Explanations and Designing Solutions	**LS2.A: Interdependent Relationships in Ecosystems** ESS3.C: Human Impacts on Earth Systems	**Cause and Effect** Patterns

BACKGROUND
Phenology is the study of seasonal changes in the life cycles of plants and animals. The development of leaf buds, flowers, fruit, color change, and leaf fall, as well as the timing of animal reproduction and migration, are all examples of phenological events. Temperature, precipitation, and photoperiod (or the seasonal changes in day length) impact the timing of these events.

Because plant development is closely tied to weather and climate, the earth's changing climate will alter the timing of seasonal patterns. For example, plant green-up (appearance of leaves) dates and flowering dates are occurring earlier in the year. Changes in when and how long plants grow and bloom can have a domino effect in ecosystems, impacting pollinators, herbivores, and other animals. You can learn more about phenology and how to collect phenology data as a community scientist from the USA National Phenology Network (https://www.usanpn.org/).

One way to better understand phenological cycles and patterns is to monitor and track vegetation changes over a long period and relate these patterns to environmental cues like temperature, precipitation, and day length. Scientists do this through regular observations and repeat photography of the same

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plants over many years. These observations can be done in person or through cameras, like the Phenocam Network (https://phenocam.nau.edu/webcam/).

In the Desert Southwest, plant phenology is largely driven by water availability, but uneven access to groundwater results in two phenological patterns. Shrubs with deep roots are able to take advantage of groundwater reserves that change very slowly. With their near-constant access to water, these plants green-up in a predictable seasonal pattern. Temperature or photoperiod may be the driving factor for when these plants green-up each spring. In contrast, short-rooted plants, including grasses and annual forbs, must rely on precipitation, and they green-up quickly after rainfall. The variable timing of rainfall results in unpredictable green-up times for these plants, and in times of drought, there may be no green-up observed at all.

These two phenological patterns: predictable green-up times for long-rooted plants, and variable green-up times for short-rooted plants, favor the survival of long-rooted plants (typically shrubs) over short-rooted plants (typically grasses) during times of drought. Climate change will increase the intensity and frequency of droughts in the southwest, shifting desert grasslands to desert shrublands, a phenomenon which has been recorded in the 20th century in the Chihuahuan Desert.

MATERIALS

- When is the Grass Greener worksheet (1 per student)
- PowerPoint presentation
- Apple tree phenology cards (one set for every 2-4 students)
- For every 4 students:
  - o 2 long straws: approximately 6 inches
  - o 2 short straws: approximately 4 inches
  - o 4 small bathroom cups with a line drawn approximately 1 cm from the bottom
  - o 1 water bottle (if using reusable water bottles, use one with a narrow opening)
- Paper towels
- Timer (if you are not using the counter on slides 12 and 16)

PREPARATION

1. Print one worksheet per student.
2. Set up the slides on the screen.
3. Print and cut the apple tree phenology cards. Prepare one set of cards for every 3-4 students.
4. Cut straws to 6 inches and 4 inches. You will need one straw per student. Half the class should have 4-inch straws, and half the class should have 6-inch straws.
5. Draw a line approximately 1 centimeter from the bottom of each cup with a permanent marker. If the cups are opaque, draw the line on the inside of the cup.

PROCEDURES

INTRODUCTION TO PHENOLOGY (15 MINUTES)

1. **Slide 1**: Introduce the topic of the lesson.
2. **Slide 2:** Put students into groups of 2-4 and give each group a set of apple tree phenology cards with the instructions to put the cards in the order the events happen. Each card represents a phenological stage of an apple tree's annual cycle. Give students 2 minutes to discuss the proper order for their cards.
   a. Correct order: leaf bud, leaf, flower buds, flowers, pollination, fruit
   b. Note that these stages are cyclical, and students could order them to begin at a different stage.
3. **Slide 3:** Show students the correct order and ask students what these cards represent (answers might include seasonal patterns or life cycles).
   a. Note that other plants follow similar patterns; these pictures show milkweed and saguaro cactus as examples.
4. **Slide 4:** Define phenology: the study of these seasonal patterns and cycles in nature.
   a. Point out to students that the events in their cards happen at certain times of year.
   b. People have studied and recorded phenological patterns for thousands of years because the cycles in nature impact many aspects of daily life. Seasonal weather, planting crops or gathering wild plants, hunting seasons, and allergies are all ways that these patterns can impact humans.
   c. The Tohono O'odham people in the Sonoran Desert associate the harvest of Saguaro fruit with preparing for the rain dances and the coming rainy season.
   d. Ask students what phenological events and

changes they notice throughout the year? What phenological changes happen around their birthdays?

5. **Slide 5:** The timing of phenological events is important because many plants rely on other species with their own phenological patterns. For example, pollinators interact with flowers, and some insects lay their eggs on leaves. What would happen if the events and interactions did not line up at the same time? For example, if bumblebees can't pollinate apple flowers, the trees won't produce apples (click forward on the slide). These mismatches would affect many crops we rely on. The scientific term for this is phenological mismatch.
6. **Slide 6:** The timing of phenological events is controlled by factors like temperature, precipitation and day length. Climate change is expected to impact these factors and lead to phenological mismatches. Changes in phenology can have a domino effect in ecosystems. Today, we are going to investigate the phenological patterns of four desert plants, specifically when they green up, or sprout their first leaves of the year. We will think about how climate change will impact their phenology and the ecosystem.

ANALYZE PHENOLOGICAL DATA (10 MINUTES)

1. **Slide 7:** To monitor plant phenology, scientists must observe when plants are going through phases like growing leaves, blooming, or losing leaves. They can do this by directly observing plants. Many scientists also use Phenocams, which are web-connected cameras that take pictures at regular intervals. A computer program can then analyze the greenness of each pixel and graph the data. You can see the annual cycles in greenness in the graph on the slide. Dr. Dawn Browning is a researcher at the USDA's Jornada Experimental Range and uses both methods to collect phenology data.
2. **Slide 8:** Since 1993, Dr. Browning and other scientists have been observing plant phenology in the Chihuahuan Desert in Las Cruces, New Mexico. They go out every month and record what month green leaves first appeared on individual plants. These graphs show how many plants were observed greening-up in each month of the year. Support students in reading these graphs and have them answer questions 1 and 2 on their worksheet.
   a. Phenological pattern of honey mesquite bush: Most plants green up in April. It is a fairly predictable pattern.
   b. Phenological pattern of tarbush: Green up almost always happens in January. It is a fairly predictable pattern.
   c. Phenological pattern of black grama grass: Green up most commonly happens in March, but also in January. Most plants green up in the spring, but the green-up dates are more variable than in honey mesquite or tarbush.
   d. Phenological pattern of ear muhly grass: Green up most commonly happens in January, but is also common in February, March, and April. Green-up dates are quite variable, and there is another small peak in July. Green up generally happens in the spring.
   e. What could be the cause of these phenological patterns? Temperature, precipitation, sunlight, and day length are most likely causes.
   f. Have students discuss and answer question 2 on their worksheet: What is the difference between the phenology of the bushes (honey mesquite bush and tarbush) and the grasses (black grama grass and ear muhly grass)? [The bushes both have very predictable phenological patterns. The grasses are much more variable in their timing.]
3. **Slide 9:** Show students the root diagrams and discuss what they observe. Note that the two long-rooted shrubs (honey mesquite and tarbush) have more predictable phenology, and the two short-rooted plants (black grama grass and ear muhly) have more variety in their phenology. Remind students that roots are very important in getting water to plants.
   a. Dr. Browning has a hypothesis that root length plays a large role in plant phenology.

MODELING PHENOLOGY OF DESERT PLANTS (10 MINUTES)

1. **Slide 10:** We will play a game to try to model and understand how root length might affect phenology. In our model, a water bottle will represent groundwater, a straw will represent the plant roots, and a cup will represent the main body of the plant. Time will be an important part of our model too.
2. **Slide 11:** Put students in groups of 3 or 4. Give each group a water bottle, 2 long straws and 2 short straws, and a cup for each student. Each student will use 1 straw.
   a. The goal for each student is to fill their cup to the line using their straw and finger. Students will do this by inserting the straw into the water bottle and placing their finger on top of the straw, then moving the straw over their cup and releasing their finger. Students are NOT putting their mouth on the straw.
   b. Rules: don't tip or squeeze the water bottle to get the water higher. If you can't reach the water, you can't reach.
   c. Students should clear their desks, as they will get wet. Consider putting a towel, paper towel or tray on the table.
   d. Give students 30 seconds to practice moving water with the straw, then return water to the bottle

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before the game begins.

e. Students should place the water bottle in the middle of the table where everyone in their group can reach it. **It is a good idea for one student to hold the base of the water bottle to keep it from falling over.**

f. The game begins when you click forward in the slide show and the slide says “Go!”.

g. When the game begins, students use their straws and fingers to get water out of the bottle and into their cup. When they fill their cup, they must look up at the screen and make a note of what number is showing on the screen.

3. **Slide 12:** Start the game by clicking forward on the slide you will see the words “Ready, Set, Go!” flash on to the screen. Then the numbers will automatically advance until they reach 25. Numbers advance every 5 seconds.
   a. If the water level drops below the reach of the short-rooted plants, those plants will remain dormant (no green-up) that year.
   b. If you cannot use the counter in the slides, use a timer to count seconds. Have students note how many seconds it took to fill their cup, divide that time by 5 (to make it equivalent to the timer in the slides), and round to the closest whole number. Use that number when recording data in the data table.
4. **Slide 13:** Create two graphs of the class data on the board, using the template in Fig 1. Create one graph for long-rooted bushes, one graph for short-rooted grasses and have students report the number that was showing when they filled their cup on the appropriate graph.

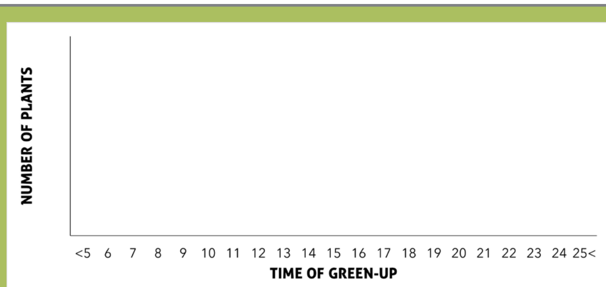

Figure 1.

   a. Compare your graphs for long-rooted bushes and short-rooted grasses to the four phenology graphs on page 1 of students’ worksheets. Discuss the importance of water availability on the green-up timing plants.
5. **Slide 14:** Ask students why long-rooted bushes are able to green up at about the same time every year. [It is because they have access to a reliable source of deeper groundwater.] If we had a lot of rain, would the short-rooted grasses have greened up earlier? [Yes, if there is more water in the top layer of soil where grass roots grow, those plants can green up earlier.]
6. Have students answer questions 3 and 4 on their worksheet.

APPLYING PHENOLOGY KNOWLEDGE AND SOLVING PROBLEMS (10 MIN)

1. **Slide 15:** Climate change is predicted to change when rain falls, how much rain falls, and how much and how fast water evaporates in the southwest. Discuss with students how that will impact both long-rooted bushes and short-rooted grasses.
2. Give students time to discuss with their group and answer question 5: Read the scenarios below and apply what you know about phenology, climate change, and desert plants to predict how each person will be affected by climate change. If time allows, have students share and discuss their answers as a class.
3. Scenarios:
   a. Freddy is a rancher whose cows graze on desert grasses. If there isn’t enough grass, Freddy must bring in hay or supplemental food to ensure his cows stay healthy. Based on what you know about the phenology of grasses, how will Freddy be impacted by climate change? How can Freddy adapt to climate change or solve the problem it is causing?
   b. Mariana walks to school every day. Next to the school is a large area with no buildings. On windy days, lots of dust is picked up off the ground from this area and gets in her eyes, mouth, and hair. Mariana has noticed that when grass is growing, there is less bare ground and the grass seems to hold onto the soil. Based on what you know about the phenology, how will Mariana’s walk to school be impacted by climate change? How can Mariana adapt to climate change or solve the problem it is causing?

MODELING CLIMATE CHANGE CONDITIONS

1. **Slide 16:** If time allows, you can use the game to model climate change conditions.
   a. Refill most groups’ water bottles. Select two or three groups to represent drought conditions, and do not refill their water bottles. Ensure drought groups have enough water that the short roots will be able to reach it at first, but it’s ok if they struggle to fill their cups.
   b. The teacher (or assign 1 or 2 students to this task) will represent rain by adding water to each group’s bottle during the game. Groups will receive different amounts of water at different times (random), creating more variability in the results

for short-rooted grasses, but having less impact on long-rooted bushes.

2. **Slide 17:** Add your results from this round to the same graphs you used in round one. Use a different color for round two data.
   a. Compare your graphs for long and short-rooted plants and discuss the impact of climate change on each.
   b. Note that short-rooted grasses are more reliant on rain because they can't reach as much groundwater as long-rooted plants, so changes in rain have a larger impact on grasses.
   c. Can students use this knowledge to predict when each plant will green up next year?

EXTENSIONS

1. Let students explore phenology data and images on the PhenoCam website (https://phenocam.nau.edu/webcam/). Ask students to pick a site that interests them and use the pictures and data to describe the phenological patterns of that site and hypothesize what environmental factors influence those patterns (i.e., temperature, rain, sunlight, day length). Then ask students to predict how climate change could impact those factors and the phenological patterns.
2. Mini Data Jam: Have students summarize one of the data trends shown on one of graphs from the lesson or from the PhenoCam website. Then challenge them to complete a Mini Data Jam based on the instructions in this video.

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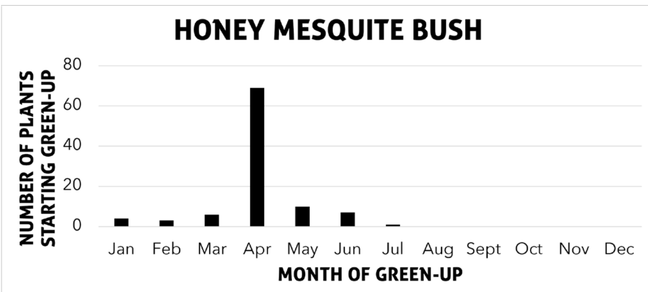
Name: ______________________ Date: ______________ Period: __________

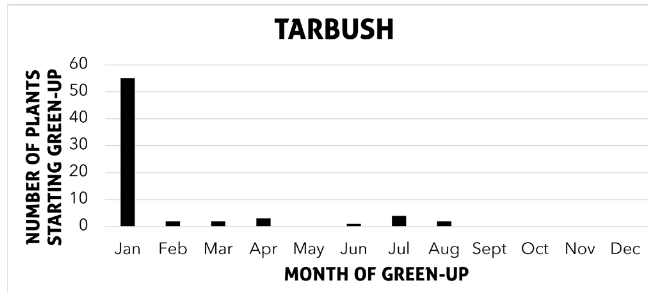
A Desert Phenology Lesson

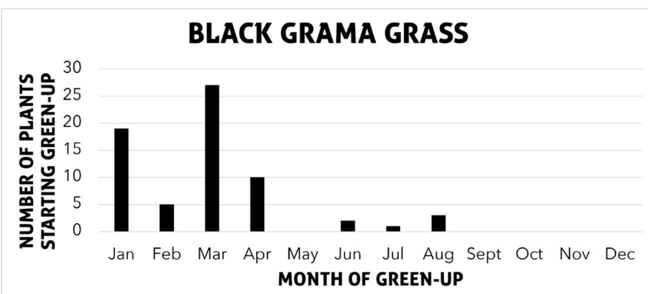
WHEN IS THE GRASS GREENER?

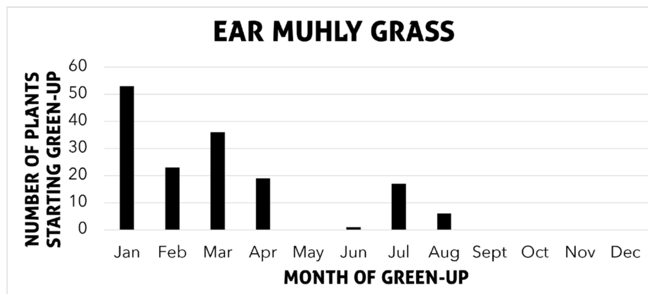
PHENOLOGY:
The study of seasonal patterns in plants and animals and their timing.

1. These graphs show how many plants greened up each month during the study. Briefly describe the phenology of each plant below.









Honey Mesquite Bush:

Tarbush:

Black Grama Grass:

Ear Muhly Grass:

2. What is the difference between the phenology of the bushes (honey mesquite bush and tarbush) and the grasses (black grama grass and ear muhly grass)?

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3. Based on the diagram of plant roots, and the game you played, explain how plant roots affect phenology.

4. If climate change leads to more drought and less frequent rainfall in the southwest, which plants will be most affected?

5. Read the scenarios below and apply what you know about phenology, climate change and desert plants to predict how each person will be affected by climate change.

    a. Freddy is a rancher whose cows graze on desert grasses. If there isn't enough grass, Freddy must bring in hay or supplemental food to ensure his cows stay healthy. Based on what you know about the phenology of grasses, how will Freddy be impacted by climate change? How can Freddy adapt to climate change or solve the problem it is causing?

    b. Mariana walks to school every day. Next to the school is a large area with no buildings. On windy days, lots of dust is picked up off the ground from this area and gets in her eyes, mouth, and hair. Mariana has noticed that when grass is growing, there is less bare ground and the grass seems to hold onto the soil. Based on what you know about phenology, how will Mariana's walk to school be impacted by climate change? How can Mariana adapt to climate change or solve the problem it is causing?

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Seasonal SAWTOOTH PATTERNS in the CARBON CYCLE

A Phenology and Climate Lesson for 9th-12th Grade Students

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SEASONAL SAWTOOTH PATTERNS IN THE CARBON CYCLE

A Phenology and Climate Lesson for 9th-12th Grade Students

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A Phenology and SEASONAL SAWTOOTH PATTERNS IN THE CARBON CYCLE *Climate Lesson*

Seasonal Sawtooth Patterns in the Carbon Cycle

DESCRIPTION

Students compare atmospheric carbon dioxide levels and plant phenology (or seasonal "greenness") data to determine why atmospheric carbon dioxide levels follow a sawtooth trend and how that contributes to a feedback loop.

PHENOMENON

What causes the sawtooth pattern in the carbon dioxide graph?

GRADE LEVEL
9-12

OBJECTIVES

Students will:

- identify the correlation between seasonal cycles in atmospheric carbon levels and photosynthetic activity.

TIME
45 MINUTES

NEXT GENERATION SCIENCE STANDARDS

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data	ESS2.A: Earth Materials and Systems	Scale, Proportion, and Quantity
Engaging in Argument from Evidence	ESS2.D: Weather and Climate	Stability and Change
Constructing Explanations and Designing Solutions	ESS2.E: Biogeology	

BACKGROUND

Since the Industrial Revolution, average atmospheric carbon dioxide (CO_2) levels have steadily increased. However, if you look closely at the data, you'll notice a repeating annual pattern: CO_2 levels drop slightly during the spring and summer, then rise sharply in the fall and winter. This "sawtooth" pattern appears in measurements from around the world, but it is especially clear in long-term data collected at the Mauna Loa Observatory in Hawaii (NOAA).

This seasonal pattern is mostly due to photosynthesis in the Northern Hemisphere, which has most of Earth's landmass. Plants in the Northern Hemisphere absorb large amounts of CO_2 during their growing season in spring and summer. As plants grow leaves and actively photosynthesize, they take in CO_2 from the atmosphere. In the fall and winter, when many plants lose their leaves and photosynthesis slows down, CO_2 levels begin to rise again.

Phenology is the study of seasonal changes in plants and animals, such as when trees grow leaves, flowers bloom, or birds migrate. These changes are triggered by environmental factors such as temperature, rainfall, and daylight hours.

Tracking these changes over time helps scientists understand how ecosystems respond to climate and weather patterns. For example, researchers monitor plants using regular observations or time-lapse photography, sometimes over many years. A network of cameras called Phenocams does this automatically by taking repeated images of the same plants or landscapes. The cameras calculate a "greenness" index from each image, which reflects how actively plants are photosynthesizing. You can explore live Phenocam data and images here: Phenocam Network

By comparing Phenocam and CO_2 data, you can see a correlation between carbon dioxide levels and photosynthesis. When Phenocam images

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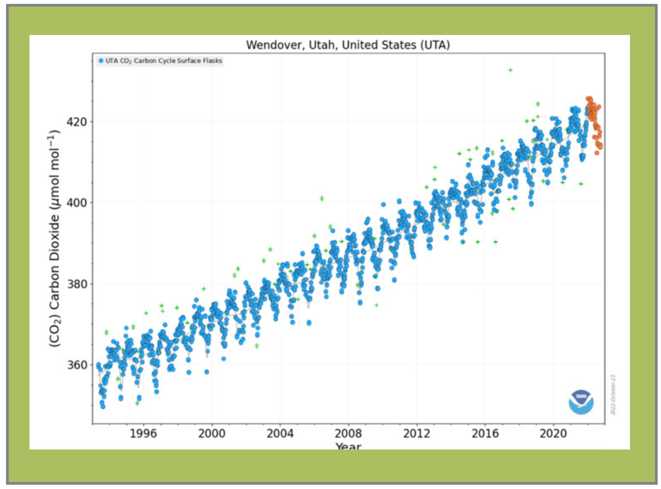
show greener vegetation, it indicates that plants are photosynthesizing and removing CO_2 from the atmosphere, and the evidence of this can be seen in the CO_2 data. In contrast, browner images suggest less photosynthesis and higher CO_2 buildup in the atmosphere. Examining this connection between plant activity and CO_2 levels will help students visualize how Earth's natural systems influence atmospheric gases.

PREPARATION

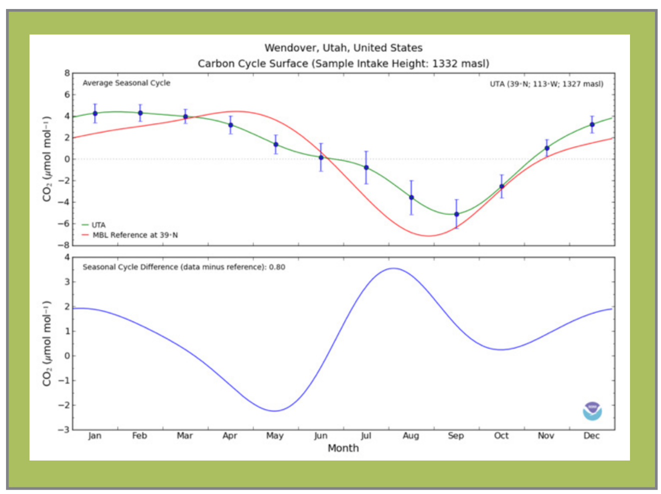
1. Optional: If you would like to use data from a site closer to you, replace the graph on Slides 4 and 5 with data from a local site. Use this NOAA site to find a nearby atmospheric carbon monitoring station and pull up the data, using the instructions below. Save the graph and use it to replace the graph on slide 4.
2. Optional: Replace the graph on Slide 3 of atmospheric CO_2 recorded at Mauna Loa with the most recent graph found here. These graphs are updated weekly and will always show the data from the previous year. The graph in the slides is from January 2024 to January 2025.
3. If your students do not have access to computers or you have limited time, you can skip the instructions on slides 11-14 and instead show students graphs of your choosing. If using the provided graphs on Slides 4 and 5 from Wendover, Utah, use the phenology graph on Slide 21 from Onaqui, Utah. Slides 22-24 have graphs from other locations you can use.

PROCEDURES

1. **Slide 2:** Show students the atmospheric carbon dioxide (CO_2) graph from Mauna Loa, Hawaii. The National Oceanic and Atmospheric Administration (NOAA) measures the amount of carbon dioxide in the atmosphere from the top of the Mauna Loa volcano in Hawaii. Because Mauna Loa is in the middle of the Pacific Ocean, away from large cities, the carbon dioxide levels there give a clear picture of changes in the atmosphere. NOAA releases updated graphs frequently; visit https://gml.noaa.gov/ccgg/trends/mlo.html for the most recent graph.
    a. Ask students to summarize the trends in the graph.
        i. CO_2 in the atmosphere is increasing. This is largely due to the burning of fossil fuels. CO_2 is one of the most common greenhouse gasses contributing to climate change. You can explore this phenomenon in other lessons in Climate Change and the Carbon Cycle, and Insulating You, Insulating Earth.
        ii. CO_2 goes up and down every year. When we see this pattern on a graph, we call it a sawtooth pattern.
    b. Point out the sawtooth pattern and brainstorm ideas about what might cause it.
2. **Slide 3:** Zoom in on one year. We hear a lot about rising CO_2 levels, but why does atmospheric CO_2 vary in such a predictable pattern during one year? Why does atmospheric CO_2 decrease between June and September? Note: You can visit https://gml.noaa.gov/ccgg/trends/weekly.html for the most recent graph.



3. **Slide 4:** Show students a CO_2 graph from a local CO_2 monitoring station; the instructions for finding these graphs are below. Or you can use the example from Wendover, Utah, which is already in the slides. Note the sawtooth pattern is still present in a more local dataset, and it looks a lot like the graph from Mauna Loa.



4. **Slide 5:** Use the seasonal patterns graph to determine which months have maximum and minimum CO_2. The green line is the CO_2 level for the location you choose. The key identifies the green line with the points and error bars with a 3-letter code associated with that site (UTA= Utah). The red line (with no points and error bars) is the Marine Boundary Layer (MLB), a reference line from an ocean site at the same latitude. Marine sites are

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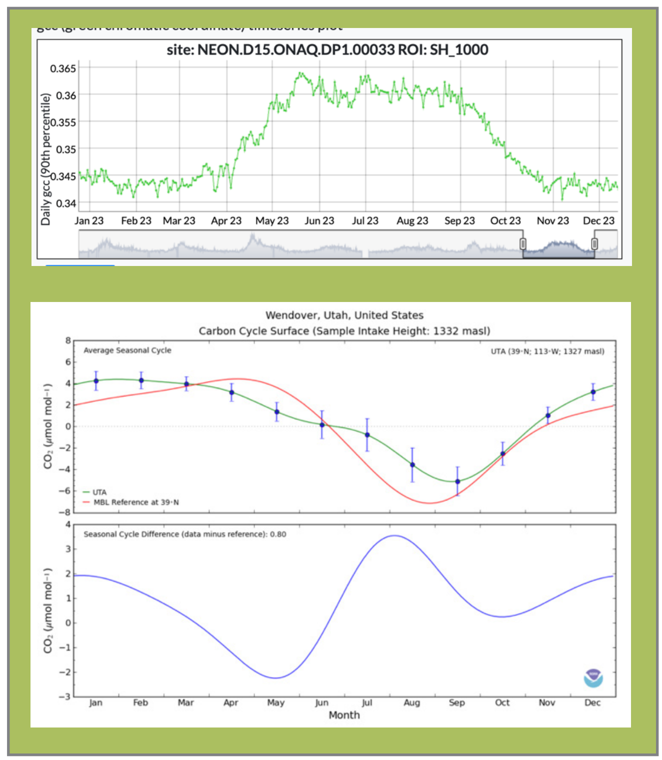
generally far from major carbon sources and sinks, so therefore serve as a more globalized reference. The bottom graph shows the difference between the red and green lines and can be ignored for the sake of this activity. Use the months along the bottom axis to help answer questions using the green line with the points on it from the top graph.

  a. As a class, answer question 1 on the worksheet and have students sketch the seasonal cycle graph on question 2 using the points on the green line on the graph for both questions.

5. **Slide 6:** Show students this diagram of the carbon reservoirs and discuss where carbon goes when it leaves the atmosphere.
   a. Ocean via gas exchange and photosynthesis by phytoplankton
   b. Biosphere via photosynthesis by plants
   c. Ask students if either of these could be responsible for the drop in CO_2 in the summer? [More photosynthesis is happening during summer months than during winter months.]
6. **Slide 7:** Remind students what is happening during photosynthesis. Plants break apart CO_2 removed from the air and water to create glucose and oxygen.
7. **Slide 8:** The biosphere is doing a lot more photosynthesis in the summer than in the winter, as you can see in these photos taken between March and November 2022 near Sedona, Arizona (shown in the map on the upper right of the slide). Therefore, plants are pulling more CO_2 out of the air during summer months. Note that the southern hemisphere summer is during the northern hemisphere winter. However, the seasonal pattern is visible in the global data because the majority of land covered in plants is in the northern hemisphere. **Phenology is the study of seasonal patterns in living things.**
8. **Slide 9:** A Phenocam is an internet-connected camera that scientists use to monitor plant greenness over time. Phenocams are operated by a network of scientists around the world and coordinated by scientists at Northern Arizona University. A Phenocam takes images on a regular basis, and each image is analyzed to calculate the number and intensity of green pixels in the photo. The graph shows the greenness of images from the Phenocam near Sedona, Arizona. Note the seasonal rise and fall of greenness. Remind students that plants are green because they are full of chloroplasts, which is where the plant converts CO_2 to glucose.
9. **Slide 10:** The graph in the previous slide is showing a value called Green Chromatic Coordinate (GCC) for each picture taken by the Phenocam. This value is calculated based on how green each pixel in the image is. We are using the GCC as a proxy for when plants have more or less photosynthetic capacity
10. **Slide 11:** Show students the Phenocam webpage (https://phenocam.nau.edu).
    a. Click on the map menu at the top of the page.
    b. Click the layer button to add state borders.
    c. Green dots represent active Phenocams. Click on a dot to see the most recent picture.
    d. Click on a picture to access all data from the camera.
11. **Slide 12:** Once on the camera's page, use the ROI button to see the graph of the GCC or "greenness" data. You can also use the Browse Images button to see all the images from the Phenocam.
12. **Slide 13:** Use the slider at the bottom of the graph to zoom in on one year, as demonstrated in the video. Move the first slider to Jan (year) and the second slider to Dec (same year). This will probably be the hardest part for students so demonstrate carefully. Note that the number after the month is the year, not the day.



13. **Slide 14:** Give students time to explore the Phenocam website to look for nearby Phenocams. Instructions are on the worksheet. Students will use the local CO_2 graph you showed them earlier and nearby Phenocams, and then answer questions 3-6. If students don't have computers, or time is limited, the teacher can pull up local Phenocam data to examine in groups or as a class. For advanced classes or classes with ample time, see the extension below in which students choose their own CO_2 monitoring site also.

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14. **Slide 15:** Climate change will have many impacts, and they will vary across the globe. In the Southwest, climate change is expected to cause more frequent and extreme droughts and more forest fires because as temperatures rise, evapotranspiration (the combined effect of evaporation and transpiration in plants) increases, drying out the air and soil, all of which could limit plant growth and photosynthesis. Using what you know about phenology and carbon dioxide, how will higher temperatures affect carbon dioxide levels in the atmosphere?
    a. More CO_2 will lead to increasing temperatures.
15. **Slide 16:** Increasing CO_2 leads to higher global temperatures.
16. **Slide 17:** This leads to higher evapotranspiration. Unless precipitation also increases, this will lead to drier air and soil.
17. **Slide 18:** Drier air and soil can lead to plant stress, reducing plants' ability to photosynthesize, which leads to even more CO_2 in the atmosphere because less is taken up by plants. Rising carbon dioxide levels can create a positive feedback loop, leading to even higher CO_2 levels in the future.
    a. A positive feedback loop is a scenario in which cascading events lead to a less stable system, as opposed to a negative feedback loop, which reinforces a stable system.
    b. In this case, the higher CO_2 levels lead to a series of events that continue to increase CO_2 levels, creating instability and change in the system. A positive feedback loop does not necessarily lead to a positive outcome.
    c. Have students answer question 7 on their worksheet.
18. **Slide 19:** Give students time to discuss and answer questions 8 and 9 on their worksheets. If time allows, ask groups to share their answers and reasoning.
    a. Question 8: A wildfire that kills a large number of plants will increase atmospheric carbon dioxide in two ways. The first is all the carbon dioxide released as the plants burn. After the fire, the lack of plants means that carbon dioxide is not being removed from the atmosphere through photosynthesis. So local CO_2 levels will be higher until the plant life recovers.
    b. Question 9: Students may argue that 100 trees will be a large increase in local photosynthesis, especially over the life of the trees. They may also argue that 100 trees will have only a small impact globally.
19. **Slide 20:** This graph shows Phenocam data from a research station in Sweden, close to the Arctic Circle. Note that 2021 and 2022 had higher peak greenness than usual. What could be causing this? Warmer temperatures in the far north are leading to more plant growth, when cold temperatures were a limiting factor in the past.
    a. How could this impact photosynthesis and atmospheric CO_2 levels? Have students answer question 10 on their worksheet and discuss.
    b. Places that were too cold for much plant growth could become more vegetated, increasing photosynthesis in those regions. These regions could turn from a carbon source, emitting more CO_2 than they take in, to a carbon sink, absorbing more CO_2 through photosynthesis than they emit.
    c. In this location, we MAY actually see rising CO_2 trigger a LOCAL negative feedback loop, because higher CO_2 levels lead to more photosynthesis, which could actually lower CO_2 locally. However, at some point, continuous increasing CO_2 would reach a tipping point and start having negative effects on photosynthesis. We would need local CO_2 data to back this up.

EXTENSIONS

1. Rather than having students find Phenocams near the CO_2 monitor you show, you can have students choose their own monitoring station and Phenocam to answer questions 1-7.
2. Look at the extra graphs on slides 22-24 and discuss the differences in these graphs and others you have viewed.

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INSTRUCTIONS FOR FINDING LOCAL CARBON DIOXIDE LEVELS
NOAA INTERACTIVE ATMOSPHERIC DATA VISUALIZATION (IADV)

1. Open this website if it is not already open: https://gml.noaa.gov/dv/iadv/
2. Use the "+" symbol to zoom in on the area.
3. Hover over and then click on the **red** dot that is closest to where you live. Red dots indicate active sites.
   a. Ensure that the name of the sampling location that you would like to use (closest to where you live) is listed in the first drop down menu at the top of the page.
4. In the drop down menus near the top of the page:
   a. Find programs, and choose "Carbon Cycle Gases."
   b. Leave the other two drop down menus on their default settings.
      i. Popup detail: "Full"
      ii. Active Sites: "All Sites"
5. In the right side bar, click on the "Carbon Cycle Gases" button.
   a. Two or more plot types will appear.
      i. Click on "Time Series."
      ii. Save this graph and use it to replace the graph on slide 4.
6. In the right side bar, click on the "Seasonal Patterns" button.
   a. Hit Submit.
   b. Save this graph and use it to replace the graph on slide 5.

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