Smithsonian

SCIENCE *for Global Goals*

CLIMATE ACTION!

Part 3:

Energy and Climate

SUSTAINABLE DEVELOPMENT GOALS

developed by

Smithsonian Science Education Center

in collaboration with

iap SCIENCE HEALTH POLICY

the interacademy partnership

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PART 3: ENERGY AND CLIMATE

Find out More!

For additional resources and activities, please visit the *Climate Action!* StoryMap at bit.ly/CLIMATEACTION2030.

Planner

Activity	Description	Materials and Technology	Additional Materials	Approximate Timing	Page Number
Task 1: How do humans understand energy elements in the atmosphere?					
Discover	Learn how humans express their current understanding about energy in Earth's system.	• Paper • Pen or pencil		30 minutes	80
Understand	Model energy within Earth's system.	• 20–50 balls, rolled-up socks, or crumpled pieces of paper or aluminum foil • 2 baskets or buckets • Watch or timer • Colored tape (optional)		40 minutes	85
Act	Communicate about energy elements in Earth's system to people in your community.	• Paper • Pen or pencil		40 minutes	91
Task 2: How do changes in the atmosphere affect Earth's energy in the system?					
Discover	Understand the natural and human additions of greenhouse gases into the system.	• Pen or pencil • Paper • Bottle with cap or lid • Thermometer • Watch or timer		60 minutes	93
Understand	Model how greenhouse gas additions and removals affect Earth's energy system.	• Pen or pencil • Paper • Game cards • 2 dice • 50 small objects, such as rocks, marbles, or cotton balls		40 minutes	100
Act	Identify where you can research greenhouse gas additions in your community.	• Pen or pencil • Paper • Paper or digital maps of your local area		60 minutes	111

Meet Your Research Mentor, Marcus Johnson, PhD

Meet Dr. Marcus Johnson. Marcus (pronounced MAHR-kuhs) will be your research mentor to help you learn more about the connections between energy and climate.

Marcus is the project manager of the NASA Advanced Capabilities for Emergency Response Operations (ACERO) project. He focuses on the improving **wildland fire** management by modernizing aviation operations. Marcus has a keen interest in exploring new technologies, particularly artificial intelligence. He prefers hands-on experimentation over simply observing. He is also trained as a Type 2 Wildland Firefighter and has a drone pilot license. This approach of blending personal interest with professional development allows Marcus to continually find value in learning new skills, enriching both his personal and professional life. Since Marcus is now working with you, it is important to understand who he is.

Marcus's Identity Map

- Interested in machine learning
- African American / Italian
- 38-year-old male
- Father
- Likes to tinker with robotics
- Comes from a big family
- Ph.D. from University of Florida in aerospace engineering

- Project manager
- Black hair, brown eyes, and tanned skin
- Plays soccer
- Drone pilot
- Has two sons and a daughter
- Big reader (fantasy and science fiction)
- Loves immersing himself in problems to find solutions

Task 1: How do humans understand energy elements in the atmosphere?

Earth's energy system is like a big bank account that keeps track of all the energy transactions happening between three important players: the sun, Earth, and gases in the atmosphere. Every day, the sun makes generous energy deposits in the bank of Earth, in the form of sunlight. Earth receives the sun's energy and distributes it in different ways. Some energy is reflected directly back into space and plays no further part in the Earth's energy system. Some energy is absorbed by land, water, and plants, which then redistribute the sun's energy as heat.

There are gases in the atmosphere, such as **carbon dioxide** and **methane**, that trap some of the heat energy as it tries to make its way back to space and send the heat back to Earth. They act like a cozy blanket around Earth. This is what keeps our planet warm. But if we have too many gases in the atmosphere, they can trap more and more heat energy, making the blanket too thick. This could cause Earth to get too hot. Understanding this energy system helps people learn about our climate and how to keep it in balance.

In this part, you will discover, understand, and take action to understand the complex energy relationships of the Earth, sun, and atmosphere system.

Before you begin the rest of Part 3, think quietly to yourself about Marcus's identity map and compare it to your *Identity Map*.

- Are there things you have in common with Marcus?
- Are there ways in which you are different from Marcus?
- Can you see anything about Marcus's identity that relates to understanding climate action?

Throughout Part 3 you will notice Marcus sharing ideas and experiences with you. He may help you understand better ways to do your research or share some of the research he has done.

In this task you will first ***discover*** more about how people *express* elements about energy data in the Earth system. You will then ***understand*** how changing gases in the atmosphere can affect energy in the system. Finally, you will ***act*** by creating a form of expression about the energy exchange between the sun, Earth, and gases in the atmosphere.

Discover: *How do humans express their current understanding about energy in Earth's system?*

1. Examine the images shown in Figures 3.1 and 3.2 and discuss the questions for each.

Figure 3.1: Painting 1—Tree Line Migration.

Part 3 Task 1

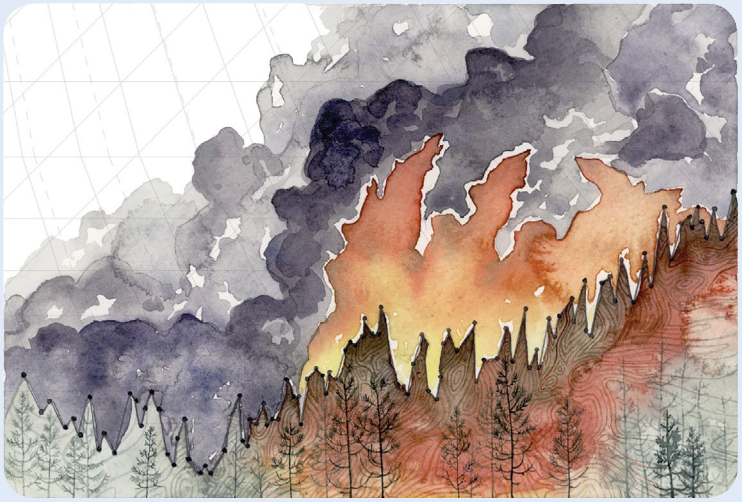


Figure 3.2: Painting 2—Increasing Forest Fire Activity.

For each, painting discuss:

a. Emotion: How does the artwork make you feel?
b. Composition: What elements does the artist use in the painting?
c. Color: What colors are used? Is there an emphasis on certain colors?
d. Light: Where is the light focused in the painting?
e. Line: What kinds of lines are used in the painting? Where do they lead your eye?
f. Rhythm: Is there any repetition in the painting? Where?
g. Balance: How is the painting arranged? Are all sides equally filled up?
h. Perspective: Where is the observer positioned in the painting? Where would the onlooker have to be standing to see it this way?
i. What do you think might have inspired this artwork?
j. Why do you think the artist chose to depict this moment in time?

Read the artist's explanations of each piece.

Painting 1—Tree Line Migration

This painting is the fifth and final painting in a series depicting how Norway spruce and other trees may shift **habitat zones** as the climate changes rapidly today. The lower portion shows a dense forest of spruce—they stop growing on the mountainside at the tree line (the edge of their habitat.) I chose to make this line a graph of global atmospheric temperature data from 1880 to 2020. Above this line there may be a few trees. These are usually very old and worn-looking (krummholz) and are typically clonal trees, growing from an old root system that has birthed trees for hundreds or even many thousands of years. They persist from times when perhaps the tree line was higher under a different climate—living proof of the resilience of species like Norway spruce. As temperatures warm and precipitation zones shift, species like the spruce will have to migrate or adapt to the new conditions. One response may be growing at higher elevations and latitudes.

—Jill Pelto, watercolor and colored pencil, 2021

Painting 2—Increasing Forest Fire Activity

Increasing Forest Fire Activity uses global temperature rise data from 1880 to 2015. Fortunately, I was not near any of the massive forest fires that raged before, during, and after my two weeks in Washington in the summer 2015, but I was greeted with many smoke-filled days. On some days, when the winds blew from the fire toward us, the smell and taste of the smoke overpowered my senses, even though the fire was about 100 miles away. As temperatures increase, and drought and drier than average conditions persist, forest fires become a huge threat to the forest, plants, animals—and of course, to people and structures.

—Jill Pelto, watercolor and colored pencil, 2015

2. Examine the global temperature and solar activity data shown in Figure 3.3. Jill used these data when she was creating her paintings. The red line represents changes in the global average temperature of Earth from 1880 to 2020. The units are in degrees (positive or negative) from the historical average.

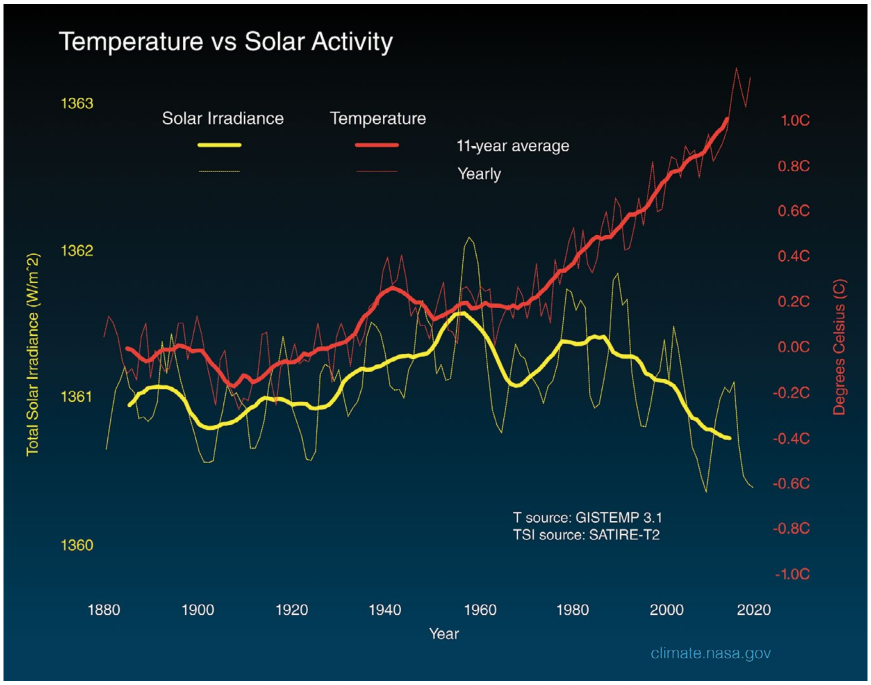


Figure 3.3: Temperature and solar activity from 1880 to 2020.[1]

3. Compare the red line on the graph with the two paintings. How was the temperature data incorporated into each of the paintings in different ways?
4. Discuss with your team:
   a. How has the global average temperature changed between 1880 and 2020?
   b. How does knowing the data that inspired these artworks make you think about them differently?
   c. How have the paintings captured some of the possible different effects of this global temperature change?
5. Read *Solar Irradiance*.

Solar Irradiance

Solar irradiance is the total amount of energy emitted by the sun, as measured on Earth. It's like measuring how much energy is shining down on us from the sun every day. When you stand outside on a sunny day, you can feel the warmth and see everything clearly because of the sun's energy. Solar irradiance is a way for scientists to measure and understand how much of that energy is reaching Earth at a specific time.

Part 3 Task 1

All the energy that we need to survive comes from the sun. This energy drives many systems on Earth, including:

- Weather
- Seasons
- Plant growth
- Food
- Renewable energy
- Climatem

Understanding solar irradiance is important because it helps us understand how the sun's energy affects our planet and our daily lives. By knowing the solar irradiance at different times, scientists can understand how much energy the sun is sharing with us, and how that is changing over time.

6. Look at the yellow line in the graph in Figure 3.3, which shows solar irradiance from 1880 to 2020. This line shows how much energy is reaching Earth. When the line is higher, more energy was emitted by the sun. When it is lower, less energy was emitted by the sun.
7. Discuss with your team:
    a. Do you notice any patterns in the yearly or average solar irradiance over time? If so, describe them.
    b. How does yearly or average solar irradiance compare to global temperature between 1880 and 2020?
    c. Do they follow similar or different patterns? If the sun's energy (irradiance) is dropping, why might Earth's temperature be increasing?
8. Read Marcus's thoughts about Earth warming that was shown in the data on the graph.

Marcus says . . .

Climate change affects everyone globally, with Earth warming at an unprecedented rate. This is leading to more frequent and severe **natural disasters** like wildfires, showcasing the dire effects of human-caused **global warming**. It's crucial for everyone to grasp how our actions influence the atmosphere and climate, use data to better understand the changing climate's impact on our ecosystems—such as wildlife, water, and food sources—and take steps to lessen climate change effects.

Specifically, in the United States, a mix of longer fire seasons, human-induced climate effects, and the growing overlap between wildland vegetation and human communities has made fires more common and larger. This escalation results in more significant adverse effects on the economy through the loss of structures and communities; public health issues, including loss of life, air pollution, and contamination of water and soil; as well as shifts in ecosystems—highlighting the urgent need for action against climate change.

Part 3 Task 1

Understand: *How do humans model energy within Earth's system?*

Imagine Earth's energy system as a big game of hot potato. Hot potato is a game where you toss away an object as soon as possible after it reaches you. The sun is like the player who starts the game by throwing a glowing ball of energy toward Earth. When Earth catches this energy ball, it warms up like a hot potato. But Earth can't hold onto all that heat energy for too long, so it tosses some of it back out into space. But that energy must travel through the atmosphere to get to space.

Some gases in the atmosphere can act like a team of players trying to catch the hot potato and keep some of that energy near Earth, before it can go into space. If they *catch* the potato, the heat energy warms the atmosphere that wraps around Earth. Just like when you wrap yourself in a warm blanket on a chilly day, the atmosphere holds onto this energy. Understanding this energy flow between the sun, Earth, and atmosphere will help us work toward maintaining the right balance of warmth for our planet.

1. Read *Modeling Earth's Energy System Game* and follow the instructions to play the game.

Modeling Earth's Energy System Game

Number of People

This game should include all your team and works best with four or more participants.

Space

You'll need enough space to form two long lines arms-length apart, with a large gap between them. You may need to be outside for the full game.

Equipment

- Balls or rolled-up socks or crumpled-up pieces of paper or aluminum foil (20–50, depending on the size of the team playing)
- 2 baskets or buckets
- Watch or timer
- Colored tape (optional)

Setup

Figures 3.4, 3.5, 3.6, and 3.7 show how the game is set up at different stages.

a. Organize one-quarter of the team members to stand in a line shoulder to shoulder. This line will represent the surface of a part of Earth.
   - Optional: Use tape to make a line that team members cannot cross.

b. Organize another one-quarter of the team to form a line shoulder to shoulder facing the first line, standing about an arm's length apart. This should leave a few meters of space between the two lines. This second line will represent the surface of the sun.
   - Optional: Use tape to create a line that these team members also cannot cross.

c. Put all the balls in one bucket or basket and place it in the middle of the sun team.

d. Explain that the balls represent solar irradiance.

Part 3 Task 1

e. Organize another one-quarter of the team to stand in the space between the two lines. This third line will represent the gases in Earth's atmosphere. You should now be set up as shown in Figure 3.4.

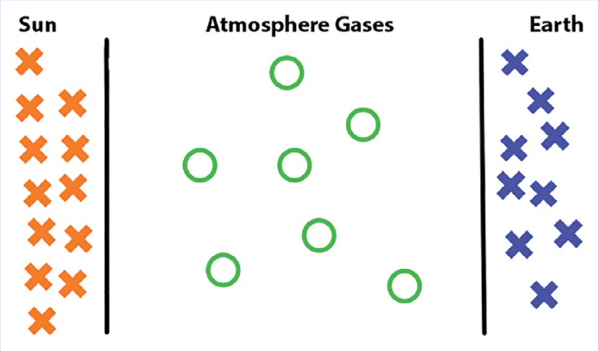


Figure 3.4: Setup for the first round.

f. Place the empty bucket or basket in the center of the atmosphere gases.

g. Organize the final quarter of the team to stand on the side as observers and to gather balls for the first round.

Play the Game

a. Team members in the sun line start with all the balls of energy.

b. The game begins when the sun line throws their energy balls (solar irradiance) to the team members in the Earth line, as shown in Figure 3.5. To start, each person will throw one ball.

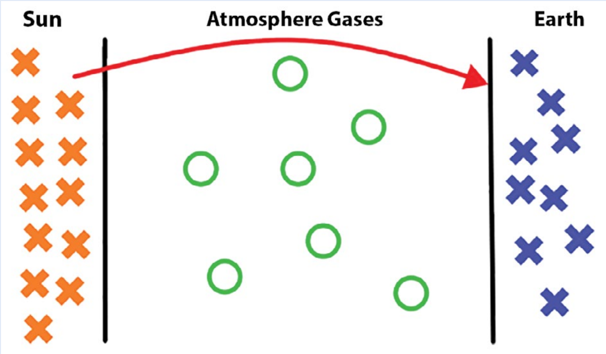


Figure 3.5: In the first round, the sun line throws their energy balls to the Earth line.

c. The atmosphere gases team members standing in between the two lines will NOT attempt to catch or intercept the energy balls (solar irradiance) when they are traveling from the sun to Earth.

Part 3 Task 1

d. The team members in the Earth line will catch the balls and immediately try to throw the balls back toward the sun. This time, when the Earth team throws the balls, the atmosphere gas team members in between WILL try to intercept the balls. Any ball that is even touched by an atmosphere gas team member will be considered intercepted. The intercepted balls will be gathered in the empty basket in the center.

- The balls thrown by the Earth line should be thrown underhand, or in a way that the balls are not thrown far over the heads of the atmosphere gas team.
- The balls should immediately be thrown back after being caught by players on the Earth or sun line. They cannot be held for extended periods of time.

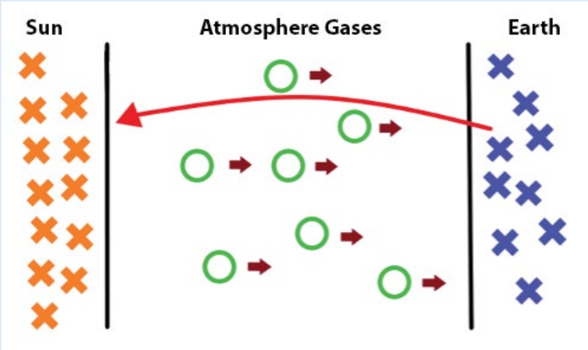


Figure 3.6: The atmosphere gases players focus on the balls coming from the Earth line and only attempt to block balls coming from that side.

e. Balls that make it back to a person in the sun line will be thrown back to Earth, but not intercepted by the atmosphere gases (see Figure 3.6), and the game continues.
f. Set a watch or timer for two minutes.
g. Start the round.
h. Game play continues until the time expires or all the balls are intercepted—whichever comes first. If all the balls are intercepted, record the time length of the round.
i. At the end of the round, count the number of balls intercepted or the time it took to intercept all the balls.
j. Repeat this same setup for a total of three trials. Rotate roles to ensure every team member has a chance to play each role.
k. Average the total number of balls intercepted and the time of the round from the three trials.

Part 3 Task 1

l. Now, add the team members who were observing to the atmosphere gases group (see Figure 3.7) and play one more round. Use the same number of balls and play for the same two minutes. Record these results.

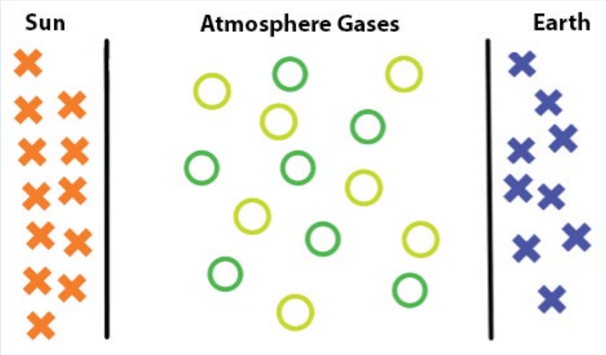


Figure 3.7: More team members acting as atmosphere gases.

m. Run a total of three trials and average the data for this round.
n. You can repeat this game many times, changing other variables one at a time, to see how different setups affect the data you collect.

Alternate Setup: People Act as Energy

a. Organize most of the team into one horizontal line, standing shoulder to shoulder. These players represent energy leaving Earth's atmosphere.
b. Pick a few team members to represent atmospheric gasses. They will stand a few meters in front of the energy line, facing them. The space between them represents the atmosphere. The space behind them represents outside Earth's atmosphere.
c. The goal of the players' representing energy is to move across the atmosphere to the other side, outside the Earth's atmosphere.
d. To begin, team members standing in the energy line will run across the atmosphere as the gasses attempt to tag them. Tagged team members will raise one hand and walk to a designated "out" zone. Count and record the number of players out in this round.
e. After a brief rest period, reorganize team members back to the original line. This time however, double the number of team members acting as gasses. Play the game again, counting and recording the number of students who were tagged out.

Part 3 Task 1

2. Using the data you collected, discuss:
    a. How did the number of energy units or the time it took to collect them all change across the different rounds?
    b. If the energy units represented heat or temperature, which atmosphere (more atmosphere gases or less) would you predict to get warmer faster?
    c. Look again at the graph in Figure 3.3 to answer the following questions.
        - Solar irradiance (yellow line) is comparable to how many energy units the sun players were throwing to the Earth players in the game. On average, how much did the amount of energy from the sun change between 1880 to 2020?
        - Temperature is comparable to the amount of energy units the atmosphere gases collected during the game. Using the graph and the models you just ran, what years on the graph would you predict to show higher gas levels in the atmosphere?
3. Read Marcus's thoughts about gases added to the atmosphere from wildfires. Think about the team members who acted as gases in the game as you read. What are some ways humans add gases to the atmosphere?

Marcus says . . .

Wildfires emit gases and **particulates** into the atmosphere, which have a negative impact on the climate. Many of the wildfires, at least I could say within the United States, are human-caused. We start the fire, whether intentionally or not. I think I've seen some statistics all the way up to, like, 85 percent to 90 percent of the fires started in the US are by humans or some human activity.

Fires are a natural part of ecosystems, so it's not a bad thing that we have wildfires. We don't want to try to put out all wildfires. That's not really the goal. There's always going to be emissions of gases into the atmosphere from wildfires, so it's good to some extent. But it's not good when these fires become very large. They grow very intensely, adding radiative heat and gases into the atmosphere.

Part 3 Task 1

Act: *How can you communicate about energy in Earth's system to people in your community?*

Understanding energy changes in Earth's system can be complex or new to many people. Luckily, humans can help each other understand complex elements and relationships in the system in many unique ways. Imagine all the different ways humans communicate with each other to understand something complex or new. Developing ways to communicate about elements and relationships in Earth's energy system can help build relationships with other people in your community.

1. Look again at the graph in Figure 3.3.
2. Think about the different elements and relationships in the *Modeling Earth's Energy System Game* in the Understand activity.
3. Look at Jill's paintings in Figures 3.1 and 3.2.
4. Think about how you could use this data or what you learned in your game to communicate something about Earth's energy system, like Jill did. Consider the following:
    a. What form of expression could you use? Use the examples from Part 2, task 2 as needed.
    b. How will you incorporate elements of the graph into your form of expression?
    c. How could you incorporate the sun, Earth, energy, or the atmosphere into your form of expression?
    d. How could you incorporate elements of the *Modeling Earth's Energy System Game* into your form of expression?
    e. How could you incorporate different perspectives (social, environmental, economic, ethical)? For example, Jill included environmental elements such as mountains, trees, wildfire, and temperature data in her paintings.

f. Think about the different things on Earth that are affected by the sun and temperature. How could you incorporate these elements in your form of expression? For example:
   - Weather
   - Seasons
   - Plant growth
   - Food
   - Renewable energy
   - Climate
5. Use a piece of paper or a class board to make some notes or sketches of your different ideas.
6. Read what Marcus says about how he thinks about communication in his work and how he manages conflicts on a team.

Marcus says . . .

I often find that clear communication and listening are keys to effective collaboration. And understanding that communication styles are different for each individual, so you are making sure you are leveraging different ways to communicate and listen to your teammates (group meetings, one-on-one meetings, emails, instant messages, etc.). When conflict arises between members of the team, I have often used value-based negotiation (that is, I focus on what we've gained rather than who wins or loses) to get to the root of which values are important for each individual and to help the team understand each other's values, so differences in approach can be seen in a different light.

7. Pick one of the ideas that you and your team would like to work on more.
8. Create a more detailed outline of this form of expression.
9. Write a short statement to describe what inspired your form of expression and what it means to the people on your team.
10. Share your outline and statements with other team members, family, and friends.
11. Display them for the community if you're comfortable doing that. Display physically in your school or online.

Task 2: How do changes in the atmosphere affect Earth's energy in the system?

In this task you will first ***discover*** more about natural and human additions of **greenhouse gases** into the atmosphere. You will then ***understand*** how modeling greenhouse gas additions and removals can affect Earth's energy in the system. Finally, you will ***act*** by identifying where in your community you could research local additions and removals into Earth's energy system.

Discover: *What are the natural and human additions of greenhouse gases into the system?*

1. Read *Greenhouse Gases*.

Greenhouse Gases

The atmosphere is composed of different types of gases. These gases, which include oxygen, support human life on Earth. As you learned in task 1, Understand, some of these gases in the atmosphere can trap energy from the sun. When sunlight reaches Earth's surface, it **emits** energy in the form of heat. Some of the heat **radiates** back into space, but certain specific gases in Earth's atmosphere can also absorb some of this heat before it can escape. This natural process, known as the **greenhouse effect**, keeps our planet warm.

If you can, model the greenhouse effect using the setup shown in Figure 3.8. You'll need:

- Glass or plastic bottle
- Bottle cap, lid, or tape
- Thermometer
- Timer

a. Stand the thermometer inside the bottle and place it in a sunny spot.
b. After one hour, check the temperature and write it down.

Part 3 Task 2

c. Put the cap, lid, or a thick piece of tape over the opening of the bottle and leave it for another hour. Check the temperature and compare it with the earlier temperature.

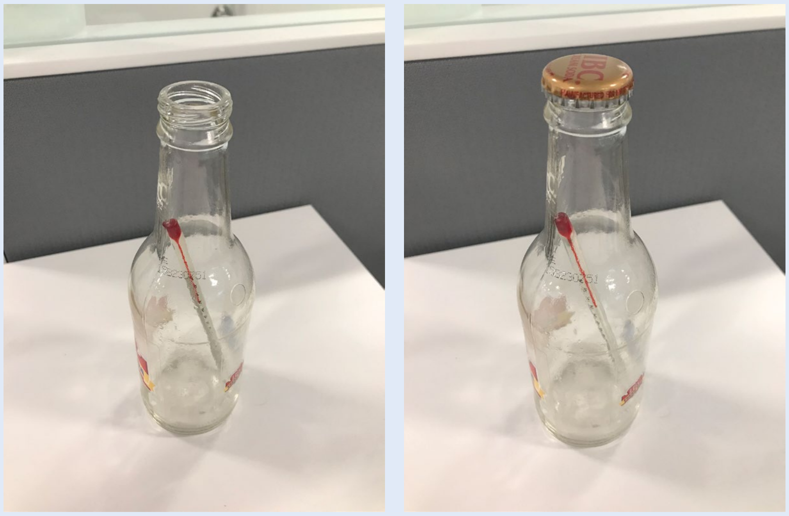


Figure 3.8: Setup for the greenhouse gas model.

The bottle and cap in this model are like the gases in the atmosphere that trap heat. The specific gases in the atmosphere that trap heat are known as greenhouse gases. Greenhouse gases are present in the atmospheric system due to a combination of natural processes and human activities. Some greenhouse gases are put into the system through both natural and human processes, while some are additions only from one or the other.

Natural processes that add greenhouse gases into the system include:

- **Ocean:** The ocean adds greenhouse gases into the atmosphere when tiny organisms break down organic matter. And when the water warms up, it can't hold as much carbon dioxide, so it releases some into the atmosphere.
- **Volcanoes:** Volcanoes add greenhouse gases into the atmosphere when they erupt, emitting carbon dioxide and other gases from Earth's interior and contributing to the natural balance of gases in the atmosphere.
- **Forest fires:** Forest fires add to the release of greenhouse gases into the atmosphere by burning trees and plants, releasing stored carbon dioxide and adding new carbon dioxide when organic matter burns.
- **Wetlands:** Wetlands are areas where the land (soil, rocks, and organic matter) is either permanently or seasonally filled with water. Wetlands add greenhouse

Part 3 Task 2

gases into the atmosphere when bacteria in the waterlogged soil break down organic matter.

- **Permafrost thaw:** Permafrost is a type of land (soil, rocks, and organic matter) that remains frozen for long periods of time, typically hundreds to thousands of years. As temperatures rise, this land can thaw, releasing trapped greenhouse gases from organic matter that has been frozen for thousands of years.

Human activities that add greenhouse gases into the system include:

- **Agriculture:** Agriculture adds greenhouse gases to the atmosphere when activities like fertilizer use and animal digestion release greenhouse gases.
- **Electric power:** Generating electric power adds greenhouse gases to the atmosphere when **fossil fuels** like coal, oil, and natural gas are burned to generate electricity.
- **Transportation:** Transportation adds greenhouse gases to the atmosphere when vehicles like cars, trucks, ships, and planes burn fossil fuels.
- **Industry:** Industry adds greenhouse gases to the atmosphere when factories and manufacturing plants burn fossil fuels or use processes that release gases to make products.
- **Commercial and residential buildings:** In homes and businesses, activities like using electricity, heating, and cooling often rely on fossil fuels, such as coal, oil, and natural gas, which release greenhouse gases when burned.

2. Read Marcus's thoughts about how wildfires add greenhouse gases to the atmosphere and how he uses technology to identify, monitor, and **mitigate** them.

Marcus says . . .

Wildland fires are a natural part of a healthy ecosystem and wildland fire smoke is a rich and complex mixture of greenhouse gases and **aerosols**. The NASA ACERO work uses drone technology to help enable more of the "good fire" through the use of **aerial ignition** for **prescribed burns** (a controlled application of fire to restore health to the ecosystems), which reduces the risk of fires growing to a large scale.

While not always intentional, most wildland fires are caused by human activities. Large-scale wildland fires ("bad fire") can produce a sizable contribution of greenhouse gases and aerosols to the atmosphere. The NASA ACERO technology will help identify, monitor, and mitigate wildland fires to support firefighters' efforts to manage wildland fires.

3. Read *Atmosphere Concentration Activity* and complete the activity.

Atmosphere Concentration Activity

a. Make a prediction:

- Total greenhouse gases: What percentage of the total global greenhouse gases in the atmosphere do you think is added through natural processes? What percentage is added through human activities?
- Natural source greenhouse gas additions: Just focusing on the natural processes, what percentage out of 100 percent do you think each of the following natural sources adds into the system?
  - Ocean
  - Volcanoes
  - Forest fires
  - Wetlands
  - Permafrost thaw
- Human activity greenhouse gas additions: Just focusing on human activity, what percentage out of 100 percent of each of the following human activities do you think is added into the system?
  - Agriculture
  - Electric power
  - Transportation
  - Industry
  - Commercial and residential buildings

b. Using the blank pie charts in Figure 3.9, color in the percentages of your guesses. Each piece represents 1 percent.

c. Create a key below each pie chart.

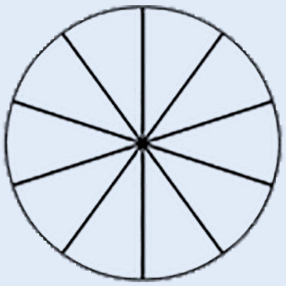
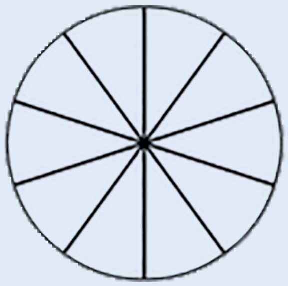
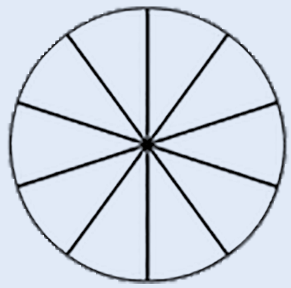
A. Total Global Greenhouse Gases	B. Natural Source Greenhouse Gas Additions	C. Human Activity Greenhouse Gas Additions
 Natural processes= Human processes=	 Ocean= Volcanoes= Forest fires= Wetlands= Permafrost thaw=	Agriculture= Electric power=  Transportation= Industry= Commercial and residential buildings=

Figure 3.9: Pie charts showing your predictions about atmosphere concentration percentages.

d. After everyone has finished their pie charts, share your results with the teams members around you.

   a. Are there any similarities or differences between your predictions and those around you?

   b. Discuss how you made your predictions.

e. Compare your predictions to the actual data.

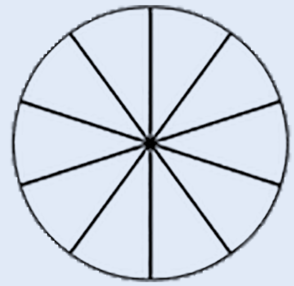
A. Total Global Greenhouse Gases	B. Natural Source Greenhouse Gas Additions	C. Human Activity Greenhouse Gas Additions
Natural processes=45 percent Human processes=55 percent	Ocean=21 percent Volcanoes=3 percent Forest fires=38 percent Wetlands=17 percent Permafrost thaw=21 percent	Agriculture=11 percent Electric power=25 percent  Transportation=28 percent Industry=23 percent Commercial and residential buildings=13 percent

Figure 3.10: Atmosphere concentration data.[2]

4. Discuss:
    a. How did your predictions compare to the actual values?
    b. Are you surprised by any of the actual values?
5. Read about research happening at the Smithsonian Environmental Research Center to better understand greenhouse gas additions from wetlands and how they might change in the future.

At the Smithsonian

Smithsonian scientists are working hard to learn more about coastal ecosystems, such as wetlands, which are areas where the land meets the water. These places are important because they face a lot of changes and challenges in our world today. Genevieve Noyce is a senior scientist studying wetlands at the Smithsonian Environmental Research Center (SERC). She is currently working on a project called GENX.

GENX started in 2021, and is all about studying coastal wetlands. Wetlands are special places because they can both remove and add greenhouse gases into the atmosphere. The project is trying to figure out how much of these greenhouse gases, such as methane, carbon dioxide, and nitrous oxide, are coming out of these wetlands. This study is happening at a place called the Global Change Research Wetland, where scientists have been exploring how these areas might change for more than 30 years.

Figure 3.11: Automatic chambers setup in the Global Change Research Wetland at SERC.

What's cool about GENX is that it uses automatic machines called chambers to catch gas emissions from the wetlands, without needing people to watch them all the time. This means they can collect data when it is night, raining, or even when

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the tide is high, helping scientists understand more about how these conditions affect gas emissions.

GENX also looks at what happens when the soil in wetlands gets warmer, giving us clues about how climate change might make things different. Genevieve named the project after herself, calling it Genevieve's Experiment, or GENX for short, because it's the first big project she's led from the beginning. This project underscores researchers' deep commitment to advancing our understanding of the impact of climate change on wetland ecosystems and finding ways to mitigate those impacts.

***Understand:** How can greenhouse gas additions and removals affect Earth's energy system?*

Understanding how greenhouse gas additions and removals affect Earth's energy system is crucial for our planet's well-being. Greenhouse gases, such as carbon dioxide and methane, trap heat from the sun in our atmosphere, creating a natural greenhouse effect that keeps Earth warm enough to support life. However, human activities, such as burning fossil fuels and **deforestation,** have greatly increased the amounts of these gases. This excess has led to global warming and climate change, affecting weather patterns, sea levels, and ecosystems.

By learning about the ways greenhouse gases influence Earth's energy balance, we can make informed decisions to reduce our impact, mitigate climate change, and create a sustainable future for generations to come.

1. Read *Modeling Greenhouse Gas Additions and Removals Game* and play the game.

Modeling Greenhouse Gas Additions and Removals Game

Number of People

This game can be played by a single person and up to eight players.

Materials

- Natural Additions Cards (Figure 3.12)
- Natural Removals Cards (Figure 3.13)

- Human Additions Cards (Figure 3.14)
- Human Actions Cards (Figure 3.15)
- 2 dice (or you can use a digital two dice roller, or pick numbers written on slips of paper out of a cup or hat)
- 50 of the same small items, such as rocks, marbles, coins, or cotton balls (to represent greenhouse gases)

Setup

a. Print out and cut up one copy of each set of game cards. Or copy them out onto pieces of paper or cardstock.

b. Organize the game cards into the following three stacks.
   - Natural Additions and Natural Removals
   - Human Additions
   - Human Actions

c. The game will be played in three trials. The following cards will be used in each trial.
   - Trial 1: Natural Additions and Natural Removals, shuffled together
   - Trial 2: Natural Additions, Natural Removals, and Human Additions, all shuffled together
   - Trial 3: Natural Additions, Natural Removals, and Human Additions, all shuffled together, plus Human Actions in a separate pile

d. Place five of the small items in the center of a table. These items represent units of greenhouse gases that are currently in the atmosphere.

e. Place the remaining small items in a pile at the side of the table. These represent greenhouse gases that are in the Earth system but are not currently in the atmosphere.

Game Play for Trials 1 and 2

a. Shuffle the appropriate cards for the trial and place them in a stack, face down, next to the five items (greenhouse gases) currently in the atmosphere.

b. Have the first player flip over the top card from the stack. Each card will indicate the following:

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- Additions or Removals card.
  - Natural or Human Additions cards have the possibility of adding greenhouse gases to the atmosphere in the central pile.
  - Natural Removals cards have the possibility of taking greenhouse gases away from the atmosphere in the central pile.
- The number of times the player must roll the two dice together is written on the card.
- The other numbers, if rolled, mean greenhouse gases must be either added or taken away from the central pile.

c. Roll the two dice together the number of times indicated on the card.

- If any of the numbers indicated on the card is rolled one or more times, add or take one greenhouse gas item to the central pile for each time that number came up.
  - For example, if an Additions card indicates three rolls and has the numbers 6, 7, 8 on it, you roll the dice three times. Let's say you get 6, 8, and 11. The numbers 6 and 8 match the numbers on the card, so you add two greenhouse gas items to the central pile. Then your turn is over.
  - If you do not roll any of the numbers on the card, your turn is over and play moves to the next person.

d. The next player flips over the next card in the main stack and follows the directions on that card.

e. Continue playing until one of the following occurs:

- The greenhouse gases in the central pile go down to zero.
- You play through every card in the stack.

f. Count the number of greenhouse gases in the central pile at the end of play, and write down the number.

g. Shuffle the Human Additions cards into the stack and play Trial 2. Write down the data for this trial.

Game Play for Trial 3

Trial 3 follows the same rules as Trials 1 and 2, with the following additions.

a. Before starting the trial, shuffle and deal three Human Actions cards to each player. The players should hold these cards so the other players cannot see them.
b. Place the remaining Human Actions cards in a stack face down on the table.
c. A Human Actions card can be played only on the Human or Natural Additions card that it is specifically associated with. When played, it cancels out that Additions card and the player does not need to roll the dice.
    - For example, if a player flips over a Natural Additions—Forest Fires card and that player has a Human Actions—Forest Fire card in their hand, they can play the card if they wish. If they choose to play the card, they place it in the discard pile and their turn is over. They do not need to roll the dice, and no greenhouse gases are added to the atmosphere.
d. Continue play until the end of the trial and collect the data.
e. Additional optional elements you can choose to add to Trial 3:
    - Players can also play Human Actions cards for other players. For example, if a player picks a Human Additions—Transportation card and another player has a Human Actions—Transportation card, they can choose to donate their card to that player. This cancels the card and the turn moves to the next player.
    - When rolling on any single Additions or Removals card, if every roll on that card results in an addition or removal of greenhouse gases, the player picks another Human Actions card from the remaining stack and places it in their hand.
    - Scoring option: In addition to counting the total number of greenhouse gases in the center of the table, consider:
        - Create a data table to keep track of the Additions, Removals, and Human Actions Cards used by each player, and the Human Actions cards donated to other players. Then you can compare and contrast the data for individual players to the group greenhouse gases total in the center of the table.

Natural Additions **Forest Fires** **8 – 9 – 10 – 11** **3 rolls**	**Natural Additions** **Forest Fires** **8 – 9 – 10 – 11** **3 rolls**	**Natural Additions** **Forest Fires** **8 – 9 – 10 – 11** **3 rolls**	**Natural Additions** **Forest Fires** **8 – 9 – 10 – 11** **3 rolls**
Natural Additions **Forest Fires** **8 – 9 – 10 – 11** **3 rolls**	**Natural Additions** **Forest Fires** **8 – 9 – 10 – 11** **3 rolls**	**Natural Additions** **Forest Fires** **8 – 9 – 10 – 11** **3 rolls**	**Natural Additions** **Forest Fires** **8 – 9 – 10 – 11** **3 rolls**
Natural Additions **Ocean** **9 – 10 – 12** **3 rolls**	**Natural Additions** **Ocean** **9 – 10 – 12** **3 rolls**	**Natural Additions** **Ocean** **9 – 10 – 12** **3 rolls**	**Natural Additions** **Ocean** **9 – 10 – 12** **3 rolls**

Figure 3.12: Natural Additions Cards. (continued)

<u>**Natural Additions**</u> **Permafrost Thaw** ______ **9 – 10 – 12** ______ **3 rolls**	<u>**Natural Additions**</u> **Permafrost Thaw** ______ **9 – 10 – 12** ______ **3 rolls**	<u>**Natural Additions**</u> **Permafrost Thaw** ______ **9 – 10 – 12** ______ **3 rolls**	<u>**Natural Additions**</u> **Permafrost Thaw** ______ **9 – 10 – 12** ______ **3 rolls**
<u>**Natural Additions**</u> **Wetlands** ______ **10 - 11 – 12** ______ **3 rolls**	<u>**Natural Additions**</u> **Wetlands** ______ **10 - 11 – 12** ______ **3 rolls**	<u>**Natural Additions**</u> **Wetlands** ______ **10 - 11 – 12** ______ **3 rolls**	<u>**Natural Additions**</u> **Wetlands** ______ **10 - 11 – 12** ______ **3 rolls**
<u>**Natural Additions**</u> **Volcanoes** ______ **12** ______ **3 rolls**	<u>**Natural Additions**</u> **All Natural Additions** ______ **8 – 9 – 10 – 11 - 12** ______ **3 rolls**	<u>**Natural Additions**</u> **All Natural Additions** ______ **8 – 9 – 10 – 11 - 12** ______ **3 rolls**	<u>**Natural Additions**</u> **All Natural Additions** ______ **8 – 9 – 10 – 11 - 12** ______ **3 rolls**

Figure 3.12: (continued)

Natural Removals **Forests** **6 – 7 – 8** **3 rolls**	**Natural Removals** **Forests** **6 – 7 – 8** **3 rolls**	**Natural Removals** **Forests** **6 – 7 – 8** **3 rolls**	**Natural Removals** **Wetlands** **6 – 7 – 8** **3 rolls**
Natural Removals **Wetlands** **6 – 7 – 8** **3 rolls**	**Natural Removals** **Ocean** **6 – 7 – 8** **3 rolls**	**Natural Removals** **Ocean** **6 – 7 – 8** **3 rolls**	**Natural Removals** **Mangroves** **6 – 7 – 8** **3 rolls**
Natural Removals **Mangroves** **6 – 7 – 8** **3 rolls**	**Natural Removals** **All Natural Removals** **3 – 4 – 5 – 6 – 7 – 8** **3 rolls**	**Natural Removals** **All Natural Removals** **3 – 4 – 5 – 9 – 10 - 11** **3 rolls**	**Natural Removals** **All Natural Removals** **3 – 4 – 5 – 9 – 10 - 11** **3 rolls**

Figure 3.13: Natural Removals Cards.

Human Additions **Industry** **3 – 7** **4 rolls**	**Human Additions** **Industry** **3 – 7** **4 rolls**	**Human Additions** **Industry** **3 – 7** **4 rolls**	**Human Additions** **Industry** **3 – 7** **4 rolls**
Human Additions **Industry** **3 – 7** **4 rolls**	**Human Additions** **Electric Power** **4 – 7** **4 rolls**	**Human Additions** **Electric Power** **4 – 7** **4 rolls**	**Human Additions** **Electric Power** **4 – 7** **4 rolls**
Human Additions **Electric Power** **4 – 7** **4 rolls**	**Human Additions** **Electric Power** **4 – 7** **4 rolls**	**Human Additions** **Transportation** **5 – 7** **4 rolls**	**Human Additions** **Transportation** **5 – 7** **4 rolls**

Figure 3.14: Human Additions Cards. (continued)

Human Additions **Transportation** **5 – 7** **4 rolls**	**Human Additions** **Transportation** **5 – 7** **4 rolls**	**Human Additions** **Transportation** **5 – 7** **4 rolls**	**Human Additions** **Commercial & Residential Buildings** **6** **4 rolls**
Human Additions **Commercial & Residential Buildings** **6** **4 rolls**	**Human Additions** **Commercial & Residential Buildings** **6** **4 rolls**	**Human Additions** **Agriculture** **5** **4 rolls**	**Human Additions** **Agriculture** **5** **4 rolls**

Figure 3.14: (continued)

Human Actions **Forest Fires** Increase management resources	**Human Actions** **Forest Fires** Increase management resources	**Human Actions** **Forest Fires** Create policy to fund management	**Human Actions** **Ocean** Engage in conservation efforts
Human Actions **Ocean** Create policy to manage oceans into the future	**Human Actions** **Wetlands** Engage in conservation efforts	**Human Actions** **Wetlands** Engage in conservation efforts	**Human Actions** **Commercial & Residential Buildings** Switch to renewable sources of energy
Human Actions **Commercial & Residential Buildings** Switch to renewable sources of energy	**Human Actions** **Commercial & Residential Buildings** Switch to renewable sources of energy	**Human Actions** **Industry** Use new energy-efficient techniques	**Human Actions** **Industry** Use new energy-efficient techniques
Human Actions **Industry** Switch to renewable sources of energy	**Human Actions** **Industry** Create policy to manage industry into the future	**Human Actions** **Electric Power** Use new energy-efficient techniques	**Human Actions** **Electric Power** Switch to renewable sources of energy
Human Actions **Electric Power** Create policy to manage electric power into the future	**Human Actions** **Permafrost Thaw** Create policy to manage permafrost	**Human Actions** **Permafrost Thaw** Conduct research on permafrost	**Human Actions** **Agriculture** Conduct research on agriculture practices
Human Actions **Agriculture** Create policy to manage agriculture into the future	**Human Actions** **Transportation** Increase public transit options	**Human Actions** **Transportation** Switch to new fuel sources	**Human Actions** **Transportation** Create policy to manage transportation into the future

Figure 3.15: Human Actions Cards.

2. Compare the data from each round of game play. If you are able, graph the data you collected.
3. Discuss with your team:
    a. How did the total greenhouse gases change across the three trials? How did the rate at which they changed differ across the three trials? What could explain any differences?
    b. What impact, if any, did adding Human Actions cards have on the overall system?
    c. If you added any of the optional game rules, what effect did these changes have on the overall game and trends in the data?
4. Read what Marcus says about how he thinks about the effects of human actions on wildfires.

Marcus says . . .

There is good fire and there is bad fire. This is kind of the cost of managing a fire on the **back end** versus being preventive and managing it on the **front end**. And really trying to get to a happy place so that people are comfortable if they start seeing smoke more regularly, because maybe it's a good thing that we're doing more prescribed fires and keeping the ecosystem healthy. If they see smoke and it's heavy on the back end, maybe that's still okay because we're managing a fire and we're protecting people and property and letting a fire naturally burn out as it should.

One of the challenges that we have is everyone is investing in different solutions for the same problems. And so we're trying to get the community together for a common vision, a common architecture, to see how technology can work so their investments make sense and feed into a bigger picture. That's one of the efforts our project is looking at as a concept of operations, a technology roadmap—really getting people to speak the same language and to not duplicate investments.

Act: *Where can we research greenhouse gas additions and removals in our community system?*

As action researchers, you will begin investigating the greenhouse gas additions and removals in your local community. Before you can do this, you need to decide as a team what local community area you will be using as your research area. In this activity, you will decide and map the boundaries of your research area.

1. Read Marcus's ideas about fieldwork and research areas and what his project is trying to accomplish.

Marcus says . . .

Wildland fires are a big problem all over the world, and NASA's ACERO project is working on new ways to help fight these fires. They're teaming up with local, regional, and tribal groups to create solutions that work well for everyone involved in stopping fires. They also work with businesses and research teams from other countries to make sure their ideas can help fight fires globally. The places where ACERO does its research and field studies in the United States are chosen with the help of agencies that deal with wildland fires.

NASA is also working on better technology to help with every part of fire management—before, during, and after fires happen. The ACERO project is improving things like how planes and drones are managed in the air, making better communication tools, and making aircraft that can fly on their own. These improvements are meant to make fighting fires safer and more effective. They're planning to use drones to give firefighters live updates about fires, help them communicate better, carry equipment, and help put out fires from the air. This will make it safer for firefighters and help them do their job better at every step of dealing with a fire.

2. Read about the research area of the TEMPO mission at the Smithsonian Astrophysical Observatory in *At the Smithsonian*.

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At the Smithsonian

Smithsonian scientists are working to understand the details of where, when, and how atmospheric additions happen. The Tropospheric Emissions: Monitoring Pollution (TEMPO) mission is a collaboration between the Smithsonian Astrophysical Observatory and NASA. It monitors atmospheric additions in a super-detailed way from space, using a special tool called a spectrometer. In 2023 this tool caught a ride into space on a satellite, and is now up about 22,000 miles (about 35,000 kilometers) above Earth.

Figure 3.16: Artist's illustration of the satellite that carries the TEMPO spectrometer.

From up there, the boundaries of TEMPO's research site is North America, from the Atlantic Ocean to the Pacific Ocean, and from Mexico City to Canada. It will keep an eye on all the natural and human additions into the atmosphere over North America every hour when it's sunny. It can see things in the atmosphere, such as additions of gases from human activities. And it's good at seeing small areas of the atmosphere, way better than the technology we had before.

The data from TEMPO will help scientists better understand where additions to the atmosphere come from. They'll share this information with everyone, so we all can know and decide what actions to take.

TEMPO is going into space around the same time as two other satellites that have a research site over Europe (Sentinel 4) and a research site over Asia (GEMS) that also watch additions to the atmosphere. Together, they form a team to watch the atmosphere in different parts of the world. They'll focus on how things that are added to the atmosphere move between different parts of the world, like from North America to Europe or Asia, across the Atlantic and Pacific Oceans.

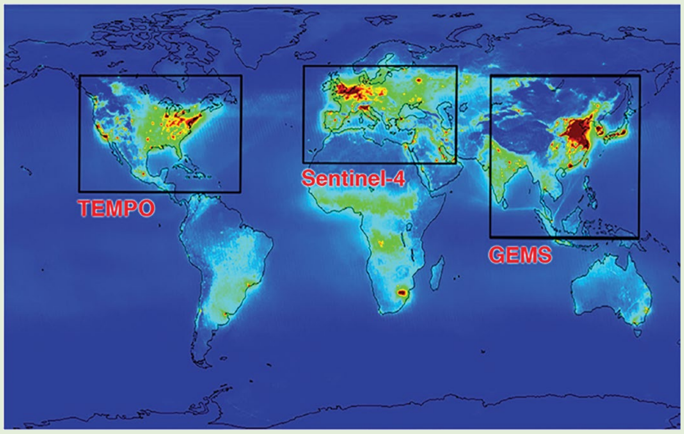

Figure 3.17: Research boundaries of the three satellites tracking additions to the atmosphere.

3. Think about possible research areas. Your research area will be the place where you will conduct investigations about greenhouse gas additions and removals. Think about the following when you consider which area to choose to be your research area.
    a. Try to choose a space that is not too big, so you can get to know the area and its problems well.
    b. Choose an area that has a variety of places in it. For example, it probably would be a good idea to choose an area with some housing, some shops, and some public areas.
    c. Think about a place in your community you would like to know more about.
    d. Consider access. Make sure all your team members will be able to reach your research area. Be sure they can all work there comfortably and safely. It may be best to have your research area near your school or near the places where team members live.
    e. You can choose to have more than one research area, if that works best for your team.
    f. These decisions are all up to your team. It is also okay to change the size and number of research areas later as you collect more information.

4. By yourself, think about the area or areas that are best to do your community action research. Write or draw your ideas on a piece of paper. Or you can just think about the area you think is best.
5. With a partner or with your whole team, share your ideas about where it might be best to do your research.
6. Decide with your team where you will do your research.
7. Now you and your team need to mark the edges or boundaries of your research area. You can do this using a map. Some boundaries you might want to consider include:
    a. Team housing boundaries: set a boundary that includes all the homes of the team members, the meeting place of the team, and the surrounding area
    b. Natural boundaries: mountains, rivers, different land features
    c. Political or administrative boundaries: city or county lines, school district lines, neighborhood lines
    d. Physical infrastructure boundaries: roads, transportation networks
    e. Other boundaries: determine your own reasons for a boundary
8. As a team, you can either use an existing map or create your own *My Research Area* map to show your boundaries. You will continue to add details to this map throughout the guide, so make sure the map is big enough that you can add to it. Read *Using an Existing Map* and *Creating a New Map* to learn more.

Using an Existing Map

You can use a map that already exists to help you save time.

a. Obtain any maps of the community around where your team meets that may be useful to get you started.
    - Online: Use free online mapping programs, such as Google Maps, to download and/or print a map of the community.
    - Print: Good maps of the community are often published and available in local libraries, government planning offices, travel offices, road atlases, or tourist centers.

- Local: Local community leaders or other local sources, such as elders, may have maps available to share.
- Accessible maps: People who are blind or have low vision sometimes use tactile or Braille maps. These maps used raised surfaces to describe where things are.

b. Mark the edges of your research area on the map. Figure 3.18 shows an example.

Figure 3.18: Example of using an existing map to define the research area.

Creating a New Map

You and your team can create your own map. If you are going to do that, here are some instructions that can help.

a. Use a blank piece of paper or grid paper. If you can look at a print or online map to help you draw, that might be useful.
b. If you don't want to use paper, you can make your map on a computer. Or you can draw your map outside in dirt, sand, or other material. You can also describe your map out loud with your team.
c. Start by marking on your map the location where your team meets. You will work outward from this location to determine your research site boundaries.

d. Your map should include:
    - Roads and other infrastructure
    - Businesses and other important buildings
    - Natural features such as rivers or forests
    - Parks or other shared spaces
e. Next, draw the edges of your research area on the map.
f. Your map does not need to be perfect; it just needs to make sense to you and your team. You can always add to it or fix it later.

9. When you have finished marking the boundaries on your *My Research Area* map, keep it in a safe place. You will use this map in Part 4 to mark down important information about additions and removals of greenhouse gases in your community.
10. Acknowledge: Take a moment and recognize that you took more actions in this guide. Understanding human relationships with energy in the system is an essential action. You are part of a human system. Humans are complex social animals. To effectively act on human impacts to the atmosphere, such as climate change, you must understand and respect the system.

Congratulations!

You have finished Part 3.

Find out More!

For additional resources and activities, please visit the *Climate Action!* StoryMap at https://bit.ly/CLIMATEACTION2030.

References

1. "Graphic: Temperature vs. Solar Activity," NASA Global Climate Change Vital Signs of the Planet, July 10, 2020, https://climate.nasa.gov/climate_resources/189/graphic-temperature-vs-solar-activity/
2. "Climate Change: Atmospheric Carbon Dioxide," NOAA, May 12, 2023, https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

Glossary

This glossary can help you understand words you may not know. You can add drawings, your own definitions, or anything else that will help. Add other words to the glossary if you would like.

Aerial ignition: Setting a fuel on fire by dropping materials from an aircraft

Aerosols: Fine particles of liquid droplets in air

Back end: The later part of a process or span of time

Carbon dioxide: A greenhouse gas that is part of Earth's atmosphere; increasing carbon dioxide levels in the atmosphere is one of the causes of climate change

Deforestation: the action of clearing a wide area of trees

Emits: Produces and discharges

Fossil Fuels: Types of fuel that come from the fossilized remains of plants and animals

Front end: The earlier part of a process or span of time

Global warming: The long-term heating of Earth's surface, which has been observed since the pre-industrial period (between 1850 and 1900)

Greenhouse effect: The process by which heat is trapped near Earth's surface by greenhouse gases

Greenhouse gases: Gases such as carbon dioxide and methane that cause the atmosphere to get warmer

Habitat Zones: an area with similar environmental conditions throughout it.

Methane: A greenhouse gas that contributes to climate change

Mitigate: To make less severe or less harmful

Natural disasters: Natural events such as floods, earthquakes, or hurricanes that cause great damage and/or loss of life

Particulates: Small airborne particles, such as pollen, dust, or smoke

Prescribed burns: A planned fire that is set to meet management objectives

Radiate: To diverge or spread out from

Solar irradiance: The total amount of energy emitted by the sun, as measured on Earth

Wildland fire: Uncontrolled fire in a forest, grassland, brushland, or land planted with crops

